Collective Action in Smart Energy Hubs

Managing Energy as a Common-Pool Resource to Mitigate Net Congestion

MSc. Thesis

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Abstract

This thesis explores the dynamics of Smart Energy Hubs, focusing on collective action and energy management within two case studies in the Netherlands. Smart Energy Hubs are collaborative frameworks that harness cooperation between various stakeholders, including municipalities, businesses, and energy suppliers, to enhance energy efficiency and reliability while mitigating grid congestion. The research investigates how these hubs operate as community-based energy systems, employing theories of collective action, network governance, and common-pool resource management.

Utilising a middle-range theoretical approach, the study bridges the gap between broad theoretical concepts and practical applications in energy management. Key constructs such as trust, reciprocity, and governance structures are operationalized to assess their impact on collaboration within the hubs. Findings indicate that the success of Smart Energy Hubs depends on several factors: **strong contractual agreements** that establish clear roles and responsibilities, **effective stakeholder engagement** to ensure active participation, **robust governance structures** for transparent decision-making, **financial sustainability** to secure long-term viability, and **open communication** channels to build trust among participants.

Data collected through semi-structured interviews with stakeholders provides insights into the challenges and opportunities faced in developing and maintaining these energy collectives. While Smart Energy Hubs offer significant potential for sustainable energy management, they also encounter challenges such as funding constraints and power dynamics.

The research concludes that Smart Energy Hubs, if developed and managed effectively, can play a key role in the energy transition by improving community resilience and promoting sustainable practices. Recommendations include effective communication channels, developing inclusive governance models, securing financial support, and strengthening contractual agreements to ensure clear roles and responsibilities among stakeholders. This study contributes to a deeper understanding of collaborative governance in energy systems, offering insights for future sustainable energy initiatives.

Key words: *Collective Action, Smart Energy Hubs, Stakeholder Engagement, Governance Structures*

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Best regards,

Anniek

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List of Acronyms

TSO - Transmission System Operator
DSO - Distribution System Operator
CGR - Collaborative Governance Regime
DER - Distributed Energy Resources
RES - Renewable Energy Sources
SES - Smart Energy Systems
DSM - Demand-Side Management
EMS - Energy Management Systems
ESS - Energy Storage Systems
MES - Multi-Energy System
SEH - Smart Energy Hubs
MEH - Macro Energy Hubs
CCHP - Combined Cooling, Heating, and Power
DR - Demand Response
FCR - Frequency Containment Reserve
GOPACS - Guaranteed Operating Reserve Capacity Service
aFRR - Automatic Frequency Restoration Reserve
MFRR - Manual Frequency Restoration Reserve
NPE - National Energy System Plan
RVO - Netherlands Enterprise Agency
MEZK - Ministry of Economic Affairs and Climate
ESCOs - Energy Service Companies

Chapter 1: Introduction

1.1 Background

Since the Paris Climate Agreement and the Dutch National Energy Agreement have been concluded in 2015 and 2013, the Dutch energy landscape has been changing significantly (Van Vuuren et al., 2017). Many countries around the world have accelerated the process of transforming their power systems to generate a greater share of electricity from renewable energy sources. The growing employment of distributed electricity generation from renewable energy sources affects power systems with increasing net congestion (Schermeyer et al., 2018). This is also the case in the Netherlands where the supply of green electricity has been growing as the energy transition progresses, especially over the past ten years. Due to grants from the government, rapid development of technologies in the field and the goal of not being dependent on natural gas by the year 2050, the amount of solar panels and wind parks has grown quickly. With the use of less natural gas, the demand for electricity has been rising fast and will continue to rise further (Wampack, 2023).

Net congestion refers to the situation where the infrastructure of the local grid experiences limitations in transmission capacity (Wampack, 2023). Net congestion is assessed based on the maximum allowable energy consumption per connection. However, DSOs (distribution system operators) can identify net congestion even before this maximum is reached, as their priority is to maintain a safe and stable grid. DSOs operate, manage or sometimes own local or regional energy distribution networks that transport electricity to end users. Besides DSOs, a Transmission System Operator (TSO) is responsible for ensuring the efficient and reliable transmission of electricity from generation plants through the power grid to regional or local distribution operators (gridX, n.d).
A lack of transmission capacity causes net-congestion when large amounts of electricity are generated. In the Netherlands, TenneT manages the transmission grid and manages congestion (the high voltage network of 110 kV and above). Congestion happens when the flow of electricity is bigger than what the grid can handle without surpassing the voltage, stability and thermal thresholds. When the grid goes out of balance, in times of congestion, there are risks associated with it such as blackout risks and inflated operational costs (Wampack, 2023). A grid is explained to be only stable if the amount of power that is fed into the grid matches the power that is taken out. TSOs play an important role in intervening before such a bottleneck occurs to ensure a stable and secure supply of electricity. However, in many places such bottlenecks have already been identified and net congestion is still growing there (TenneT, n.d.).

In several places on the Dutch electricity grid, the demand for transport of electricity has become higher than the capacity to transport it, resulting in net congestion. Energy producers are no longer able to supply sufficient energy to the grid and consumers are not able to take enough energy from the grid (Wampack, 2023). This problem calls for more effective sustainable energy management and grid congestion mitigation.

Smart Energy Hubs can serve as a tool to improve sustainable energy management and mitigate grid congestion. Energy hubs can be used to improve the needed flexibility on the Dutch electricity grid. An energy hub can be defined as a local point in an integrated energy system, where the conversion, production, consumption and storage of different energy carriers can take place (Gerner, 2023). However, it is important to note that this research does not suggest Smart Energy Hubs to be a single solution to grid congestion. Energy hubs respond to specific empirical contexts to mitigate some of the problems that societal actors face in transforming the energy system.

This research focuses specifically on energy hubs located in industrial areas. Industrial zones are particularly suitable for energy hubs due to their high and diverse energy demands, potential for on-site energy generation, and opportunities for synergy among different businesses.In this document, the terms 'Smart Energy Hubs' and 'energy hubs' are used interchangeably to refer to integrated energy systems that utilise smart technologies for efficient energy management. A technology is considered 'smart' when it can communicate and interact with other networked technologies, enabling automated or adaptive functionality and allowing remote access or operation from anywhere (Williams, n.d). While there may be slight technical distinctions in specific contexts between Smart Energy Hubs and Energy Hubs, for the purposes of this discussion, these terms are used equivalently to emphasise the broader concept of modern energy management systems.

1.2 Research Problem

The development and implementation of energy hubs present a complex challenge involving multiple stakeholders, including companies and local governments. Despite the potential benefits of energy hubs for addressing grid congestion and promoting sustainable energy use (discussed in section 3.3.2), their formation has been slow. Research indicates that this slow progress can be largely attributed to cooperation problems among the involved stakeholders, a topic that will be explored further in this study. Companies and local governments often encounter difficulties in aligning their interests, resources, and strategies to effectively manage energy as a common-pool resource (CPR). Common-pool resources are finite quantities of resource units that are collectively shared and managed (Ostrom, 2002) While energy in itself is not inherently a common-pool resource, it assumes this role within energy hubs when shared among multiple stakeholders. In such scenarios, the consumption of energy by one party reduces its availability for others, and excluding any participant from accessing it becomes challenging. This dynamic, central to understanding the governance of energy hubs, will be addressed in section 2.7. The varying levels and forms of cooperation among initiatives like Smart Energy Hubs further complicate the management of energy as a CPR. Therefore, it is crucial to study the factors influencing cooperation within energy hubs and to identify the barriers and opportunities within this collaborative framework.

1.3 Research Objective

The main objective of this research is to gain a more comprehensive understanding of the collaborative efforts between stakeholders in the formation and operation of energy hubs, using theoretical explanation, empirical analysis and practical application. In particular, this research aims to understand how existing general theories related to common-pool resource management, collective action, and cooperative governance can be applied to explain variation in and the extent and manner of collaboration among stakeholders in the specific context of *Smart Energy Hubs*. Furthermore, this paper aims at analysing real-world cases of Smart Energy Hubs to review opportunities and challenges in stakeholder cooperation. This empirical analysis helps to understand how cooperation within energy hubs serves as a solution to grid congestion and assesses the development of energy hubs over the past decade. Lastly, this research aims at translating theoretical insights into practical recommendations for improving cooperation in the development and management of Smart Energy Hubs. By addressing these objectives, the research aims to provide valuable insights for both the scientific community as well as practitioners involved in the development and management of local energy initiatives such as Smart Energy Hubs. The goal of this study is to enhance the effectiveness of Smart Energy Hubs as a tool for sustainable energy management and grid congestion mitigation.

1.4 Research Question

The main research question of this thesis investigates the success of energy hubs by examining how companies and local governments address cooperation problems. To achieve this objective, the following main research question is formulated:

How can we theoretically explain the ways actors collaborate to address common-pool resource problems in Smart Energy Hubs?

To answer the main question, it is divided into four sub questions, each contributing in its own way to addressing the main question. This study uses a theoretical framework that encompasses key areas such as collaborative/network governance, collective action, common-pool resources, and network governance. These interconnected concepts provide a lens for examining the subject matter, facilitating an understanding of the dynamics of cooperation in energy hubs. By integrating these theoretical perspectives, this research aims to gain meaningful insights and contribute to the broader discourse on sustainable energy management through energy hubs.

In the first sub-question, a theoretical explanation of variation in collaboration is given, using collaborative governance theory, network governance theory, collective action theory and common-pool resource framework to understand the factors influencing variations in collaboration. This theoretical research will be the largest part of the study and lays the foundation for the case studies.

1. Theoretical explanation of variation in collaboration:
    - Sub-question 1: How can we theoretically explain the manner in which stakeholders collaborate to optimally utilise energy as a common-pool resource?

The second sub-question aims at examining cooperation as a solution for grid-congestion, by studying how energy hubs function as a tool to mitigate grid congestion and what the role of cooperation between companies and local governments is in this process.

2. Cooperation in Energy Hubs as a solution for grid congestion:
    - Sub-question 2: In what way does cooperation take place within energy hubs as a solution for grid congestion?

The third sub-question aims to gain insights regarding the development of energy hubs over the past decade. This sub-question will analyse the evolution of energy hubs, considering factors such as slow development and increasing grid congestion, to understand the historical and current trends.

3. Development of energy hubs over the past decade:
    - Sub-question 3: How has the concept of energy hubs developed over the past 10 years?

The fourth sub-question will involve empirical research through case studies of two selected energy hubs, focusing on their ability to manage energy as a common-pool resource and the level of cooperation among stakeholders

4. Case study of two selected energy hubs:
    - Sub-question 4: What are the opportunities and challenges encountered in the development of the Smart Energy Hubs A and B, and how do these experiences contribute to understanding collaboration dynamics in energy collectives?

By addressing these sub-questions, this research aims to provide a detailed understanding of the factors contributing to the success of energy hubs, and offer insights into overcoming cooperation problems among stakeholders.

1.5 Scientific Relevance

The scientific relevance of this study is found in several important aspects. Firstly, it aims to translate general theories about cooperation in managing common-pool resources to the specific context of energy hubs. The application of these theories—such as collaborative governance, collective action, and network governance—to energy hubs is relatively unexplored. Several aspects have not been thoroughly investigated in literature, including the dynamics of stakeholder interaction, the influence of local socio-economic contexts, and the role of emerging technologies in shaping cooperation. This gap in the literature presents an opportunity to delve deeper into how various stakeholders—such as companies, governments, and communities—interact, negotiate, and collaborate to optimise energy resources. By focusing on these relatively unexplored aspects, this research contributes to the academic understanding of how these theoretical frameworks can be used to address cooperation problems in a new and significant area of study. Secondly, this study will advance the scientific discourse by examining how different stakeholders, namely companies and local governments, collaborate within energy hubs to manage energy as a common-pool resource. The insights gained from this investigation can inform both theory and practice, offering a nuanced understanding of the factors that facilitate or hinder successful cooperation. Thirdly, this research integrates multiple theoretical perspectives to provide a comprehensive analysis of cooperation in energy hubs. By combining theories of collaborative governance, collective action, common-pool resources, and network governance, the study not only deepens the understanding of each theory individually but also demonstrates their interconnectedness and collective applicability. This integrative approach adds value to the theoretical landscape and provides a framework for analysing complex cooperation dynamics. Additionally, the study's empirical component, examining real-world cases of energy hubs, will provide valuable practical insights that can bridge the gap between theory and practice. The findings can help policymakers, practitioners, and researchers develop more effective strategies for ensuring cooperation among stakeholders in energy hubs, thus enhancing the practical relevance of theoretical models. Lastly, the research will contribute to the broader discourse on sustainable energy management and grid congestion mitigation. By highlighting how cooperation within energy hubs can address these complex issues, the study adds to the existing body of knowledge on sustainable development and resource management. The outcomes of this research can support future studies, encouraging further exploration and application of cooperation theories in various contexts related to sustainability and resource management.

1.6 Societal Relevance

The societal relevance of this study can be found in various aspects, addressing important sustainability and energy management challenges. Starting off, Smart Energy Hubs play an important part in promoting sustainable energy practices. By improving cooperation among companies and local governments, these hubs can enhance the efficiency and effectiveness of energy use, contributing to broader environmental benefits such as reduced carbon emissions and increased integration of renewable energy sources. Secondly, energy hubs can serve as a solution to the ongoing issue of grid congestion. As energy demands increase and renewables become more prevalent, the need for stable and reliable grid management is ever more important. This study's insights into cooperation within energy hubs can help mitigate grid congestion and ensure a more stable energy supply that supports consumers and energy providers. Economically, successful energy hubs can lead to substantial cost savings through more efficient energy use and the creation of new jobs in the energy sector. By stimulating local economies and innovation, Smart Energy Hubs can drive economic growth and development. Furthermore, Smart Energy Hubs have the potential to empower local communities by involving them in energy decision-making processes. Such participation can create a sense of ownership and responsibility towards local energy management and sustainability initiatives. Enhancing cooperation among local governments, businesses and communities can lead to more self-sufficient and resilient energy systems. Moreover, from a policy perspective, the findings can inform energy policy at various levels. Effective policies that support expansion and development of Smart Energy Hubs can promote sustainable energy practices and improve stakeholder cooperation, ultimately benefiting society. Finally, the successful implementation of energy hubs in the studied cases can serve as models for other regions in the country. The strategies and solutions identified in this research can be replicated and scaled to contribute to global sustainability efforts and wider adoption of Smart Energy Hubs.

1.7 Methodology

This chapter outlines the methodological approach used to investigate cooperation problems in energy hubs. It integrates theoretical explanations and empirical examinations to provide a comprehensive understanding of cooperation dynamics. The methodology encompasses data collection, data analysis, reliability, validity, and ethical considerations.

1.7.1 Research Approach

This thesis adopts a qualitative, deductive approach and is explorative of nature. This methodology starts with established theoretical frameworks related to collaborative governance and collective action. The study generates contextualised expectations based on these theories and explores these through empirical case studies of two selected energy hubs: Energy hub Harderwijk and Energy hub Lorentz III.

Theoretical Frameworks:

- **Collaborative Governance** explores how various stakeholders collaborate to achieve common goals, focusing on processes and structures that facilitate cooperation.
- **Collective Action Theory** examines how individuals or organisations work together to manage shared resources and address common challenges.
- **Common-Pool Resource Management** analyses how groups manage resources that are accessible to all but are susceptible to overuse.
- **Network Governance** looks at the role of networks in governance, emphasising the importance of relationships and coordination among diverse actors.

By applying these frameworks, the research aims to validate existing theories and provide insights into how these theoretical concepts manifest in real-world settings. The goal is to enhance understanding of energy management practices by examining cooperation dynamics and operational strategies within these hubs.

Middle-range theory, developed by sociologist Robert K. Merton, serves an important role in social research by offering a bridge between abstract theoretical frameworks and empirical observations. It focuses on specific elements of social phenomena that are empirically verifiable and applicable across various contexts. Unlike grand theories that attempt to explain all-encompassing social processes, middle-range theories provide a more manageable and focused approach to understanding societal dynamics (Merton, 1968).

In the study of Smart Energy Hubs, middle-range theory helps operationalize theoretical constructs from collective action theory, collaborative governance theory, common-pool resource management, and network governance theory into measurable variables. This operationalization allows for a systematic investigation of how these theoretical concepts appear in real-world settings. By identifying and defining constructs such as trust, reciprocity, transparency, resource dependency, and facilitative leadership, contextualised expectations can be generated that are grounded in empirical findings. These expectations guide the investigation, data collection, and analysis, and help evaluate the validity of theoretical claims within the study's context.

Middle-range theory facilitates the development of a structured methodology for data collection and analysis. In the context of Smart Energy Hubs, this involves creating a semi-structured interview guide based on the identified constructs. Interviews with stakeholders provide qualitative data that can be systematically analysed to explore the expectations derived from middle-range theory. This approach helps to ground the study in theoretical accuracy while capturing the dynamics of collaboration and governance within energy collectives. By employing middle-range theory, the study not only aims to uncover the specific opportunities and challenges faced by Smart Energy Hubs but also aims to contribute to a broader theoretical understanding. It provides insights into how theoretical frameworks can address practical issues in sustainable energy management and enhance stakeholder collaboration, linking sociological concepts directly to observable phenomena in real-world contexts like energy hubs.

1.7.2 Case Selection Methodology

The selection of Energyhub Harderwijk and Energyhub Lorentz III as case studies was strategically informed by their distinct characteristics and stages in the energy hub development process. This approach allows for a comparative analysis that captures a range of dynamics within energy hubs.

Energy Hub Harderwijk: Chosen for its advanced stage, currently in the contracting phase, Energyhub Harderwijk provides insights into the practical implementation of energy hub concepts. The advanced stage provides a basis to explore how stakeholder cooperation is managed and evolves from planning to execution. The lessons learned from Harderwijk can offer practical insights into the challenges and solutions associated with for instance implementing energy technologies.

Energy Hub Lorentz III: Selected for its early orientation phase, where planning and exploratory activities are ongoing, Lorentz III is valuable for understanding foundational decisions that influence long-term success. Studying Lorentz III provides insights into stakeholder engagement strategies and initial approaches to resource management before full implementation. This early-phase analysis helps to identify best practices and potential challenges in the initial stages of energy hub development.

Including cases at different stages—contracting for Harderwijk and orientation for Lorentz III—enables the research to capture a broader range of dynamics within energy hubs. Comparing these phases helps to identify challenges at various stages of development, supporting the understanding of the energy hub lifecycle from planning to execution.

This systematic approach to case selection aligns with established methodologies in qualitative research. Specifically, it reflects the most-similar case technique, as both cases are energy hubs but differ significantly in their development stages, allowing for focused comparisons on the impact of these stages on energy hub dynamics (Seawright & Gerring, 2008). Additionally, the selection embodies a diverse case approach, capturing a range of dynamics that enhance the analysis (Lijphart, 1971).

In terms of data collection, a systematic interviewing methodology was employed, utilising semi-structured interviews with key stakeholders involved in the energy hub. This approach facilitates in-depth discussions while allowing for flexibility in exploring relevant topics, thereby enriching the qualitative data gathered (Kvale, 1996; Patton, 2002).

By grounding the case selection and interviewing methodologies in established literature, this research aims to enhance the credibility of the findings related to collaboration in energy hub development.

1.7.3 Data Collection

Data collection involves two main components: literature research and empirical research.

Literature Research

This component focuses on gathering existing knowledge and theoretical insights related to:

- Collaborative Governance Theory: Examines frameworks and models of governance that facilitate stakeholder collaboration.
- Collective Action Theory**:** Investigates how groups work together to manage shared resources and address collective challenges.
- Common-Pool Resource Management: Analyzes strategies for managing resources that are accessible to multiple users.
- Network Governance: Looks at the role of networks in governance and the coordination among diverse actors.
- Historical Development of Energy Hubs**:** Reviews the evolution of energy hubs, including technological advancements and policy changes.

The literature review includes academic journals, books, conference papers, and policy documents. This comprehensive review establishes a theoretical framework and contextual background for the study, providing a solid foundation for analyzing empirical data.

Empirical Research

Empirical research is conducted through case studies of Energyhub Harderwijk and Energyhub Lorentz III. Data collection methods include:

- Interviews: Semi-structured interviews are conducted with hub directors or managers of the selected energy hubs. These interviews aim to gather detailed insights into cooperation processes, challenges, and opportunities. The interview guide is developed based on theoretical constructs, focusing on aspects such as cooperation dynamics, technological integration, and stakeholder management. The semi-structured format allows for flexibility and in-depth exploration of participants' experiences and perspectives.

- Document Analysis: Relevant documents including reports, project documents, policy papers, and other materials related to the selected energy hubs are analyzed. This provides contextual and background information that supports the case studies. Document analysis helps to validate interview findings and offers additional insights into the energy hubs' development and operational processes.

Selection Criteria for Interviewees

To ensure an unbiased perspective, interviewees were selected based on their roles in overseeing the energy hubs rather than preconceived notions about project success or challenges. The primary criterion was their comprehensive oversight of the projects, typically as hub directors or managers. This approach ensures that the insights gathered are representative of the overall project dynamics and provide a well-rounded view of the energy hub development process.

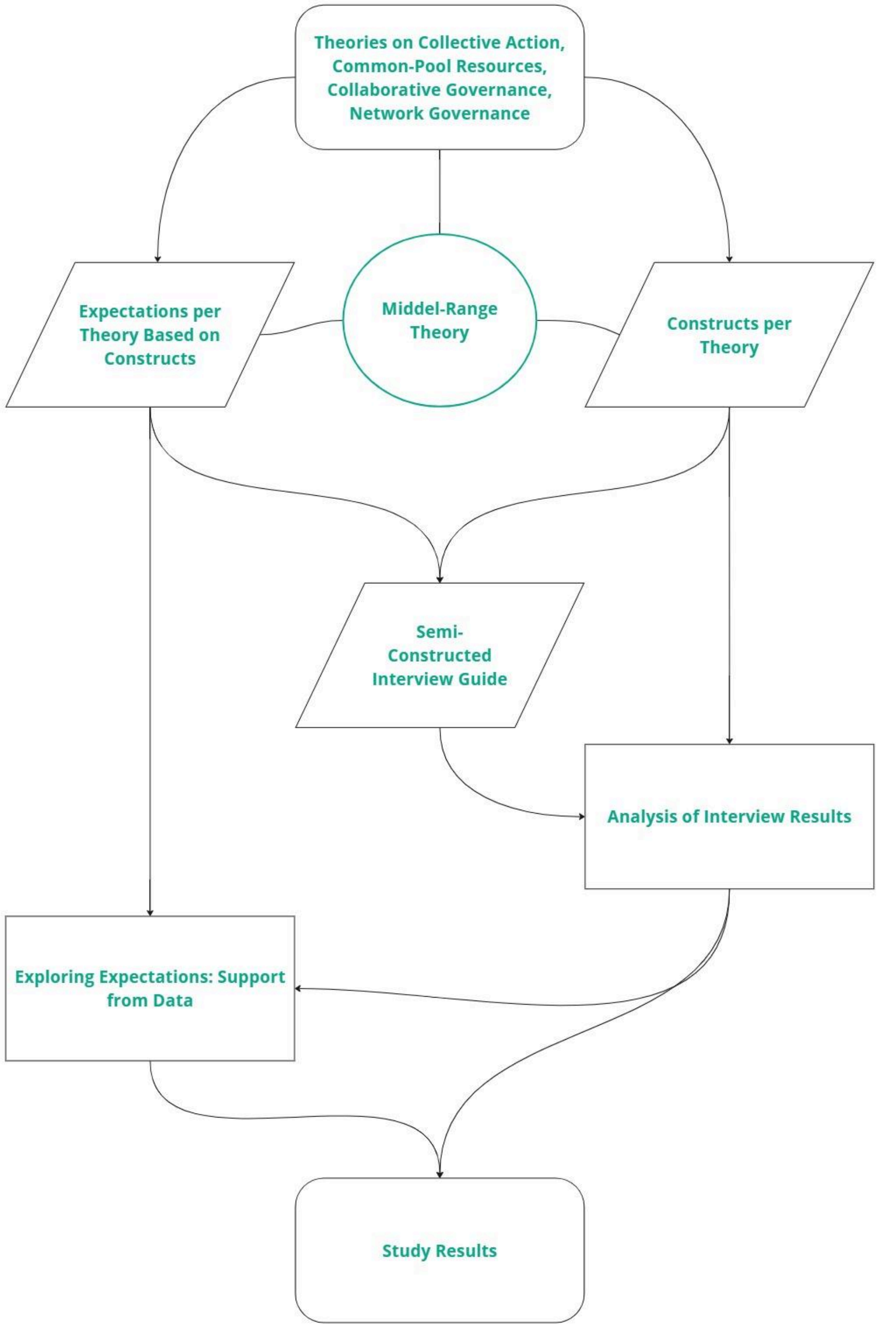
1.7.4 Data Analysis

Due to the limited amount of data, formal coding schemes were not employed. Instead, sensitising concepts related to cooperation dynamics, technological integration, and regulatory challenges guided the analysis. This approach ensures that even with limited data, the analysis remains focused and relevant to the study’s objectives.

Despite the research’s limited number of interviews, the selection of these specific cases provides focused, in-depth insights into critical aspects of energy hub development. Although findings may not be fully generalizable, the detailed analysis of these cases contributes valuable, context-specific examples to broader discussions on energy management, technological integration, and stakeholder cooperation. The qualitative data collected will be analysed to identify key themes and patterns that can inform future research and practice.

Figure 1:

Schematic overview of Data Collection and Analysis



Source: Created using Miro.com

1.7.5 Reliability and Validity

To ensure reliability, the study maintains a consistent methodological approach across data collection and analysis stages. This includes:

- Standardised Semi-Structured Interviews: Ensuring that each interviewee is asked similar questions to maintain consistency.
- Cross-Verification: Using multiple data sources, including interviews and document analysis, to confirm the consistency of findings. This triangulation helps validate the data and reduces the risk of bias.

The validity of this research is addressed by:

- Defining and Operationalizing Constructs**:** Constructs such as cooperation dynamics, technological integration, and regulatory challenges are carefully defined and operationalized to ensure accurate measurement of theoretical concepts.
- Diverse Case Studies: Although the study focuses on two specific energy hubs, the findings aim to offer insights that are generalizable to similar contexts. The diverse case studies and comprehensive analysis enhance external validity by capturing a range of dynamics and strategies.

1.7.6 Ethical Considerations

Key ethical guidelines include:

- Informed Consent: Ensuring that all interview participants are fully informed about the research purpose, their role, and their rights. Consent is obtained before conducting interviews to respect participants' autonomy and rights.
- Confidentiality and Data Security: Protecting the confidentiality and anonymity of participants and sensitive information related to the energy hubs. Data integrity and privacy are maintained through secure storage and handling practices.
- Data Handling: Ensuring that data is used responsibly and ethically, with strict adherence to privacy and confidentiality standards.

Member checking, or the process of returning to interviewees to confirm interpretations of their responses, was not conducted in this study. Member checking is a recommended practice for enhancing the validity of qualitative research by ensuring that participants' views are accurately represented. However, due to time constraints this step was not feasible in this research. To address the absence of member checking, the study employed other strategies to enhance the reliability and validity of the findings:

- Detailed Documentation: A thorough record of the research process and data analysis was maintained to allow for transparency and potential replication.
- Thematic Analysis**:** Data was analysed using thematic analysis to identify key themes and patterns, ensuring a structured and systematic approach to interpreting the qualitative data.

While member checking was not performed, these alternative measures were implemented to uphold the integrity of the research process and to mitigate potential issues with data interpretation. The study aims to contribute valuable insights to the field while acknowledging the limitations of not including member checking.

By adhering to these methodological principles, this study aims to provide a thorough analysis of cooperation dynamics within energy hubs. The research seeks to offer valuable insights for both academic theory and practical applications, contributing to a deeper understanding of energy hub development and management.

1.8 Thesis Outline

The second chapter addresses the first sub-question by exploring theories that explain variations in how companies collaborate to optimise energy as a common-pool resource. It delves into collaborative governance theory to manage conflicts and enhance resource management, supported by diagrams. Additionally, collective action theory is discussed to bridge conflicting interests, alongside the common-pool resource framework applied to energy management. Network governance theory is also examined to highlight its role in energy hub management. The third chapter discusses the concept of energy hubs as tools to solve grid congestion issues and examines whether they offer sufficient benefits to incentivize cooperation among companies and governments. It explores how the concept of energy hubs has evolved over the past decade. The chapter also investigates cooperation dynamics within energy hubs as solutions for grid congestion. Middle Range Theory is used to integrate theoretical research with empirical research. The fourth chapter investigates specific case studies of selected energy hubs, addressing the fourth sub-question. It analyses problems and opportunities encountered in developing these hubs, focusing on their ability to jointly manage energy as a common-pool resource. The final chapter summarises findings from the thesis, discussing implications for theory and practice in energy hub management. It reflects on limitations and offers recommendations for future research, concluding with insights into the cooperative dynamics essential for sustainable energy solutions.

Chapter 2: Theoretical Framework

2.1 Purpose of the Chapter

This part of the research aims to answer sub-question 1 by exploring various theories that can help to explain variation in the extent to which, and the way, companies collaborate to optimally utilise energy as a common-pool resource. Collective action theory is studied to identify what drives and hinders individual stakeholders to collaborate for reaching common goals, and to understand how individuals come together to sustainably manage shared resources, or common-pool resources. While collective action theory focuses on individual cooperation to achieve collective benefits, collaborative governance theory puts focus on joint decision-making processes involving diverse stakeholders. Network governance on the other hand, emphasises coordination among interdependent organisations. Each of these theories is studied as they offer unique insights into collaboration mechanisms, governance structures and motivations behind collective efforts.

2.1.1 Relevance of Theoretical Frameworks to Context

The frameworks that are selected for this thesis—collective action theory, common-pool resource management, collaborative governance and network governance—are specifically chosen as they provide a comprehensive lens to grasp the complexities of stakeholder collaboration in energy hubs. These theories are integrated as they collectively address different aspects of cooperation. Before delving into these frameworks in detail from section 2.2 onwards, this section will first outline the relevance of each theoretical framework included in this thesis to provide a clear understanding of how they contribute to the overall analysis.

Collective Action Theory helps to explain how stakeholders can work together despite individual incentives to act otherwise. Common-Pool Resource Management focuses on the governance of shared resources, which is essential to the context of energy management in energy hubs. Collaborative Governance explores the mechanisms through which different actors coordinate and cooperate. Lastly, Network Governance considers the structure of interactions and the role of networks in facilitating cooperation.

With the integration of these frameworks, the thesis aims to provide a holistic understanding of what is needed to address collaborative challenges in Smart Energy Hubs. However, this research does acknowledge that full integration of the theoretical frameworks is challenging due to the different emphases of each framework. They could be more integrated by further aligning theoretical constructs and operationalizing them in a unified empirical model.

Collective Action Theory

In the realm of managing shared resources, Collective Action Theory offers a strong framework to understand the complexities and challenges faced by stakeholders. This theory, grounded in the works of Elinor Ostrom and others, provides insights into how individuals and organisations coordinate their efforts to achieve common goals, particularly in environments where cooperation is highly needed.

Collective Action Theory is important for understanding the dynamics of cooperation among stakeholders in managing shared resources like energy in Smart Energy Hubs. This theory highlights the challenges of collective efforts, particularly the free-rider problem, where some participants benefit from the collective outcome without contributing (Ostrom, 2010).. In the context of Smart Energy Hubs, where coordinated actions are necessary to optimize energy use and prevent grid congestion, this theory provides insights into how trust, fairness, and effective incentives can foster collaboration and overcome these challenges. Moreover, the exploration of contextualised expectations related to trust, reciprocity, and incentives within this thesis draws directly from the principles of Collective Action Theory, underscoring its relevance to sustainable energy management.

Common-Pool Resource Management

While energy is traditionally viewed as a private good, the context of Smart Energy Hubs presents unique challenges that align it more closely with the characteristics of a common-pool resource. Understanding these dynamics requires a thorough exploration of Common-Pool Resource Management principles, which emphasise the need for collective strategies to manage shared resources sustainably.

Common-Pool Resource (CPR) Management is a framework that explores how resources shared by multiple users—such as fisheries, forests, and in this case, energy—can be managed sustainably (Wolsink, 2012). Traditionally, energy is viewed as a private good, but in the context of Smart Energy Hubs, it can exhibit characteristics of a CPR, particularly when access to and distribution of energy becomes congested or scarce. This thesis posits that under specific conditions, energy within a Smart Energy Hub can be perceived as a CPR, requiring collective management strategies to avoid overuse and ensure equitable access. By applying CPR principles, this research highlights the need for robust governance mechanisms, community involvement, and cooperative strategies to manage energy as a shared resource effectively.

Collaborative Governance

Given the complexity of managing energy systems that involve multiple stakeholders, Collaborative Governance emerges as an important framework. It provides a structured approach to involving diverse stakeholders in decision-making processes, ensuring that governance is not only inclusive but also effective (Ansell & Gash, 2008).

Collaborative Governance is a framework that emphasises the importance of involving diverse stakeholders in the decision-making process to manage complex societal issues, such as energy management in Smart Energy Hubs. This approach aligns closely with Collective Action Theory but extends it by focusing on the institutional structures and processes that facilitate cooperation among stakeholders, including governments, private sector entities, and local communities. Collaborative Governance is particularly relevant in the energy context, where the complexity of managing multiple stakeholders with varying interests requires structured and inclusive governance mechanisms. This thesis adopts Collaborative Governance to explore how stakeholders can be effectively engaged in the governance of energy resources, ensuring that decisions are made transparently and inclusively, leading to more sustainable and equitable outcomes.

Network Governance

In a decentralised system like Smart Energy Hubs, where governance is distributed across a network of actors, Network Governance offers a valuable perspective. It allows us to understand how various stakeholders interact, share information, and coordinate their efforts in managing energy resources efficiently.

Network Governance provides a lens through which the interactions and coordination among a network of actors—ranging from governmental agencies to private sector players and community organisations—can be understood and managed (Kenis & Provan, 2008). In the context of Smart Energy Hubs, where no single entity has control over the entire system, Network Governance becomes essential. It allows for a decentralised approach to governance, where power and decision-making are distributed across a network of interconnected actors. This thesis uses Network Governance to examine how these actors collaborate, share information, and coordinate their efforts to manage energy resources efficiently.

2.2 Collective Action Theory

Collective action theory delves into how individuals collaborate to achieve common goals across various contexts such as natural resource management, community governance, and public policy. At the forefront of this theory is Elinor Ostrom, whose seminal research highlights the potential for collective benefits when individuals cooperate. Ostrom's work emphasises that collective action can yield outcomes that surpass what could be achieved through individual efforts alone (Ostrom, 2010-1). This concept is important in scenarios where shared resources or public goods are at stake, as collective action can enhance public services, infrastructure development, and social cohesion (Ostrom, 2010-2).

Padovan et al. (2019) builds upon Ostrom's framework by applying it to contemporary challenges, such as sustainable energy transitions. Their research underscores the role of collective action in addressing complex societal issues that require coordinated efforts and shared responsibilities. By expanding the scope to include new challenges and contexts, Padovan et al. illustrate how Ostrom's principles remain relevant and adaptable across diverse fields.

2.2.1 Drivers and Challenges of Collective Action

Motivation is a cornerstone in fostering participation in collective action initiatives. Individuals are driven by perceptions of fairness, trust in fellow group members, and confidence in the effectiveness of collective efforts (Padovan et al., 2019). These motivators are often reinforced by incentives such as social recognition and reciprocity, which encourage individuals to contribute actively to group initiatives.

A challenge to deal with when participating in collective action is the free-rider problem. It refers to individuals benefiting from group efforts without proportionally contributing. This dynamic can have a negative impact on cooperation and hinder the achievement of collective goals, as those who do not contribute may still enjoy the benefits generated by the group (Ostrom, 2010-1). Furthermore, coordinating actions and decisions among multiple participants can be resource-intensive and complex. Effective coordination is essential for aligning diverse perspectives and strategies towards shared objectives. High coordination costs can act as barriers to effective collaboration, requiring structured approaches to streamline decision-making processes (Padovan et al., 2019). Besides that, participants in collective action often bring diverse interests, priorities, and preferences to the table. Aligning these varying perspectives towards a common goal requires strong consensus-building processes and negotiation skills. Resolving conflicts and finding common ground are necessary steps in stimulating favourable group dynamics and sustaining collective efforts over time (Ostrom, 2010-2).

2.2.2 Overcoming the Challenges

When it comes to overcoming the challenges, establishing transparent and open communication channels among participants is believed to be fundamental. Clear communication facilitates the exchange of information, coordinates efforts, and resolves misunderstandings or conflicts. It builds trust and mutual understanding, essential for maintaining collaborative relationships within the group (Padovan et al., 2019). Besides that, Ostrom highlights the idea that cultivating shared norms, values, and expectations within the group ensures a sense of common purpose and identity. When individuals share common beliefs and principles, they are more likely to cooperate and align their actions towards achieving collective goals. These shared norms serve as guiding principles that shape group behaviours and decision-making processes (Ostrom, 2010-2). Moreover, designing effective incentive structures are used to motivate active participation and discourage free-riding behaviour. Incentives can range from material rewards to social recognition within the group. By rewarding cooperative behaviours and contributions, organisations can stimulate sustained engagement and commitment among members (Padovan et al., 2019). Furthermore, Ostrom explains that implementing mechanisms to monitor and enforce compliance with group rules and agreements is essential. Monitoring ensures transparency in actions and holds members accountable for their commitments. Enforcement mechanisms deter opportunistic behaviours and ensure that all participants contribute their fair share to collective efforts, thereby maintaining equity and fairness within the group (Ostrom, 2010-1). Additionally, creating a sense of mutual accountability and shared responsibility encourages individuals to take ownership of collective outcomes. When participants feel personally invested in the group's success, they are more likely to engage actively in decision-making processes and contribute proactively to achieving shared objectives. Shared responsibility promotes collaborative attitudes and strengthens cohesion within the group (Padovan et al., 2019).

Ostrom's research points out that effective leadership plays a key role in facilitating collective action. Leaders mobilise group members, provide strategic guidance, and articulate shared goals that inspire collective commitment. Organisational structures support coordination, resource allocation, and the implementation of strategies necessary for achieving collective objectives. Strong leadership and well-defined organisational frameworks enhance the efficiency and effectiveness of collective action initiatives, ensuring sustainable outcomes and long-term impact (Ostrom, 2010-2).

2.3 Common-pool Resource Management

2.3.1 Theory Background

Besides Collective Action Theory, Elinor Ostrom has worked on the topic of the previously mentioned common-pool resources. Common-pool resource theory is closely related to collective action theory, as both fields aim to understand how individuals come together to manage shared resources. Collective action theory examines the mechanisms and challenges involved in individuals cooperating to achieve common goals, which can include the (sustainable) management of common-pool resources. Therefore, the following part of this study delves deeper into the latter, the topic of common-pool resources.

Common-pool resources, CPR in short, are explained in her research as systems that generate 'finite quantities of resource units', where one person's use of the resource subtracts from the quantity available to others. Ostrom explains common-pool resources have a competitive nature of resource consumption, where individual use impacts the availability of the resource for others. Examples of such resources include fisheries, grazing lands and forests. Such resources are often shared between various users, and efforts to exclude others can be costly due to the nature and size of the resource system. The research states that when the resource units are highly valued and can benefit multiple stakeholders through production processes, exchange, and consumption, the actions of one individual might create negative externalities for others. Furthermore, the importance of effective institutional design and governance in managing common-pool resources sustainably is emphasised throughout her research. By implementing the right boundaries, rules, and monitoring mechanisms, communities can mitigate the risk of overexploitation and ensure long-term viability of shared resources (Ostrom, 2002). In later work, Ostrom adds to her explanation of common-pool resources the idea that such resources are sufficiently large to make it difficult to define the recognized users and exclude users altogether (Ostrom, 2008).

2.3.2 Energy as a Common-Pool Resource

This section aims to further explain the nature of common-pool resources and when energy can become one in the context of Smart Energy Hubs. The concept of common-pool resource management offers a useful framework for understanding the challenges associated with managing distributed energy. Common-pool resources are characterised by their inherent rivalry and the difficulty in excluding others from accessing them. This concept is important for understanding how energy resources, such as electricity, renewable energy generation capacity, and storage, operate within modern smart energy hubs (Wolsink, 2020).

Energy systems, especially in the context of smart grids and energy hubs, exemplify the complexities of managing common-pool resources. Electricity, renewable energy sources, and storage systems all exhibit different degrees of rivalry and excludability, which influence their availability and accessibility. In a Smart Energy Hub, managing these resources involves balancing the demand and supply while addressing issues related to congestion, capacity constraints, and access control (Choe & Yun, 2017).

Understanding how rivalry and excludability exist in these contexts is needed for designing effective energy management strategies. The following table delves into specific energy goods within smart energy hubs, examining how they fit within the common-pool resource framework.

Table 1:

Rivalry and Excludability of Energy Goods

**Note: Energy Goods in this table that are not yet mentioned before will be explained in the following chapter.*

Energy Good	**Rivalry**	**Excludability**	**Explanation**
Electricity (within a Smart Grid)	High	High	In smart energy hubs, electricity is rivalrous because one entity's consumption can reduce availability for others. Excludability is managed through advanced metering and grid controls that enforce access and billing.
Renewable Energy Generation Capacity (e.g., Solar, Wind)	Moderate (due to grid constraints)	High	Generation capacity is somewhat rivalrous when the grid is at capacity, leading to possible constraints. Excludability is high as it is regulated by grid access rules and market mechanisms.
Energy Storage Systems (e.g., Batteries)	High	High	Energy storage is rivalrous as stored energy is finite; once used, it is no longer available to others. Excludability is high due to ownership and control mechanisms.
Demand Response Programs	Low	High	Demand response programs are non-rivalrous because one participant’s change in usage does not affect others. Excludability is high through program enrollment and incentive structures.
Smart Grid Data and Analytics	Low	Moderate to High	Smart grid data is non-rivalrous as its use by one entity does not diminish its availability for others. Excludability is moderate, controlled through data access policies and security measures.

Public EV Charging Stations	High	Moderate	Charging stations are rivalrous because simultaneous use by multiple vehicles can lead to congestion. Excludability is moderate; access can be controlled but not completely restricted.
Grid Infrastructure (e.g., Transformers, Transmission Lines)	Moderate (during peak usage)	High	Infrastructure is somewhat rivalrous during peak usage due to capacity limits. Excludability is high as it is controlled by grid operators and regulatory bodies.
Energy Efficiency Technologies (e.g., Smart Thermostats)	Low	High	These technologies are non-rivalrous as their use by one does not impact availability for others. Excludability is high through product sales and installation controls.

Source: Information based on Cloe & Yun (2017).

2.3.3 Successful Common-Pool Resource Management

In her earlier work, Ostrom identified a set of key design principles that ensure successful common-pool resource institutions. The following principles are explained to be important for the sustainable management of shared resources. First, having clearly defined boundaries that define who has the rights to withdraw resource units from the common-pool resource is needed (Ostrom, 2002). Secondly, the distribution of the benefits gained from using the resource should be proportional to the costs that are imposed by the rules governing the resource (Ostrom 2002). In other words, there should be a proportional equivalence, or congruence, between benefits and costs, where rules specify the amount of resource products a user can have based on input requirements and local conditions. Rules governing the place, time, technology and quantity of resource units should be tailored to the local conditions to ensure effective resource management (Ostrom, 2008). Furthermore, she mentioned collective-choice arrangements to be an important principle to ensure successful common-pool resource institutions. This means that individuals affected by operational rules should get the opportunity to participate in modifying those rules. This is a participatory approach that can ensure fair rules that reflect the community needs (Ostrom, 2008). Besides that, monitoring plays an important role in overseeing the conditions of common-pool resources, as well as the behaviour of its users. Such monitors are meant for accountability and transparency in resource management (Ostrom, 2008). Furthermore, the principle of graduated sanctions states that users who violate rules should receive sanctions from other users or accountable officials, depending on the severity of the offence (Ostrom, 2008). The conflict-resolution mechanisms refer to the idea that users and officials have access to low-cost, local arenas to resolve their conflicts (Ostrom, 2008). Ostrom explains that when it comes to (environmental) choices, strong differences in values and power across parties brings along conflict. Therefore, conflict resolution may be as important an important motivation for the design of resource institutions, besides the concern with the actual resources themselves. This idea comes from the fact that people bring varying interests, fundamental philosophies and perspectives to problems of (sustainable) governance, and if their conflicts do not escalate to the point of dysfunction, change and learning can be sparked (Ostrom, 1990). Furthermore, a principle often observed in common-pool resource institutions is the minimal recognition of rights to organise. Users have the autonomy to adapt and create governance structures that suit their needs related to the common-pool resource. This allows users of the resource to participate in the governance process and have a say in the management, while cooperation and coordination among the stakeholders can be fostered, leading to effective outcomes for everyone involved. If users have a say in resource management, they tend to be more invested in the long-term productivity and health of the common-pool resource (Ostrom, 2008). Lastly, Ostrom discusses the principle of nested enterprises. The paper discusses how appropriation, monitoring, conflict resolution, provision, governance activities and enforcement are organised in multiple layers of nested enterprises (Ostrom, 2008). Nested enterprises are explained as a hierarchical organisational structure where various levels of decision-making and governance are interdependent and interconnected. When it comes to common-pool resources, nested enterprises help to facilitate the management of resources across the different levels of organisation. It provides a framework for organising and coordinating the management to ensure that actions and decisions at each level contribute to the use of the shared resources (Ostrom, 2002). The principle of nested enterprises applies merely to common-pool resources that are part of a larger system.

2.4 Collaborative Governance

2.4.1 Definition and Principles

Collaborative governance moves away from traditional hierarchical approaches by involving diverse stakeholders, including public and private actors, in joint decision-making processes to address complex societal issues and achieve common goals (Emerson et al., 2011; Ansell & Gash, 2008). This approach emphasises inclusivity, shared responsibility, and mutual accountability among participants, aiming to harness the collective intelligence and resources of stakeholders for more effective and sustainable solutions (Emerson et al., 2012; Ansell & Gash, 2009).

Collaborative governance initiatives often involve public actors such as government agencies, regulatory bodies, and local authorities collaborating with private actors such as industry representatives, non-profit organisations, and community groups. Together, these stakeholders co-create policies, programs, and initiatives that leverage their diverse expertise and perspectives (Emerson et al., 2012).

Ansell and Gash (2008) define collaborative governance as the direct engagement of non-state stakeholders in formal, consensus-oriented, and deliberative decision-making processes initiated by public agencies. This collaborative approach is needed for making and implementing public policies, managing public programs or assets, and responding effectively to complex challenges that a single entity cannot tackle alone (Ansell & Gash, 2008).

2.4.2 Mechanisms and Processes

Successful collaborative governance is based on several key factors identified by Ansell and Gash (2008, 2009). These factors include initial conditions, leadership, institutional design and dynamic collaboration. The context and conditions under which collaboration begins, including historical relationships and existing power dynamics among stakeholders, is a key factor for success in collaborative governance. Another key factor for successful collaborative governance is effective leadership that promotes an environment of mutual understanding, trust, and shared interests among stakeholders. Designing governance structures that facilitate collaboration, including clear roles, responsibilities, and decision-making processes is another important key factor. Lastly, recognizing that collaborative processes are iterative and non-linear, requiring adaptation to changing circumstances and stakeholder interactions is essential for successful collaborative governance (Ansell & Gash, 2008; Ansell & Gash, 2009).

Furthermore, Ansell and Gash (2009) emphasise the importance of addressing power disparities and providing incentives for stakeholder engagement to ensure genuine participation and commitment to collaborative efforts. They argue that building trust and ensuring interdependence among stakeholders are of essence for overcoming challenges and enhancing the effectiveness of collaborative governance initiatives (Ansell & Gash, 2009).

2.4.3 Factors Influencing Success

In addition to initial conditions and leadership, factors such as historical context, stakeholder incentives, and the institutional design of collaborative processes significantly influence their outcomes (Ansell & Gash, 2008). Emerson et al. (2012) introduces the Collaborative Governance Regime (CGR), which identifies three essential components driving collaborative efforts. The first one is principled engagement, which is explained as stakeholders working across boundaries to identify and address issues guided by principles of inclusivity, fairness, and transparency. Another component is shared motivation, which is described as developing mutual understanding, trust, and internal legitimacy among stakeholders to foster commitment to collaborative goals. Lastly, the capacity for joint action aims at mobilising resources, knowledge, and leadership collectively to accomplish shared objectives through effective procedural arrangements and knowledge-sharing mechanisms (Emerson et al., 2012).

2.4.4 Analysis and Integration with Ostrom's Collective Action

Collaborative governance aligns closely with Elinor Ostrom's collective action framework, which emphasises the conditions necessary for groups to manage common pool resources effectively. Ostrom's work provides valuable insights into the dynamics of cooperation and collective decision-making that underpin successful collaborative governance initiatives (Ostrom, 2010-1; Ostrom, 2010-2).

Ostrom identifies several key principles and mechanisms that are relevant to understanding collaborative governance. These principles and mechanisms include clear communication and information sharing, shared norms and values, incentive structures and monitoring and enforcement mechanisms. Effective communication channels among stakeholders are essential for coordinating efforts, sharing information, and resolving conflicts, needed in both collective action and collaborative governance contexts (Ostrom, 2010-1). Additionally, promoting shared norms, values, and expectations within the group develops a sense of common purpose and identity, enhancing cooperation and commitment to collective goals (Ostrom, 2010-2). Besides that, designing incentive structures that reward cooperation and discourage free-riding behavior helps stimulate active participation and commitment among stakeholders (Ostrom, 2010). Lastly, implementing mechanisms for monitoring compliance with agreements and enforcing rules ensures transparency and accountability, which are essential for maintaining trust and cooperation within collaborative governance processes (Ostrom, 2010-2).

Collaborative governance integrates these principles by promoting inclusive decision-making, fostering mutual trust and understanding among stakeholders, and implementing effective mechanisms for cooperation and accountability (Ansell & Gash, 2008; Emerson et al., 2012). By embracing Ostrom's insights, collaborative governance initiatives can navigate complexities, manage conflicts, and achieve more sustainable outcomes through collective efforts.

Collaborative governance thus represents a progressive approach to addressing complex societal challenges by engaging diverse stakeholders in joint decision-making. This approach not only redefines traditional governance structures but also aligns closely with Elinor Ostrom's collective action framework by emphasising the importance of inclusive decision-making, mutual trust, and effective institutional design. By integrating these principles and mechanisms, collaborative governance initiatives can enhance their effectiveness in achieving shared goals and promoting sustainable development.

2.5 Network Governance

2.5.1 Characteristics of Network Governance

Network governance involves multiple organisations or stakeholders collaborating to achieve common goals. One key characteristic of network governance is decentralised decision-making, where power is distributed among network participants rather than concentrated in a single entity. Furthermore, network governance relies on interconnected relationships between organisations, often across different sectors or levels of government (Kenis & Provan, 2008). These relationships are based on trust, cooperation and shared objectives. Besides the interconnectedness, a characteristic of such a network is flexibility and adaptability. The flexible and adaptable nature of networks allows for quick responses to changing circumstances and emerging issues. In this way the networks can evolve organically to address complex issues that require diverse expertise. Another key characteristic of network governance, as explained by Kenis and Provan, is shared resources and responsibilities among participants, considering collaboration and mutual support as key principles. Lastly, network governance focuses on outcomes and impacts, putting a strong emphasis on achieving results that benefit the community. Performance measurement is generally based on shared goals and objectives (Provan & Milward, 2001). These characteristics are again described by Provan and Kenis in their work of 2008, highlighting the decentralised nature, collaborative decision-making processes and shared responsibilities that define network governance in comparison to the centralised top-down approach that can be found in a more traditional governmental organisation (Kenis & Provan, 2008).

2.5.2 Differences from Traditional Governance

In traditional government governance, the decision-making process is often centralised within an organisation (or energy system). When it comes to network governance, decision-making authority is dispersed across multiple entities. Besides that, there is a difference in the hierarchical structure when it comes to network governance. Traditional governance organisations typically have a more hierarchical structure with clear lines of authority. Network governance on the other hand works with a more collaborative and horizontal structure, where partners work together as equals. While traditional governance works more with separate departments or agencies working independently, networks promote interconnectedness and collaboration across sectors and organisations. When it comes to relationships, there is also a slight difference between the two governance modes, as networks tend to be more dynamic and flexible, able to adapt to changing needs and circumstances.

While accountability and transparency are important in both forms of governance, the mechanisms and processes for accountability may differ in network governance due to the distributed nature of decision-making and shared responsibilities (Provan & Milward, 2001).

2.5.3 Benefits of Network Governance

It is believed that effective network management is essential for addressing tensions and maximising benefits within a project, especially when dealing with complex issues that require collaboration among stakeholders with diverse expertise (Provan and Kenis, 2008). Network governance stimulates collaboration among various stakeholders, including government agencies, non-profit organisations, and community groups. Networks provide a platform for sharing knowledge and resources to address difficult problems effectively. This collaboration can lead to more comprehensive and integrated solutions to complex issues. Besides that, network governance can be beneficial for organisations to pool their resources, expertise, and knowledge to address community needs more effectively. This way the network can work collaboratively towards desired outcomes, while maintaining flexibility and adaptability. This can result in cost savings and improved service delivery, as networks can quickly respond to changing circumstances and emerging challenges, making them suitable for dynamic environments. Furthermore, networks provide a platform for sharing best practices, innovative ideas, and new approaches to problem-solving. This can lead to the development of creative solutions that may not have been possible within a traditional governance structure. Another benefit of network governance is the encouragement of community engagement and participation in decision-making processes (Provan & Milward, 2001). When a project relies on the interconnectedness of multiple stakeholders, networks can provide significant benefits (Kenis & Provan, 2008).

2.5.4 Challenges of Network Governance

Managing a network involving multiple stakeholders with diverse interests and priorities can be complex. Coordination challenges, such as conflicting agendas or communicative issues, may hinder effective decision-making. Besides that, the lines of accountability may become blurred, making it challenging to attribute responsibility for outcomes and ensure transparency and accountability. Furthermore, power dynamics within a network can impact decision-making processes and resource allocation. It might be challenging to find a balance in ensuring fair representation and equitable distribution of resources. Also, if there is significant resistance from key stakeholders or organisations to participate in network governance, it may be challenging to establish effective collaboration and achieve desired outcomes. Besides that, maintaining the sustainability of a network over the long term can be a challenge. Changes in leadership, funding constraints, or shifting priorities among stakeholders may affect the continuity and effectiveness of the network (Provan & Milward, 2001).

2.5.5 Solutions to Network Challenges

When making arrangements for governance in networks with the aim of maximising benefits and minimising problems, it is useful to consider factors such as network's goals, member roles and responsibilities, communication mechanisms, decision-making processes and mechanisms for resolving conflicts (Kenis & Provan, 2008). It has proven to be beneficial to establish a clear governance structure outlining roles, responsibilities, decision-making processes, and accountability mechanisms within the network. Clearly defining roles and authority can help ensure effective leadership and oversight. Ensuring representation from all relevant parties can enhance legitimacy and promote collaborative decision-making. Furthermore, stimulating open and transparent communication channels within the network to facilitate information sharing, consensus-building, and conflict resolution support an effective network. Additionally, creating clear guidelines for resource allocation and management within the network, considering the financial and human resources needed to sustain network activities is believed to alleviate challenges within the network. Ensuring equitable distribution of resources can prevent conflicts and promote sustainability. Furthermore, implementing mechanisms for monitoring and evaluating the performance of the network in achieving its goals and objectives can be useful. Besides that, establishing key performance indicators and evaluation criteria can help assess the effectiveness of the network and identify areas for improvement (Provan & Milward, 2001), (Kenis & Provan, 2008).

2.6 Comparing Network Governance and Collaborative Governance

In 2023, Wang and Ran conducted research to portray the similarities and differences between network governance and collaborative governance, which are often used interchangeably but show distinct characteristics. Network governance is fundamentally rooted in principles of reciprocity, trust, mutual interdependence, and negotiation among diverse stakeholders. It emphasises coordinating entities that merge collaborative public goods and service provision with collective policymaking efforts (Wang & Ran, 2023). Conversely, collaborative governance is defined as a governing arrangement where public agencies directly engage non-state stakeholders in formal, consensus-oriented, and deliberative decision-making processes to formulate or implement public policy and manage public programs or assets (Ansell & Gash, 2008; Emerson et al., 2012; Wang & Ran, 2023).

2.6.1 Commonalities Between Network Governance and Collaborative Governance

In their comprehensive analysis, Wang and Ran identified sixteen common themes between network governance and collaborative governance, underscoring key areas of convergence and shared principles (Wang & Ran, 2023). Among these, resource dependence emerged as the most prevalent theme across both theories. It is universally acknowledged that interorganizational collaboration is often necessitated by resource interdependencies, where stakeholders pool resources to collectively address complex societal challenges (Ansell & Gash, 2009; Emerson et al., 2012; Wang & Ran, 2023). Resources serve as strategic tools to influence and activate partners, providing significant collaborative advantage and power dynamics within governance networks (Wang & Ran, 2023).

Leadership also emerged as an important theme in both network and collaborative governance theories. Effective leadership plays a key role in facilitating interaction, building trust, mitigating conflicts, constructing networks, aligning stakeholder interests, stimulating creativity, promoting systematic thinking, and ultimately enhancing governance outcomes (Ansell & Gash, 2009; Wang & Ran, 2023).

Trust, another fundamental theme, is essential for both network and collaborative governance. Building trust among stakeholders is believed to be very important, particularly in voluntary collaborations where the mobilisation of resources relies on mutual reliability, past successful cooperation, network embeddedness, and organisational reputation (Emerson et al., 2012; Wang & Ran, 2023). Trust not only enhances collaboration but also improves the overall quality and sustainability of governance networks (Wang & Ran, 2023).

Power dynamics represent a significant challenge in both governance approaches. Stakeholders gain power derived from various sources such as control over financial resources, expertise, and legitimate decision-making authority. Managing power imbalances is needed to ensure equitable participation and achieving voluntary acceptance of collective decisions within collaborative and networked arrangements (Ansell & Gash, 2008; Wang & Ran, 2023).

Performance measurement is the final common theme, focusing on evaluating the effectiveness and efficiency of collaborative efforts. Research has utilised diverse indicators including procedural measures (e.g., degree of deliberation, democracy in decision-making) and outcome-oriented metrics (e.g., efficiency, equity, resource utilisation) to assess the impact and success of governance initiatives (Emerson et al., 2012; Wang & Ran, 2023).

2.6.2 Differences Across the Theories

While network governance emphasises structural elements and pluricentric coordination to manage interdependencies and reduce transaction costs, collaborative governance is characterised by its process-oriented approach, emphasising inclusive participation, deliberative consensus-building, and institutional arrangements that facilitate collaboration (Ansell & Gash, 2008; Emerson et al., 2012; Wang & Ran, 2023). Collaborative governance focuses on designing institutions that reduce information barriers, risks, and transaction costs, thereby promoting stable and effective multi-sectoral collaborations to address complex policy challenges (Wang & Ran, 2023).

In conclusion, while network governance and collaborative governance share common themes such as resource dependence, leadership, trust, power dynamics, and performance measurement, they diverge in their theoretical foundations and practical applications. Network governance leans towards structural coordination and transactional efficiency, whereas collaborative governance prioritises inclusive decision-making processes and institutional design to create effective multi-stakeholder collaboration (Ansell & Gash, 2008; Emerson et al., 2012; Wang & Ran, 2023).

2.7 Collective Action and the Energy Transition

2.7.1 Theoretical Foundations and Practical Applications

Elinor Ostrom's research on collective action underscores the effectiveness of self-organised groups in addressing common resource problems. Her multi-scale approach, which involves various levels of governance—local, regional, and global—is useful for tackling the multifaceted challenges of climate change. Local monitoring and community involvement, combined with accountability, lead to better resource management outcomes. Trust and cooperation among stakeholders, alongside a commitment to emission reduction, are foundational to effective climate action (Ostrom, 2010).

Applying collective action theory to energy transition, Padovan et al. explore how communities can come together to address challenges in energy distribution, consumption, and production. This includes grassroots initiatives, cooperative efforts, and community-led projects aimed at reshaping energy systems. Energy, as a common resource, highlights the necessity of collective action in its governance. Collective initiatives challenge existing power structures and promote sustainability by allowing communities to influence energy production, distribution, and consumption (Padovan et al., 2019).

2.7.2 Collective Action and Common-Pool Resources

To effectively manage distributed energy systems as a common-pool resource, applying Ostrom's principles can provide valuable insights and guidelines. Wolsink (2012) emphasises the importance of treating renewable energy as a common-pool resource within microgrids and distributed generation. This approach fosters a sense of community ownership and responsibility, leading to sustainable practices and social acceptance. Effective governance structures are adaptive and context-specific, catering to the unique needs and identities of each community (Wolsink, 2012).

2.7.3 Governance Structures and Community Engagement

Effective governance of energy systems involves various ownership models, being private, collective, public, and hybrid. Separating ownership from management can enhance the resilience and flexibility of the energy system. Governance structures that promote community involvement and decentralised decision-making are essential for managing renewable energy effectively. Community engagement in decision-making processes, energy planning, and project development ensure that energy systems address local preferences and specific needs (Wolsink, 2012; Acosta et al., 2017).

Community-based approaches, such as collaborative planning and co-production of energy, strengthen social foundations and promote a transition to decentralised sustainable energy systems (Wolsink, 2012).

2.7.4 Collective Action in Energy Hubs

Applying collective action theory to energy hubs involves multiple stakeholders, including energy consumers, producers, and regulators, each with their own preferences and interests. Ostrom's principles of equitable benefit distribution and transparent decision-making can mitigate coordination costs and diverse interests in energy hub collaborations. This promotes shared responsibility and mutual trust, leading to more effective and sustainable outcomes in the energy sector (Ostrom, 2010).

Furthermore, the concept of collaborative governance, as described by Emerson et al. (2012) and Ansell and Gash (2008), is of significant use for managing the complexities of energy hubs. Collaborative governance involves the active participation of various stakeholders—utilities, energy providers, grid operators, technology developers, policymakers, and community representatives—in designing and implementing innovative solutions for energy management. This approach promotes information sharing, collective decision-making, and trust-building among stakeholders, which are needed for overcoming regulatory barriers, technical constraints, and market uncertainties (Emerson et al., 2012; Ansell & Gash, 2008).

2.7.5 Challenges and Opportunities

Despite the benefits, collective action in energy transition faces challenges such as regulatory barriers, the need for social acceptance, and financing risks. Supportive policy frameworks are essential for encouraging renewable energy initiatives while promoting equity and diversity in energy systems. Addressing these challenges requires a comprehensive understanding of local contexts and sustained efforts to maintain effective network interactions (Padovan et al., 2019).

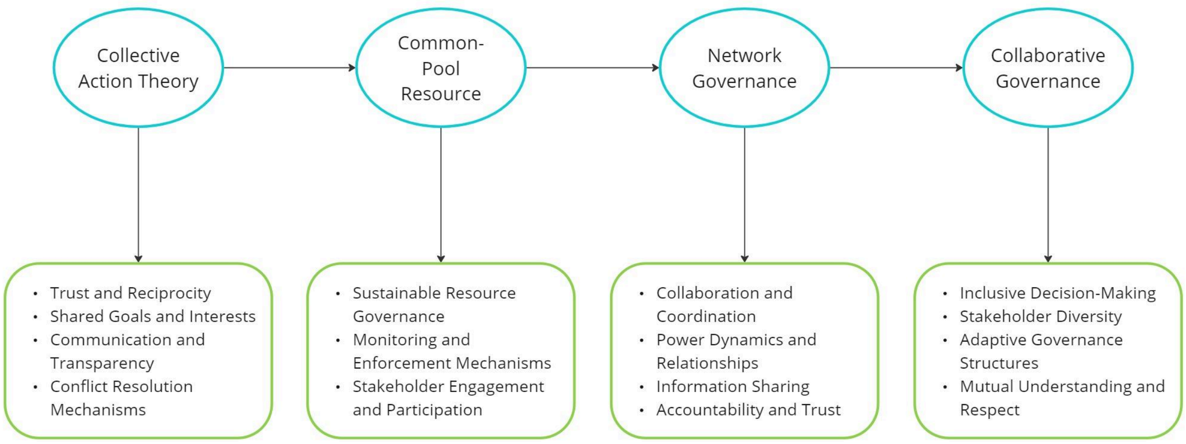
Network governance within energy hubs offers benefits like decentralisation, flexibility, and enhanced access to resources through social connections. It promotes resilience, innovation, and legitimacy, stimulating collective action and trust among stakeholders. However, challenges such as complex network structures, uncertain power distributions, resource constraints, and the need for effective coordination and integration with formal governance structures must be addressed (Parag et al., 2013).

In summary, collective action theory provides a comprehensive framework for understanding and addressing the complexities of energy transition. By supporting local and regional efforts, promoting community engagement, and adopting adaptive governance structures, communities can effectively manage energy as a common-pool resource and drive sustainable energy transitions. This comprehensive approach is necessary to navigate the complex dynamics of energy systems.

2.8 Summary of Key Themes in Theoretical Frameworks

Figure 2:

Summary of Key Themes in the Theoretical Frameworks



Source: Created using Miro.com

2.9 Conclusion to Sub-question 1

This part aims at answering the question stated at the start of this chapter of how we can theoretically explain the variation in the extent to which, and the way, companies collaborate to optimally utilise energy as a common-pool resource. Insights can be drawn from the theories studied in this chapter.

The theory of collaborative governance emphasises the essence of including diverse stakeholders, including companies, in decision-making processes to dress complex issues. Companies can collaborate with other stakeholders, such as community representatives, policy makers and energy providers, to co-create initiatives for optimal energy utilisation. Mutual understanding, inclusivity, transparency and trust can help to guide collaborative efforts between companies to create effective collaboration in energy management.

Network governance on the other hand, focuses on the collaboration and coordination of interdependent stakeholders, aiming to address complex challenges related to energy management. Companies can engage in structures of network governance with other organisations to optimise energy utilisation through collective action and shared decision-making. Network development and structural elements can ensure effective collaboration among companies to enhance sustainability and energy efficiency.

Collective action theory explains the importance of individuals collaborating to achieve common goals as sustainable energy management. When companies engage in collective action, they can share their knowledge, pool their resources and coordinate their efforts to optimise energy utilisation as a common-pool resource. Understanding the incentives and motivations for companies to collaborate in energy management initiatives helps drive effective collective action.

Common-pool resource theory highlights the need for effective governance mechanisms and institutional design when wanting to manage shared resources sustainably. Companies can apply the principles of common-pool resource theory to collectively utilise energy resources in a way that balances collective benefits with individual interests. By implementing monitoring mechanisms, rules and boundaries, these companies can ensure long-term viability of energy as a common-pool resource and mitigate the risk of overexploitation.

In conclusion, when integrating the insights gained from the theories, we can explain and identify the variation in collaboration levels and approaches to optimally utilise energy as a common-pool resource. Essentially, as informed by the theories, effective collaboration can lead to more efficient and sustainable energy management practices among companies, such as collaboration in energy hubs. This will be discussed in the next chapter.

Chapter 3: Research Context: Smart Energy Hubs

3.1 Purpose of the Chapter

This chapter delves into the comprehensive study of Smart Energy Hubs, aiming to provide a thorough examination of their technological evolution, role in mitigating net congestion, historical development, and the factors influencing their slower adoption. Beginning with an exploration of their technological evolution from smart grids to integrated smart energy systems and finally to the concept of Smart Energy Hubs, the chapter traces their development over the past decade. It examines how these hubs manage and optimise the conversion, production, consumption, and storage of multiple energy carriers within unified multi-energy systems (MES), addressing challenges such as grid congestion and inefficiencies in traditional energy systems. By analysing these aspects, the chapter aims to provide a detailed understanding of Smart Energy Hubs and their role in enhancing grid stability, improving energy efficiency, and promoting sustainability within modern energy landscapes.

This chapter will answer the following sub-questions:

- *Sub-question 2: In what way does cooperation take place within energy hubs as a solution for grid congestion?*
- *Sub-question 3: How has the concept of energy hubs developed over the past 10 years?*

3.2 Technological Development of the Concept

Historically, fossil fuels have been the main energy source, converted into electricity at large thermal power plants and transmitted over long distances. However, besides being highly polluting, this method is inefficient and costly due to high transmission and distribution losses, causing researchers to study better ways to manage energy.

3.2.1 An evolutionary timeline

Before discussing the concept of smart energy hubs in depth, it is essential to understand the evolutionary path that the concept has followed. Therefore, this part of the research will start off by explaining the progression of the concept in text, followed by a figure showing the evolution (Figure 3).

The development started with the concept of smart grids, which serves as the foundation for modern energy management. By integrating smart metres (SM) and advanced information and communication technologies (ICT), traditional power systems are transformed into so-called smart grids. Smart grids enable automated control, real-time monitoring, and efficient management of electricity distribution, transmission and generation. Smart grids incorporate intelligent technologies for data processing, collection and decision-making. The initial benefits of a smart grid entail enhanced energy reliability, reduced operational costs, improved energy efficiency, and better integration of distributed energy resources (DER) and renewable energy sources (RES) (Mohammadi, 2018).

The concept of smart grids later developed into smart energy systems. Building on the smart grid, the concept of Smart Energy Systems (SES) expands the focus from electricity alon to multiple energy carriers such as water, heat and natural gas. A SES aims to integrate various energy infrastructures, including cooling, heating, electricity and transportation networks, within an intelligent and cohesive framework. SES includes demand-side management (DSM), energy management systems (EMS) and other smart technologies to optimise the performance of the energy system. DSM aims to align network needs with customer consumption patterns to reduce consumption during peak hours and smooth the general consumption curve. This enhances network reliability and stability and lowers energy bills. The advantages of SES are reduced emissions, increased efficiency, enhanced reliability and lower energy costs through the synergistic use of multiple energy carriers (Mohammadi, 2018).

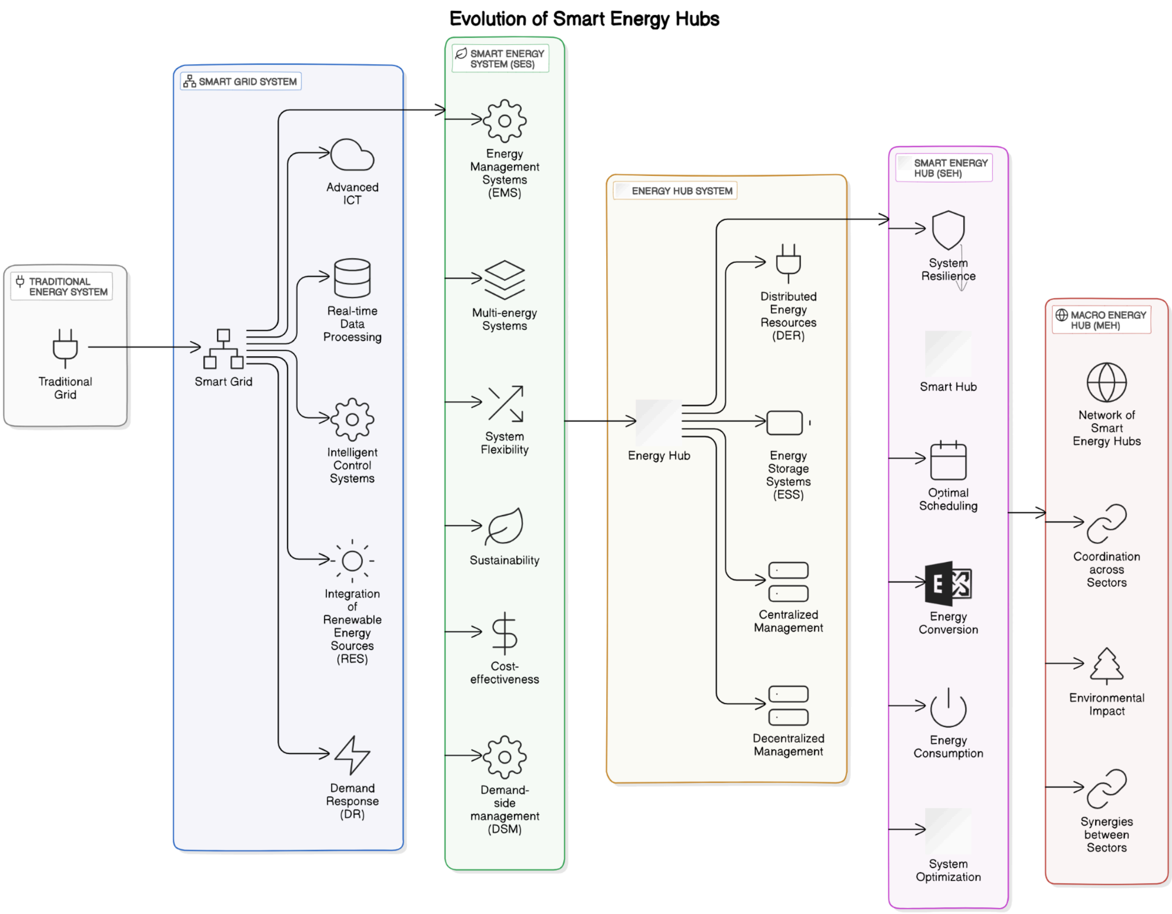
To effectively integrate DER, RES, Energy Storage Systems (ESS) and participate in DSM programs, an integrated management framework is needed: the energy hub. An energy hub models and manages the conversion, production, consumption and storage of different energy carriers in one unified multi-energy system (MES). This can represent different scales, from micro to macro energy hubs. Macro energy hubs are a network of macro energy hubs, which can be residential, industrial, commercial and agricultural. Energy hubs aim to efficiently manage the flow and conversion of energy, considering the interactions between different technologies and energy carriers under decentralised or centralised management schemes. Managing energy hubs can thus be either centralised or decentralised. In centralised management, one single unit is meant to optimise the entire energy hubs by sending control signals and collecting data. However, this approach might be impractical for larger systems due to the volume and complexity of the data. Decentralised management, a scheme where independent controllers share control decisions and manage specific areas, offers enhanced reliability, scalability and reduced computation time. This way they reduce costs, optimise resource use and enhance system flexibility (Mohammadi, 2018).

The concept of Smart Energy Hubs (SEH) evolves from integrating the previously mentioned smart grid and SES principles into the energy hubs model. SEHs incorporate intelligent control systems, real-time data processing, and advanced ICT to manage multi-energy systems efficiently. SEHs can perform optimal scheduling, energy storage management, demand response (DR) and integration of RES. Smart Energy Eubs enable dynamic interaction between different energy carriers, which improves the overall system performance. In essence, SEHs use smart technologies to handle the scale and complexity of modern energy systems, ensuring sustainability, reliability and cost-effectiveness. At a larger scale, macro energy hubs (MEH) integrate multiple Smart Energy Hubs into one optimised and coordinated network. MEHs provide a broader system of benefits by leveraging the synergies between various sectors and optimising the entire energy ecosystem. MEHs enable coordinated management across various sectors to reduce environmental impacts, waste and fossil fuel consumption, while enhancing efficiency and resilience of the system (Mohammadi, 2018).

Essentially, the development of the smart energy hub concept follows a progression from the smart grid to the smart energy system, finally arriving at the integrated smart energy hub. By adding different layers of intelligence, optimization and integration, the traditional energy grid can evolve into a modern energy management system.

Figure 3:

The evolution from traditional energy systems to smart energy hubs.



**Note: Image created using Eraser App. Figure serves as an aid by roughly visualising the textual explanation on the progression of Smart Energy Hubs.*

3.3 Mitigating Net Congestion with Smart Energy Hubs

3.3.1 Understanding Net Congestion

When the demand for energy exceeds the transport capacity of the electricity, the concept of net congestion occurs. The current Dutch electricity grid was built based on the idea of centralised production, meaning that the design of the grid should handle energy flow from a central power plant to consumers. However, the steep rise in (decentralised) renewable energy sources (RES) such as wind and solar power has put unanticipated additional pressure on the grid, leading to the issue of net congestion. When net congestion occurs, no additional production of electricity can be added to the grid, and at times consumers cannot use electricity either. However, this energy flow of consumption and production is separate, meaning that even though produced energy cannot be added to the grid, it might be possible that there is still enough capacity to manage the consumption of energy. One solution to prevent and mitigate net congestion is to strengthen the grid. However, this process can take up to about 10 years due to a shortage of qualified engineers, complexity of the work and complex laws. Meanwhile, the demand for energy transport has a higher growth rate than the grid can be strengthened. Aiming to address net congestion more quickly and in a more flexible manner, technologies such as Smart Energy Hubs (SEHs) have been proposed (Gerner, 2023).

3.3.2 Energy Hubs as a Solution

SEHs act as localised points in the integrated energy system where energy is converted, consumed, stored and produced, to make energy systems more efficient and flexible. SEHs aim at self-sufficiency by utilising Renewable Energy Sources (RES) such as wind and solar power, along with energy generated using biomass, water or previously stored energy. SEHs put focus on storing energy through various methods such as ground heat, batteries or hydrogen to provide availability during energy shortages. According to research, SEHs play an important role in mitigating net congestion by enhancing reliability and resiliency, reducing energy loss, integrating RES and minimising energy consumption. SEHs can help to alleviate pressure on the electricity grid by optimising the management of energy locally, thereby reducing the risk of potential electricity problems (Gerner, 2023).

Research by Hu et al. (2021) further aims to illustrate how energy hubs can mitigate congestion issues by following several strategies. Starting off with the first strategy of integrating multiple energy resources, an addition to what is previously explained by Gerner. While each energy hub is different in scale, an energy hub can incorporate heat pumps and combined cooling, heating and power (CCHP) units with renewable energy resources. The integration allows for interaction and interconnection between the different types of energy within the hub, allowing for different energy carriers to cooperate seamlessly. Forming a flexible operation, this coupling is useful for managing energy distribution and mitigating congestion effectively. Besides that, the research writes about the optimal operation strategy. An optimal operation strategy for multiple EHs is developed, so that local energy supply can be provided during peak hours by converting gas to electricity. This operation strategy helps to balance the load by shifting the supply from electricity to other forms of energy such as cooling and heat, especially when there is excess renewable energy generation. This strategy uses so-called ‘scenario-based stochastic programming’, to ensure a more adaptive and resilient operation framework. This tool helps to account for the uncertainty in renewable energy generation. Furthermore, another strategy of energy hubs that helps to mitigate net congestion is flexibility in energy provision. During periods of peak electricity, where there is high demand for electricity from the grid, EHs can resort to natural gas to supply heating and cooling demands, reducing the burden on the grid. On the other hand, in periods with lower demand, the supply can shift back to the power grid when the electricity network is less full, and electricity may be cheaper and more abundant during these times. This strategy of shifting energy use based on grid demand helps in optimising the overall energy system's efficiency and in mitigating congestion. Lastly, Hu et al discuss the strategy of energy conversion and storage within the energy hubs. CCHP systems and heat pumps in EHs can convert electricity into cooling or heating, which can be stored and used later. This conversion is especially useful during times of low electricity demand but high renewable energy generation, further mitigating the risk of congestion by balancing supply and demand (Hu et al., 2021).

3.3.3 Cooperation to Mitigate Net Congestion

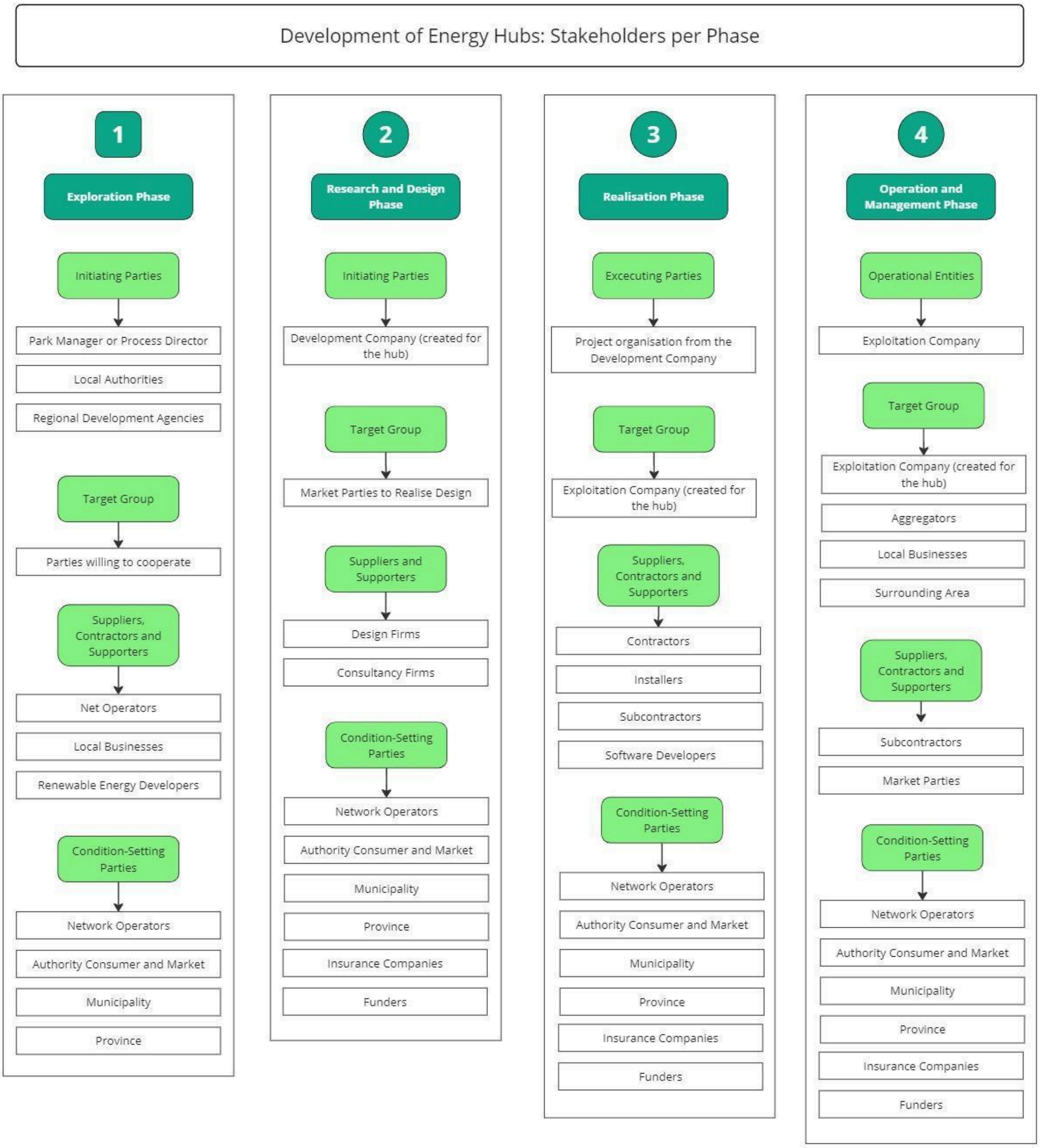
In September of 2023, a document called the ‘Blueprint for the Realisation of Energy Hubs in Business Parks, focused on the Integration of Large-Scale Renewable Energy’ was published by EIGEN. EIGEN is a collaborative project consisting of 16 parties, using their own expertise to focus on system solutions related to the large-scale renewable electricity generation and its integration.

The aim of this document is to describe the approach required to develop energy hubs in business parks. Cooperation among the many stakeholders in energy hubs is complex, but essential for mitigating net congestion. The research describes the various areas in the process of developing energy hubs where cooperation is required. This includes the involvement of multiple stakeholders, the coordination of planning and governance, the optimisation of local energy use, integrated energy management, the utilisation of flexibility services and market mechanisms, collective problem solving, and regulatory and financial collaboration (EIGEN, 2023).

Cooperation of various stakeholders (Figure 4), including businesses, local authorities, energy providers, and regulatory bodies, is required throughout the different phases of developing and operating. Such a collaborative approach is needed to manage grid congestion and integrate large-scale renewable energy. Furthermore, establishing a legal entity, such as a local energy company or development company, is recommended to manage operation, development and planning of energy hubs. These entities help to facilitate cooperation among stakeholders to ensure that actions and investments align with collective goals and regulatory requirements. Besides that, when stakeholders cooperate, the local energy demand and supply can be balanced. By coordinating consumption, production, conversion, and storage of renewable energy within the energy hub, the stakeholders can optimise their energy use locally. This helps to reduce the need for energy transport over longer distances and alleviates congestion of the grid. Moreover, stakeholders need to cooperate to implement integrated energy management systems, such as real-time monitoring and adjustment of energy flows to help maintain balance on the grid. Cooperative management ensures that all participants benefit from and contribute from the optimised energy system. Additionally, the document states that cooperation between different stakeholders enables the effective use of market mechanisms and flexibility services such as FCR, GOPACS, aFRR, and MFRR. These services allow stakeholders to manage energy demand and supply collaboratively, incentivizing businesses to adjust their energy usage patterns and contribute to grid stability. Furthermore, the document states that cooperation helps to address challenges that individual businesses encounter, which might be difficult to overcome alone. By collaborating, the stakeholders can share best practices, pool resources and develop innovative solutions to overcome the barriers to integrate renewable energy and mitigate net congestion. The last area of cooperation mentioned in the process of development is regulatory and financial coordination. When cooperating, stakeholders can better coordinate financial investments and navigate regulatory landscapes. This ensures that energy hubs are financially stable and comply with relevant regulations, which is of essence for long-term success of the project. IIn essence, the document highlights the idea that cooperation among stakeholders is fundamental to the success of Smart Energy Hubs in mitigating net congestion (EIGEN, 2023).

Figure 4:

The stakeholders involved in the development of energy hubs per phase



**Note: Image created using Miro.com*

This figure displays the many stakeholders involved in each phase of the development process, underscoring the high level of required cooperation in energy hubs. In all phases of the project, local authorities such as municipalities and provinces are involved, with municipalities focusing on planning, regulatory approval, and local support.

Provinces and Regional Development Agencies provide necessary funding and support in the early phases. Businesses on the business park are key participants and beneficiaries throughout all phases. Net Operators offer technical information, support, and infrastructure management. Consultants and technical experts guide the project during exploration, design, and realisation phases.

Regulatory Bodies set conditions and ensure compliance across all phases. Construction and technology providers handle the execution of the energy hubs. Banks and investors supply the necessary funding for development and implementation. Energy Service Companies (ESCOs) deliver technical solutions and manage operations. Local communities benefit from and support the project, playing a key role in its success.

3.4 Historical Development of Energy Hubs

The research by Maroufmashat et al. (2019) provides extensive insights into the development and challenges of energy hubs, which helps to understand the slow development of these systems. This part of the study will investigate the development of Smart Energy Hubs and what has possibly caused the relatively slow development of the concept over the past decade.

As mentioned in the previous section, energy hubs have been a viable solution to mitigating net congestion, as other solutions such as grid strengthening are quite time consuming. The concept of energy hubs has been around for decades, with significant interest emerging in the early 2000s, particularly around 2005. However, development of the EHs have been slower than anticipated, despite the early recognition of their potential (Maroufmashat et al., 2019).

The Dutch RVO reported that by 2023, around 100 energy hubs have been realised on industrial terrains. However, Rabobank's 2024 statement that one of the first energy hubs became operational in April of that year indicates a discrepancy. This contradiction reveals a significant misunderstanding regarding the actual status and progress of energy hubs. An expert in the field clarified that there are, in fact, only a few fully realised energy hubs. The confusion arises because various parties often claim to be part of an energy hub collective even when essential elements such as contracts and funding are not yet established. These claims are often more aspirational than reflective of the current reality. The discrepancy highlights that while there may be numerous initiatives and plans labelled as energy hubs, the number of operational and fully functional energy hubs is still very limited. This distinction is important for accurately understanding the current landscape of energy hub development and avoiding overestimating their actual implementation (SEH Expert, 2024).

3.4.1 Development in the Early 2000s

In the early 2000s, the smart grid concept began to gain attention as a response to the limitations of traditional electricity grids. The traditional power grids lacked the capability for real-time control and monitoring and were inefficient in nature. Alongside the development of these smart grids, the idea of integrating multiple energy carriers started gaining attention. Policymakers and researchers recognized the need for cooling, heating and transportation energy besides just electricity in one system (Maroufmashat et al., 2019).

3.4.2 Development in the Mid-2000s

After a few years, around 2005-2010, significant initiatives were taken, and investments were done globally to modernise the electrical grids. An example of this is the Smart Grid Investment Grant program that was established in 2009 by the U.S. Department of Energy. The concept of energy hubs is believed to have originated in the mid-2000s as a theoretical framework for optimising the consumption, storage and conversion of multiple energy carriers. Key publications by Geidl and Andersson in 2005 and 2007 are believed to have laid the groundwork for this concept (Maroufmashat et al., 2019).

3.4.3 Development in the 2010s

From 2010 onwards, the deployment of communication technologies, advanced sensors and smart metres became widespread, enabling the practical implementation of smart grids. Throughout this decade, the Smart Energy System (SES) concept was further developed through policy frameworks and academic research. European initiatives such as Horizon 2020 have funded various projects that were aimed at creating integrated energy systems. Throughout the 2010s, the energy hub model was applied and refined to several case studies, to demonstrate its potential in improving system efficiency and optimising energy flows. As an extension of the energy hub, incorporating smart grid and SES principles, the SEH concept emerged in the 2010s. By integrating real-time data processing and ICT into the energy hub framework, multi-energy systems could be managed more intelligently and dynamically (Maroufmashat et al., 2019).

3.4.4 Development in the Late 2010s to 2020s

Real-world implementation of SES began to appear by the late 2010s and early 2020s, integrating various energy infrastructures to improve sustainability and efficiency. Furthermore, Practical implementation and research of SEH models have accelerated in these years. Studies have shown the benefits of SEH in integrating renewables more effectively, optimising energy use and reducing costs (Maroufmashat et al., 2019).

3.4.5 Current State of Smart Energy Hubs

More recently, the Dutch Government announced the Stimulation Program Energy Hubs 2024-2030 in the National Energy System Plan (NPE) and the Spring Memorandum 2024. The program is aimed at developing local energy hubs from 2024 to 20230, with a budget of €166 million, to enhance grid stability and flexibility. The program aims at accelerating the development of decentralised energy systems through knowledge exchange, support and removing barriers. Pilot projects have been started, of which Smart Energy Hub Zwolle Noord is seen as a successful example, optimising local energy use and generation. The funds for the 2024 pilot phase are meant to support promising initiatives and knowledge building. The program is led by provinces in collaboration with network operators, regional development agencies and municipalities, focusing on selecting new initiatives and creating conditions for hub growth. The long-term goal of the program is integration with other national initiatives, upscaling and standardisation, supporting 60-70 energy hubs in the coming decade (MEZK, 2024)

3.5 Causes of Slow Development

In their research, Maroufmashat et al. have systematically reviewed more than 200 articles and have highlighted several challenges and research gaps in the field of energy hubs. According to the research, a key point in the slow development is the lack of optimization strategies and comprehensive modelling that integrate various energy vectors in an efficient manner. This fact indicates that even though the concept is theoretically robust, the practical implementation of the concept faces significant hurdles. The gap between theoretical models and practical implementation thus is a significant challenge in the development of energy hubs (Maroufmashat et al., 2019)

Theoretical models tend to simplify the complexities of real-world energy systems to make them computationally or analytically manageable. These simplifications can overlook critical factors such as variable renewable energy outputs, equipment malfunctions and real-time load variations. When moving from small-scale or pilot projects to full-scale implementations, numerous complexities are involved that are not completely captured in theoretical studies. The process of scaling-up has proven to frequently reveal practical issues that were not evident in smaller models (Maroufmashat et al., 2019).

Besides that, another factor impacting the development of energy hubs is technological readiness. Energy hubs require many technologies, such as highly efficient conversion systems and advanced storage solutions, that may still be in early adoption or even development stages. Theoretical models assume the reliability and availability of these technologies, which might not be completely realised in practice yet. The integration of multiple energy technologies and carriers within a cohesive and efficient system is a complex and technologically challenging task. Integration issues such as control system complexity, data management and interoperability can hinder practical implementation (Maroufmashat et al., 2019).

Furthermore, financial and economic factors can also hinder the development of energy hub initiatives. Theoretical models often use outdated or idealised cost assumptions for operation, installation and technology. In reality however, the costs might be higher and financial models may need to account for maintenance, market fluctuations and unforeseen expenses. Securing investment and funding for large-scale energy hub projects can be challenging, despite the newly installed funding program. Financial models in theoretical studies may not completely account for the uncertainties and risks perceived by stakeholders and investors. Besides that, the paper discusses the need for models that can economically justify the implementation of energy hubs while at the same time addressing environmental regulations. The complexity of balancing both economic and environmental considerations in real-world scenarios, slows down the adaptation of energy hubs (Maroufmashat et al., 2019).

Additionally, regulatory and policy barriers have been explained to further slowdown the process of developing energy hubs in practice. Theoretical models typically tend to operate under the assumption of a stable regulatory environment, which can be inconsistent. Navigating the complexities that come with it can alter or delay project implementation. The practical implementation of energy hubs requires strong policy support including subsidies and incentives. Theoretical models often do not account for the effort and time needed to secure this support (Maroufmashat et al., 2019).

Furthermore, operational realities tend to differ from what is portrayed in theory. Theoretical models may not adequately consider the reliability issues and maintenance needs of complex energy systems. Maintaining high levels of performance and reliability requires strong contingency plans and operational strategies. To effectively implement energy hubs, well-coordinated organisational structures and skilled personnel is needed. Such human and managerial aspects are often overlooked by the theoretical models, but are essential for practical success (Maroufmashat et al., 2019).

The last factor impacting the development of energy hubs deals with data and measurement. Research states that the accuracy of theoretical models depends on high-quality data, which might be unavailable in real-world scenarios. Inaccurate or incomplete data might lead to discrepancies between actual performance and model predictions. Implementing the advanced control and monitoring systems envisioned in theoretical models can be costly and technically challenging. Therefore, the assurance of real-time data processing and acquisition for optimal operation poses a big practical hurdle (Maroufmashat et al., 2019)

3.6 Conclusion to Sub-question 2 and 3:

Sub-question 2: In what way does cooperation take place within energy hubs as a solution for grid congestion?

Cooperation within energy hubs involves multiple stakeholders, including businesses, local authorities, energy providers, and regulatory bodies, working collaboratively to manage energy production, consumption, and storage. The development and operation of energy hubs require a high level of cooperation to balance local energy demand and supply, optimise energy use, and implement integrated energy management systems. These collaborative efforts are necessary for addressing grid congestion by ensuring that renewable energy is effectively integrated and managed locally, reducing the need for long-distance energy transport and alleviating pressure on the grid.

Sub-question 3: How has the concept of energy hubs developed over the past 10 years?

Over the past decade, the development of energy hubs has progressed, but at a slower pace than anticipated. This slow development is due to several factors:

The integration of various energy technologies and carriers within a cohesive and efficient system is complex and technologically challenging. High costs and financial uncertainties associated with the implementation and operation of energy hubs pose significant challenges. Navigating the complex regulatory environment and securing policy support are time-consuming and challenging processes. Real-world scenarios, such as equipment malfunctions and variable renewable energy outputs, complicate the practical implementation of theoretical models. Ensuring accurate and real-time data processing and acquisition for optimal operation is technically challenging and costly.

Despite these challenges, energy hubs are recognized as effective tools for quickly mitigating grid congestion. They enhance grid stability, integrate renewable energy sources more effectively, and provide local solutions to energy management issues. The insights gained from understanding these development barriers can inform future strategies to accelerate the implementation of energy hubs and improve cooperation among stakeholders.

Chapter 4: Case Studies

4.1 Introduction

4.1.1 Purpose of the Chapter

This chapter aims to answer sub-question 4: *What are the opportunities and challenges encountered in the development of the Smart Energy Hubs A and B, and how do these experiences contribute to understanding collaboration dynamics in energy collectives?* The rationale behind selecting the two energy hubs is to examine both the opportunities and challenges encountered during their development. This analysis aims to provide valuable insights for future energy hub projects and contribute to the broader understanding of the dynamics in collaboration in energy collectives. By applying middle-range theory to operationalize key constructs and expectations, the study aims to systematically analyse the interactions and outcomes within these hubs, thereby informing best practices and strategies for future sustainable energy initiatives.

4.1.2 Overview of Selected Energy Hubs

Energy Hub A

- **Location:** Smart Energy Hub 'Lorentz', in the municipality of Harderwijk.
- **Key Stakeholders:** Businesses, grid operators, the municipality, energy suppliers, platform providers, aggregators, and energy cooperatives.
- **Main objective:** Ensure continuity for businesses, manage and share energy resources efficiently, and support sustainable and scalable energy solutions. The main goal is to establish a smart energy hub that coordinates various energy flows to ensure continuity for businesses and reliable energy sources during concerns over grid congestion and energy costs.

Energy Hub B

- **Location:** Smart Energy Hubs 'Lage Weide', in the municipality of Utrecht.
- **Key Stakeholders:** Businesses within the cooperative, the network company, and supporting entities like EZK and the municipality
- **Main objective:** The objective is to establish a cooperative model energy hub where stakeholders, including businesses and network companies like Stedin, collaborate to manage and share contract capacity effectively, aiming for scalability and manageable operations from inception.

4.2 Identifying Key Constructs

In this section, relevant constructs will be identified from the theories used in chapter, which helps to bridge the gap between the broader theories and empirical data. These constructs serve as a basis for the creation of expectations, interview guides, and later the analysis of interview results. To enhance the clarity and validity of the empirical research, the constructs will be defined and operationalized. This will help to turn the abstract constructs into measurable observations. The constructs will guide the formulation of interview questions and the subsequent analysis of interview data.

Definition and Operationalization of the Theoretical Constructs

Trust is defined as the belief among stakeholders that others will act in the group's best interest. This construct is operationalized by asking stakeholders interview questions about their willingness to share detailed information, their confidence in others' reliability, and their commitment to long-term cooperation.

Reciprocity refers to the mutual exchange of benefits and support among stakeholders. To measure this, stakeholders are asked about their perceptions of mutual support and benefits, as well as their willingness to return favours or support received from others.

Incentives are rewards or benefits that motivate stakeholders to contribute to collective efforts. This construct is evaluated by asking stakeholders about the perceived benefits of participating in the energy hub, such as cost savings, improved energy reliability, and access to innovative energy solutions.

The Free-Rider Problem involves individuals benefiting from resources or efforts without contributing to them. It is investigated through questions about observed instances where stakeholders benefited from the hub's resources without making proportional contributions, as well as measures in place to prevent such behaviour.

Commitment denotes the degree to which stakeholders are dedicated to the collective goals. This is measured by assessing stakeholders' involvement in hub activities, their participation in meetings and decision-making processes, and their adherence to agreed-upon commitments.

Inclusiveness describes the extent to which all relevant stakeholders are involved in the decision-making process. It is measured by looking at stakeholders' participation in decision-making, the diversity of stakeholders involved, and how well different voices are heard and considered.

Transparency refers to openness in communication and information sharing among stakeholders. It is assessed through questions about the frequency and quality of information shared, the availability of documentation, and the perceived openness of communication channels.

Shared Decision-Making involves processes that allow for joint decision-making among stakeholders. This construct is evaluated by the extent to which stakeholders participate in decision-making meetings, the mechanisms for joint decision-making, and their perceptions of the fairness and effectiveness of these processes.

Accountability pertains to mechanisms that hold stakeholders responsible for their contributions and actions. It is investigated by asking about the systems in place to monitor and report on stakeholder contributions, the presence of accountability measures, and stakeholders' perceptions of their effectiveness.

Mutual Benefit is the degree to which collaborative efforts provide benefits to all participating stakeholders. This is measured by stakeholders' perceptions of the benefits they receive from collaboration, the balance of benefits among stakeholders, and the perceived fairness of benefit distribution.

Resource Dependency refers to the extent to which stakeholders depend on the common resource. It is assessed by evaluating the level of reliance on shared energy resources, the criticality of these resources to stakeholders' operations, and the perceived impact of resource availability on their activities.

Governance Structures involve the rules and regulations governing the use and management of the resource. These are evaluated by examining the presence and clarity of governance rules, stakeholders' understanding and adherence to these rules, and the perceived effectiveness of the governance structures.

Sustainability Practices are practices aimed at maintaining the resource over time. They are investigated by asking about sustainability measures in place, stakeholders' commitment to sustainable practices, and their perceptions of the long-term viability of resource use.

Conflict Resolution involves mechanisms to resolve disputes among stakeholders regarding resource use. It is measured by the presence of conflict resolution mechanisms, stakeholders' experiences with these mechanisms, and their perceptions of the effectiveness in resolving disputes.

Monitoring and Enforcement are systems in place to ensure compliance with agreed-upon rules and practices. This is assessed through questions about monitoring systems used, the frequency and accuracy of enforcement, and stakeholders' perceptions of compliance and enforcement effectiveness.

Coordination refers to the process of organising stakeholder activities and efforts. It is measured by the presence of coordination roles or bodies, the frequency and effectiveness of coordination meetings, and stakeholders' satisfaction with these efforts.

Information Sharing involves the exchange of information among stakeholders. It is evaluated by examining the channels and frequency of information exchange, the relevance and usefulness of shared information, and stakeholders' perceptions of information sharing practices.

Interdependency is the mutual reliance among stakeholders for resources and support. This construct is assessed by the extent of resource and support exchanges, the perceived criticality of these exchanges, and stakeholders' views on their interdependence.

Network Density refers to the number and strength of connections among stakeholders. It is measured by the number of stakeholder interactions, the strength and quality of these relationships, and stakeholders' perceptions of network connectivity.

Facilitative Leadership involves leadership that promotes cooperation and guides the network toward common goals. This is evaluated by stakeholders' views on the presence and effectiveness of leadership roles, the actions taken by leaders to promote cooperation, and the overall impact of leadership on network activities.

4.3 Generating Contextualised Expectations

In this section, the constructs are used to formulate expectations that can be explored using the qualitative data gathered from the interviews (Figure 5, Appendix A). While not all constructs are directly used in the formulation of the expectations, they do come back in the interview questions to properly bridge theory and empirical research.

Expectations based on collective action theory constructs

When considering the insights from collective action theory, several expectations can be formulated. The theory explains the idea that higher levels of trust among stakeholders will positively correlate with greater commitment to shared goals. Furthermore, greater reciprocity among stakeholders will reduce the free-rider problem. Lastly, the theory states that effective incentives will enhance stakeholders’ commitment to collective goals.

Expectation 1: Increased trust and the provision of incentives will lead to higher commitment of stakeholders to collective actions.

Expectation 2: Greater reciprocity among stakeholders will reduce free-riding.

Expectations based on collaborative governance theory constructs

When evaluating the constructs based on collaborative governance theory, other expectations can be formed. According to the theory, higher inclusiveness in the decision-making process will improve the quality and acceptance of shared decision-making. Moreover, greater transparency in communication and information sharing will lead to higher accountability among stakeholders. Lastly, collaborative efforts that provide mutual benefits will result in higher levels of inclusiveness.

Expectation 3: Mutual benefits from collaboration encourages greater inclusiveness among stakeholders, and higher inclusiveness in decision-making processes will improve quality and acceptance of the decisions.

Expectation 4: Greater transparency in communication and information sharing will lead to higher accountability.

Expectations based on common-pool resource management constructs

According to the theory on common-pool resource management, higher resource dependency among stakeholders will lead to the adoption of more 'rigorous' sustainability practices. Besides that, well-defined governance structures will improve conflict resolution mechanisms. Lastly, effective monitoring and enforcement mechanisms will positively correlate with the adoption of sustainability practices.

Expectation 5: Increased dependency on common-pool resources and strong monitoring and enforcement systems lead to better sustainability practices.

Expectation 6: Robust governance structures enhance the effectiveness of conflict resolution among stakeholders.

Expectations based on network governance theory constructs

When considering the insights derived from network governance theory, several statements can be made. Better coordination among stakeholders will increase network density. Moreover, increased information sharing will strengthen interdependency among stakeholders. Lastly, facilitative leadership will improve coordination of stakeholder efforts.

Expectation 7: Effective coordination, increased information sharing, and facilitative leadership have a positive effect on the network

These expectations are explored through empirical research to explore the interactions between these constructs and their impact on the effectiveness of collective actions, governance, and resource management strategies. The interview transcripts are analysed for themes that relate to the constructs from the middle-range theories. The themes found in the data can then be compared to the propositions created from the theories to understand the cooperation problems and successes in the energy hubs.

In Appendix B, a table is provided to summarise the above mentioned connection between these theoretical constructs and the expectations.

Table 2:

Theoretical Constructs and Connected Expectations

Main Theoretical Construct	Expectations
Trust (Collective Action Theory)	Expectation 1: Increased trust and the provision of incentives will lead to higher commitment of stakeholders to collective actions.
Reciprocity (Collective Action Theory)	Expectation 2: Greater reciprocity among stakeholders will reduce free-riding.
Mutual Benefit (Collaborative Governance Theory)	Expectation 3: Mutual benefits from collaboration encourage greater inclusiveness among stakeholders, and higher inclusiveness in decision-making processes will improve the quality and acceptance of decisions.
Transparency (Collaborative Governance Theory)	Expectation 4: Greater transparency in communication and information sharing will lead to higher accountability.
Resource Dependency (Common-Pool Resource Management)	Expectation 5: Increased dependency on common-pool resources and strong monitoring and enforcement systems lead to better sustainability practices.
Governance Structures (Common-Pool Resource Management)	Expectation 6: Robust governance structures enhance the effectiveness of conflict resolution among stakeholders.

Coordination, Information Sharing, and Facilitative Leadership (Network Governance Theory)	Expectation 7: Effective coordination, increased information sharing, and facilitative leadership have a positive effect on the network density.

4.4 Data Analysis

4.4.1 Opportunities and Challenges

Opportunities

This section serves to answer the first part of sub-question 4: *What are the opportunities and challenges encountered in the development of the Smart Energy Hubs A and B?* Several opportunities and challenges can be identified when analysing the results from the interviews. The opportunities of cooperating in an energy hub have proven to be mainly due to shared energy resources, cost efficiency, sustainability and innovation, scalability, regulatory support, network expansion, and strategic decision-making.

'The core objective of an energy hub should be to ensure continuity for companies within it'. One of the participants explains that the main goal of cooperating businesses is to continue their core business, which becomes increasingly difficult due to high energy prices and instability of electricity supply. Continuity is achieved by sharing energy resources among businesses within the hub, allowing for more reliable energy access and stability. The aim for continuity is believed to be the strongest reason for businesses to join the collective. 'Ideally, we want a system where you can establish a cooperative, secure energy connection, and know your energy costs and sources reliably'. Smart Energy Hubs are explained as a compelling alternative to relying exclusively on grid operators and energy suppliers, especially given the recent price volatility driven by geopolitical events. Cost efficiency thus serves as a significant opportunity for businesses to join an energy hub. Furthermore, Smart Energy Hubs are expected to drive innovation and sustainability, such as transitioning to more sustainable energy sources and implementing advanced energy management systems (EMS). Also, scalability is an important benefit for stakeholders to join the collective, as it is explained that well-coordinated hubs can grow and adapt to increasing demands. Besides that, when cooperating with entities like the municipality and the Ministry of Economic Affairs and Climate in an energy hub, stakeholders are more likely to gain the benefit of (financial) support and facilitation from regulatory bodies. Besides these regulatory entities, the participants emphasised the importance and subsequent benefit of fostering close relationships and maintaining communication with key figures from entities like TenneT and Stedin. Furthermore, the participants explain that the cooperative model facilitates strategic decision-making processes, allowing businesses and other stakeholders to collectively handle costs, hire managing entities, conduct studies and design systems, which benefit all parties involved.

Challenges

Several challenges of cooperating in an energy hub have been identified through the analysis of the interview results. These challenges can be categorised under trust and relationships, power imbalances, regulatory and compliance issues, coordination and communication, manageability, and technical and operational challenges. 'The biggest challenge is getting entrepreneurs to know and trust each other'. The participants explain that building trust among stakeholders is as important as it is challenging. The need for long-term cooperation and trust among companies is highlighted and is explained to be difficult to establish. When it comes to power imbalances, the results show that larger entities like TenneT can significantly impact decisions, potentially derailing local plans immediately. Such power imbalances need to be balanced by creating strong agreements and contracts to foster equal partnerships. Furthermore, the results highlight that accountability is a significant issue in such stakeholder collaboration. The collective is provided with a limit for their energy consumption and supply, and if this is exceeded this can result in financial punishment by the energy provider. The EMS is installed to monitor and analyse real-time data from the various energy sources in the energy hubs. The EMS provides insights into energy use and can point out where too much energy is used or supplied. While this is explained to be an essential tool to reduce human involvement and provide better management, this also makes accountability more complex. 'Is the creator of the EMS to blame if too much solar energy is supplied by a particular business, as the EMS should have switched the panels off on time, or did the company hinder the EMS to properly switch off when the supply limit was reached'. Monitoring compliance with energy usage agreements can be complex, requiring robust systems and strong enforcement mechanisms. Additionally, the interview results show that effective coordination among diverse stakeholders with different priorities and objectives is challenging. Participants explain that decision-making processes can be complicated by the need to involve various stakeholders who each have their own goals and requirements. To effectively manage this, 'clear and continuous communication is essential' to manage this. Another concern is maintaining effective management when scaling the energy hub. As the hub grows, managing the increased complexity becomes more difficult. Furthermore, the results show that initial phases of energy hub development are generally underfunded. Obtaining sufficient funding for research, development, and initial operations is a significant hurdle. Lastly, the participants explain that managing and implementing the advanced energy management systems and ensuring technical reliability can be difficult. It is essential to ensure that the technical infrastructure is capable of handling shared energy resources to maintain continuity of the businesses.

4.4.2 Exploring the Expectations

To explore the contextualised expectations based on the interviews provided, we can analyse the responses and insights gathered from the interviewees regarding their experiences with energy hubs. Here's how each expectation might be evaluated based on the interview content:

Expectation 1: Increased trust and the provision of incentives will lead to higher commitment of stakeholders to collective actions.

- Support from Interviews: Interviewees emphasised the importance of trust among stakeholders, highlighting that trust facilitates information sharing, cooperation, and long-term commitments. For example, it is mentioned that trust is very important for companies to share detailed information and commit to long-term cooperation within the hub.
- Result: The interviews generally support this expectation, suggesting that higher levels of trust indeed correlate with greater stakeholder commitment to shared goals and collaborative actions within energy hubs. However, as stated by one of the participants 'trust is highly important; but you always need to be able to fall back on strong agreements and contracts.'

Expectation 2: Greater reciprocity among stakeholders will reduce free-riding.

- Support from Interviews: One of the participants touches upon the concept of free-riding, mentioning that businesses that initially refuse to join later want to participate once they see the benefits growing, which could be partly mitigated by strong agreements.
- Result: The interviews provide limited support for this expectation, indicating that free-riding will most likely be mitigated by having clear agreements on joining the collective at a later stage, rather than greater reciprocity. However, it is explained that it is difficult to predict whether free-riding can be prevented at all.

Expectation 3: Mutual benefits from collaboration encourage greater inclusiveness among stakeholders.

- Support from Interviews: The interview results show the importance of involving a small group of core stakeholders initially and gradually expanding, emphasising mutual benefits as a driving force for inclusiveness in decision-making.
- Result: The interviews generally support this expectation, indicating that mutual benefits from collaboration indeed encourage inclusiveness in decision-making, leading to better-quality decisions and greater acceptance among stakeholders.

Expectation 4: Greater transparency in communication and information sharing will lead to higher accountability.

- Support from Interviews: Several parts of the interview results highlight the role of transparent communication and information sharing in building trust and ensuring accountability. One part mentions structured monitoring during operational stages, and another discusses collaborative contract development involving feedback from all stakeholders.
- Result: The interviews strongly support this expectation, suggesting that transparent communication and information sharing contribute significantly to higher levels of accountability among stakeholders within energy hubs.

Expectation 5: Increased dependency on common-pool resources as well as strong monitoring and enforcement systems lead to better sustainability practices.

- Support from Interviews: In the interviews, the role of governance structures and monitoring mechanisms in managing conflicts and ensuring compliance with sustainability practices is discussed.
- Result: The interviews provide moderate support for this expectation, indicating that while dependency on shared resources and effective monitoring are important, sustainability practices are also (if not mainly) influenced by broader regulatory and operational factors.

Expectation 6: Robust governance structures enhance the effectiveness of conflict resolution among stakeholders.

- Support from Interviews: Various parts of the interview results mention the importance of clear governance structures and resolution mechanisms in managing conflicts effectively. For example, one of the participants discusses conflicts anticipated in contracts with clear strategies for resolution.
- Result: The interviews strongly support this expectation, suggesting that robust governance structures indeed enhance the effectiveness of conflict resolution among stakeholders within energy hubs.

Expectation 7: Effective coordination, increased information sharing, and facilitative leadership have a positive effect on the network density.

- Support from Interviews: The interview results describe the role of the Director or Manager in facilitating collaboration and coordination among stakeholders, indicating the importance of effective leadership and coordination.

- Result: The interviews provide general support for this expectation, suggesting that effective coordination, information sharing, and facilitative leadership positively influence the density and effectiveness of the network within energy hubs.

In Appendix B, a table is provided to visualise the above mentioned connection between these theoretical constructs, expectation, and empirical findings from the interviews.

By comparing the themes found in the interview data to the propositions created from the theories, we can better understand the cooperation problems and successes in the energy hubs.

4.5 Conclusion to Sub-question 4

What are the opportunities and challenges encountered in the development of the Smart Energy Hubs A and B, and how do these experiences contribute to understanding collaboration dynamics in energy collectives?

The interviews revealed several opportunities associated with participating in Smart Energy Hubs. Firstly, the hubs offer businesses the chance to share energy resources, enhancing reliability and stability amidst fluctuating energy prices and supply uncertainties. This shared infrastructure facilitates cost efficiency and predictability, needed to maintain operational continuity. Moreover, smart energy hubs promote innovation and sustainability by transitioning towards renewable energy sources and implementing advanced Energy Management Systems. Scalability is another advantage, enabling hubs to expand and adapt to increasing demands effectively. Collaborating with regulatory bodies such as municipalities and the Ministry of Economic Affairs and Climate also provides access to financial support and regulatory facilitation, enhancing operational feasibility. Additionally, the hubs foster strategic decision-making among stakeholders, allowing collective management of costs, hiring practices, feasibility studies, and system design.

Conversely, the interviews highlighted several challenges inherent to collaboration in energy hubs. Establishing trust among stakeholders was identified as a significant hurdle, essential for protecting long-term cooperation and overcoming differences in interests. Power imbalances, particularly the influence of larger entities like TenneT, can hinder decision-making processes, necessitating strong agreements to ensure equitable partnerships. The challenge of accountability in collaboration arises from the complexities of attributing responsibility when technical systems fail. Coordination among diverse stakeholders with varying priorities poses another challenge, requiring clear and continuous communication to align objectives effectively. Managing scalability presents operational complexities, exacerbated by initial underfunding during hub development phases. Finally, ensuring technical reliability and implementing advanced EMS functionality remain critical to maintaining seamless energy operations across the hub.

The experiences from Smart Energy Hubs A and B provide insights into collaboration dynamics within energy collectives. They illustrate the complexities of stakeholder coordination, the critical role of governance structures in managing shared resources, and the importance of transparent communication and conflict resolution mechanisms. These experiences highlight how effective collaboration relies on inclusiveness, mutual benefit, effective governance structures, transparent communication and strong conflict resolution mechanisms. By examining these dynamics, the study contributes to refining strategies for promoting successful partnerships and sustainable energy initiatives in collective settings.

Chapter 5: Discussion and Conclusion

5.1 Interpreting the Results

This study focuses on the development and management of Smart Energy Hubs, exploring how companies, local governments and other stakeholders address cooperation problems to enhance sustainable energy management and mitigate grid congestion. The main research question revolves around understanding the success of Smart Energy Hubs based on how cooperation problems among key stakeholders are addressed. The study employs a theoretical framework, integrating theories on collective action, common-pool resource management, collaborative governance and network governance to examine the dynamics of cooperation within energy hubs. By encompassing these theoretical perspectives, the research aims to gain meaningful insights into sustainable energy management and collaboration through energy hubs.

Through case studies of two selected energy hubs, the study delves into the cooperation dynamics of stakeholders, applied governance structures and challenges faced in managing shared resources within the context of Smart Energy Hubs. The case studies reveal that while Smart Energy Hubs offer opportunities for sustainable energy practices and stakeholder cooperation, they also present challenges such as establishing trust among stakeholders, addressing power imbalances, ensuring accountability, coordinating diverse priorities, managing scalability and maintaining technical reliability. These challenges highlight the complexities involved in fostering effective collaboration in energy hubs. Furthermore, the analysis of case studies in this thesis illuminates several critical aspects of managing energy hubs. They validate the relevance of Collective Action Theory and CPR Management by demonstrating how these frameworks address the challenges of shared resource management in real-world settings. For instance, the case studies show how effective governance structures and collaborative processes can mitigate the risks associated with common-pool resource management, such as overuse and conflict among stakeholders. Additionally, the case studies reveal the importance of adaptive governance and flexible policy frameworks that can accommodate the unique dynamics of each energy hub.

The study puts emphasis on the importance of inclusive collaboration, effective governance structures, transparent communication, mutual benefit and strong conflict resolution mechanisms in promoting successful collaboration within collective energy action initiatives such as Smart Energy Hubs. By examining these dynamics, the research contributes to refining strategies for enhancing collaboration and sustainability in collective settings.

5.2 Discrepancies between Theory and Empirical Reality

Synthesising the insights from the theoretical framework with the empirical research results reveals disparities between theoretical expectations and practical outcomes. While the theoretical part of this study emphasises the significance of factors like trust, reciprocity, mutual benefit, transparency, and governance structures in fostering effective collaboration within energy hubs, the case study results challenge some of these theoretical notions.

One notable observation focuses on trust as an essential element for effective collaboration. Theory portrays trust to play a pivotal role in building strong relationships among stakeholders and facilitating cooperation. While trust is essential to start up collective action, results from the case studies suggest that it might not be mainly trust but rather the presence of solid contractual agreements that underpin and sustain effective collaboration within energy hubs. Therefore, this critique challenges the assumption that trust is the primary driver of successful partnerships and raises questions about the role of formalised agreements in ensuring reliable cooperation. Similar notions can be made about the concept of reciprocity, which suggests that mutual exchanges of benefits lead to reduced free-riding behaviour. While reciprocity is believed to be a mechanism to incentivize cooperation and discourage opportunistic behaviour, the practical outcomes show that formalised contracts or clear incentive structures play a more significant role in shaping collaborative behaviour and managing the issue of free-riding. This critique prompts a reevaluation of the relative importance of reciprocity versus contractual obligations in driving effective collaboration within energy hubs. Lastly, another notable observation centres on the role of monitoring mechanisms and governance structures in promoting sustainability practices within energy hubs. Theory suggests that increased dependency on common-pool resources, along with strong monitoring and enforcement leads to better sustainability practices. However, practical results from the interviews indicate that this is only partially true and that broader regulatory and operational factors might play significant roles in shaping sustainability outcomes such as smart energy hubs. This critique thus challenges the assumption that internal governance and monitoring are the primary drivers of sustainable practices. Questions can be raised about the influence of external regulatory frameworks and operational capabilities, suggesting that these external factors may be more important in ensuring successful collaboration within energy hubs.

However, considering the critiques, it is important to note that the theories used in this thesis are well-established and widely respected in the academic community. This research was limited to a small number of case studies, which may not fully capture the diversity of experiences and practices in different contexts. The theories are broad and might be fully applicable to other collective initiatives, rather than energy hubs. Consequently, the findings of this study should be interpreted thoughtfully, and further research is needed to explore these dynamics in a broader range of settings.

5.3 Limitations of the Study

Several limitations should be considered when interpreting the conclusions of this research. A notable limitation is the limited scope of insights gained from interviews. The study involved only a small number of high-level executives from the organisations, which may offer a more focused but potentially incomplete view of the issues. The perspectives of these top executives might not fully represent the experiences and viewpoints of other key stakeholders, such as mid-level managers or operational staff. Consequently, the findings might differ if interviews were conducted with a broader range of individuals within the organisations.

Additionally, the study's reliance on theoretical frameworks to interpret empirical findings could introduce biases or assumptions that may affect the results. Discrepancies between theoretical models and practical realities, as previously noted, highlight potential limitations in the applicability of these frameworks to real-world scenarios. The data collection, primarily based on literature research and case studies, might also overlook important perspectives or introduce biases, particularly given the rapidly evolving nature of the energy hub field.

The study’s focus on only two selected energy hubs further restricts the scope of the findings. The specific characteristics and contexts of these cases might not fully capture the broader range of challenges and dynamics present in energy hub collaborations. This limitation is compounded by the more specialised view provided by the high-level interviewees, which may not reflect the full spectrum of issues faced in these real-life cases.

Moreover, the study's timeframe and scope may limit the ability to capture long-term trends or changes in the development of energy hubs. While the research offers valuable insights into cooperation dynamics, further exploration is needed to understand the impact of policy changes and the scalability of energy hub models across different contexts. Expanding the research to include a wider range of interviewees and additional factors would enhance the understanding of the complexities and opportunities in advancing sustainable energy practices through Smart Energy Hubs.

5.5 Recommendations for Future Research

Building on the discrepancies between theoretical assumptions and practical outcomes, various recommendations for future research emerge. One area of exploration is the comparative analysis of trust-based versus contract-based collaboration models within energy hubs. Investigating the impact of different governance mechanisms on partnership outcomes can provide valuable insights into the optimal combination of trust, reciprocity and formal agreements in driving effective cooperation. Future research could delve into the role of formalised agreements within collective energy action initiatives, aiming to uncover their impact on cooperation and success. Research could focus on understanding how these agreements can be effectively developed and implemented to ensure reliable and sustained collaboration among stakeholders. By exploring the complexities of agreement creation and enforcement, the research would contribute to the optimization of governance structures in energy hubs, ultimately enhancing their efficiency and efficacy. Examining how contractual agreements adapt to changing circumstances, mitigate risks, and foster innovation, research can identify lessons learned and best practices for enhancing the collaboration dynamics in energy hubs management. Future research could further delve into the role of incentive structures and performance-based contracts in shaping collaborative behaviours within energy hubs. Understanding how penalties, rewards and financial incentives influence stakeholder engagement and decision-making processes can inform the design of more effective collaboration frameworks and governance mechanisms.

5.6 Personal Reflections

In reviewing the theoretical frameworks used in this thesis, it becomes clear that while collective action theory, common-pool resource management, and network governance offer useful insights into the dynamics of Smart Energy Hubs, there are notable limitations that need to be addressed.

Firstly, collective action theory highlights the significance of trust and reciprocity among stakeholders for successful collaboration. However, my observations indicate that applying these concepts in practice can be more challenging than the theory suggests. Building trust in real-world scenarios often takes time and requires ongoing positive interactions, which may not always be achievable in the rapidly changing field of energy management. Moreover, relying on informal relationships can create vulnerabilities, especially when stakeholders have conflicting interests or face power imbalances.

Additionally, while common-pool resource management theory provides a framework for governing shared resources, it may not fully account for the complexities of stakeholder interactions within Smart Energy Hubs. This theory focuses primarily on resource sustainability, but it could benefit from a deeper exploration of the socio-political factors influencing stakeholder behaviour and decision-making. For example, external regulations and market conditions can significantly affect how stakeholders perceive and manage common resources.

Lastly, network governance theory underscores the role of collaborative networks in managing complex systems. However, this theory might be enhanced by a more critical examination of the challenges related to coordination and accountability within these networks. The assumption that all stakeholders will act in the collective interest may overlook the reality of competing agendas and potential conflicts, which can impede effective collaboration.

In summary, while the theoretical frameworks employed in this thesis offer a valuable foundation for understanding Smart Energy Hubs, it is crucial to acknowledge their limitations. An approach that integrates considerations of trust, socio-political contexts, and the complexities of stakeholder relationships could deepen our understanding of collective action in energy management. Future research should aim to address these gaps, contributing to a more comprehensive theoretical perspective on the challenges and opportunities within Smart Energy Hubs.

5.7 Conclusion

In conclusion, this study has highlighted the complexities and challenges inherent in cooperation dynamics within energy hubs, aiming to strengthen their effectiveness in sustainable energy management and grid congestion mitigation. Through an investigation into the success of energy hubs driven by the collaborative efforts of stakeholders such as companies and municipalities, this study has uncovered insights into the factors that shape variations in collaboration and the central role that cooperation plays in addressing challenges related to grid congestion. Through the integration of theoretical frameworks such as collaborative governance, network governance, collective action, and common-pool resources, alongside empirical case studies of selected energy hubs, this research has provided a nuanced understanding of the complex dynamics driving energy hub initiatives. The study's recognition of differences between theoretical assumptions and real-world outcomes emphasises the need for a customised and context-specific approach to overcoming collaboration challenges within energy hubs. While this research enriches the discourse on sustainable energy management through energy hubs, it acknowledges its limitations, including the scope of case studies, methodological constraints in data collection, and the need for further exploration of additional factors influencing energy hub collaborations. Future research should broaden their scope to encompass a wider array of stakeholders, technologies, and market dynamics to get a more comprehensive grasp of the opportunities and challenges in advancing sustainable energy practices via smart energy hubs.

Essentially, the insights from this study can guide policymakers, practitioners, and researchers engaged in energy hub development and management, offering insights to develop successful partnerships and sustainable energy initiatives in collective settings. By addressing identified limitations and building upon the acquired insights, future research can refine strategies for enhancing cooperation dynamics within energy hubs, contributing to the global shift towards more sustainable energy systems.

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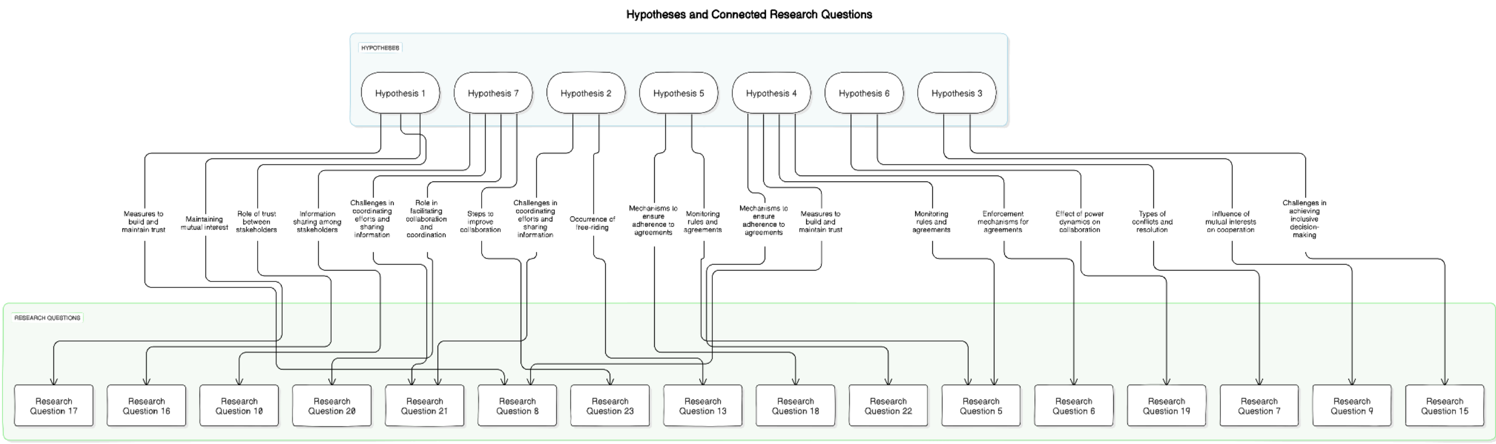
Appendix A

Figure 5

Expectations and Connected Research Questions Mapping



**Note: use zoom-in function to properly display the figure.*

***Note: In the first draft of this thesis, the Expectations were called Hypotheses. Due to technological constraints, it was not possible to change the wording in this figure. Read 'hypothesis' as 'expectation'.*

Interview Questions

- How do you envision an energy hub?
- What do you think are the objectives of an energy hub? When do you consider it successful?
- Who are the stakeholders in a smart energy hub, and what are their responsibilities?
- How are decisions typically made within the hub?
- How are rules and agreements monitored within the hub?
- Are there enforcement mechanisms to ensure stakeholders adhere to agreements?
- What types of conflicts arise among stakeholders, and how are they resolved?
- What measures are taken to build and maintain trust?
- How do mutual interests influence cooperation within the hub?
- How is information shared among stakeholders?
- What are the main areas for improvement to enhance collaboration in the hub?
- What are the long-term goals for the hubs?

- How does free-riding occur within the collaboration?
- How involved are stakeholders in the decision-making process?
- What are the main challenges in achieving inclusive decision-making among stakeholders?
- How does trust play a role between stakeholders, and how is it built?
- How is mutual interest maintained within the hub?
- What mechanisms are in place to ensure stakeholders adhere to agreements, and how is this monitored?
- How do power dynamics affect the collaboration within the hub?
- What role do you play in facilitating collaboration and coordination among stakeholders?
- What challenges do you face in coordinating efforts and sharing information among stakeholders?
- How do you see the collaboration evolving in the future?
- What steps are necessary to improve collaboration within the hub?
- How do you handle contract development and stakeholder involvement in this process?

Interview Questions Based on expectation

Expectation 1: Increased trust and the provision of incentives will lead to higher commitment of stakeholders to collective actions.

- Interview Question: What measures are taken to build and maintain trust?
- Interview Question: How does trust play a role between stakeholders, and how is it built?
- Interview Question: How is mutual interest maintained within the hub?

Expectation 2: Greater reciprocity among stakeholders will reduce free-riding.

- Interview Question: How does free-riding occur within the collaboration?
- Interview Question: What challenges do you face in coordinating efforts and sharing information among stakeholders?

Expectation 3: Mutual benefits from collaboration encourage greater inclusiveness among stakeholders, and higher inclusiveness in decision-making processes will improve quality and acceptance of the decisions.

- Interview Question: How do mutual interests influence cooperation within the hub?
- Interview Question: What are the main challenges in achieving inclusive decision-making among stakeholders?

Expectation 4: Greater transparency in communication and information sharing will lead to higher accountability.

- Interview Question: How are rules and agreements monitored within the hub?
- Interview Question: Are there enforcement mechanisms to ensure stakeholders adhere to agreements?
- Interview Question: What measures are taken to build and maintain trust?
- Interview Question: What mechanisms are in place to ensure stakeholders adhere to agreements, and how is this monitored?

Expectation 5: Increased dependency on common-pool resources and strong monitoring and enforcement systems lead to better sustainability practices.

- Interview Question: How are rules and agreements monitored within the hub?
- Interview Question: What mechanisms are in place to ensure stakeholders adhere to agreements, and how is this monitored?

Expectation 6: Robust governance structures enhance the effectiveness of conflict resolution among stakeholders.

- Interview Question: What types of conflicts arise among stakeholders, and how are they resolved?
- Interview Question: How do power dynamics affect the collaboration within the hub?

Expectation 7: Effective coordination, increased information sharing, and facilitative leadership have a positive effect on the network.

- Interview Question: How is information shared among stakeholders?
- Interview Question: What role do you play in facilitating collaboration and coordination among stakeholders?
- Interview Question: What challenges do you face in coordinating efforts and sharing information among stakeholders?
- Interview Question: What steps are necessary to improve collaboration within the hub?

These interview questions are aligned with the expectation to explore and gather insights from stakeholders involved in Smart Energy Hubs

Interview Transcript Summaries

Summary Interview: 1

Question 1: How do you envision an energy hub?

Answer 1:
I see an energy hub as a system tied to a geographical area where different energy flows are well-coordinated, benefiting the parties in that area. That's the broad outline of how I see a Smart Energy Hub.

Question 2: What do you think are the objectives of an energy hub? When do you consider it successful?

Answer 2:
I think the core objective of an energy hub should be to ensure continuity for the companies within it. Let's assume the parties in the energy hub are businesses. For example, if a company produces chairs or machines, a smart energy hub should enable them to continue their core business. It's not an end in itself, although some parties might treat it as such. Ideally, we want a system where you can establish a business, secure an energy connection, and know your energy costs and sources reliably.

Question 3: When you talk about guaranteeing continuity, do you mean dealing with grid congestion?

Answer 3:
Yes, among other things. Companies are considering Smart Energy Hubs because they're concerned about securing the energy they need to operate. This concern has grown, especially after the war in Ukraine and its impact on prices. It makes Smart Energy Hubs an attractive alternative to dealing solely with grid operators and energy suppliers.

Question 4: Who are the stakeholders in a smart energy hub, and what are their responsibilities?

Answer 4:
Stakeholders include businesses, grid operators, the municipality, energy suppliers, platform providers, aggregators, and energy cooperatives. My role, which you could call a hub director or regisseur, involves coordinating these stakeholders and ensuring the hub operates smoothly, particularly through data-driven management.

Question 5: How are decisions typically made within the hub?

Answer 5:
Decision-making depends on the hub's structure. Often, a cooperative model is used to manage the process, especially during the hub's development phase. Companies organize themselves to handle costs, hire a regisseur, conduct studies, and design the system. Decisions are usually made by the cooperative's board.

Question 6: Do you notice power imbalances among stakeholders, such as larger entities like TenneT?

Answer 6:
Yes, there are power dynamics. For instance, in Harderwijk, I've seen how regional and national grid operators can impact decisions significantly. When TenneT puts a stop to all smart energy hubs, local plans get derailed despite prior agreements.

Question 7: How are rules and agreements monitored within the hub?

Answer 7:
Monitoring differs between the development and operational stages. During development, regisseurs oversee progress through structured meetings. Once operational, data-driven systems handle monitoring, ensuring compliance with agreed energy usage limits.

Question 8: Are there enforcement mechanisms to ensure stakeholders adhere to agreements?

Answer 8:
Yes, enforcement is primarily managed through the energy management system (EMS). The EMS adjusts energy flows to prevent overloading the grid. Non-compliance can lead to penalties, enforced by the grid operator and internally within the collective.

Question 9: How is accountability determined in case of conflicts?

Answer 9:
Accountability relies on data. The EMS logs actions, helping identify where failures occurred—whether with the EMS provider or an individual company's systems.

Question 10: What types of conflicts arise among stakeholders, and how are they resolved?

Answer 10:
Conflicts can be technical, like data issues, or organisational, like changes in company plans affecting the collective. Resolution often involves referring back to contractual agreements and ensuring clear communication.

Question 11: How does free-riding occur within the collaboration?

Answer 11: Businesses that refuse to join change their minds once they see the potential growing and want to get into the collective. When this happens in a later stage of development, the existing collective has spent much effort and resources into it already.

Question 11: How does free-riding occur within the collaboration?

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Question 12: How important is trust among stakeholders?

Answer 12: Trust is crucial. Companies must share detailed information and commit to long-term cooperation. This trust underpins successful collaboration and the overall success of the hub.

Question 13: What measures are taken to build and maintain trust?

Answer 13: Contracts and monitoring are key. Transparent data sharing and consistent performance build confidence among stakeholders.

Question 14: How do mutual interests influence cooperation within the hub?

Answer 14: Strong mutual interests drive collaboration. For example, companies needing reliable energy or wanting to reduce costs have clear incentives to participate actively in the hub.

Question 15: How is information shared among stakeholders?

Answer 15: Information sharing depends on the type of hub. Energy data flows through the EMS, while investment and organisational decisions are handled through structured meetings and cooperative frameworks.

Question 16: How do you facilitate collaboration and coordination as a Director/Manager?

Answer 16: My role involves managing the process, ensuring the right stakeholders are involved at each step, and translating technical and procedural requirements across different parties. It’s about maintaining a clear, coordinated approach.

Question 17: What are the main areas for improvement to enhance collaboration in the hub?

Answer 17: Improving contract clarity and EMS reliability are critical. Clear contracts provide security, while robust EMS ensures smooth operation and trust.

Question 18: What are the long-term goals for the hubs?

Answer 18: The primary goals are sustainable and affordable energy security. Ensuring these will underpin the hubs' success.

Summary Interview: 2

Question 1: What kind of energy are we discussing today, and how does it look?

Answer 1:
We are talking about the energy at Lage Weide and how the contract capacity is shared within the cooperatives.

Question 2: When is an energy hub successful in your view? What are the components and objectives of the hub?

Answer 2:
For me, success is marked by the opening on July 11th, when the contracts are ready, the cooperative and Stedin have individual agreements with the participating parties, and the technical management is in place. The challenge then is to keep it manageable and scalable, which is my biggest concern.

Question 3: Who are the stakeholders, and what are their responsibilities?

Answer 3:
Key stakeholders include businesses within the cooperative, the network company, and support from entities like EZK and the municipality. Initially, it was important to involve a small group of core stakeholders: the cooperative, five businesses, and Stedin.

Question 4: How would you describe your role within the hub?

Answer 4:
I consider myself an initiator and perhaps an environmental manager for the hub. I oversee the project and ensure connections and communication between parties.

Question 5: How involved are stakeholders in the decision-making process?

Answer 5:
The primary stakeholders, such as the network company and the businesses in the cooperative, are heavily involved in decision-making, with input from the province and occasionally the municipality.

Question 6: What are the main challenges in achieving inclusive decision-making among stakeholders?

Answer 6:
The biggest challenge is getting entrepreneurs to know and trust each other, and to understand their energy capacities and how they can be shared effectively.

Question 7: How does trust play a role between stakeholders, and how is it built?

Answer 7:
Trust is built through short communication lines and regular interaction with key figures from Stedin, Tennet, and within the cooperative. It's about maintaining close relationships and ensuring everyone understands and supports the shared goals.

Question 8: How is mutual interest maintained within the hub?

Answer 8:
Mutual interest is maintained by ensuring that all parties have something to gain, even if some benefit more than others. We start by sharing and learning together, adjusting as we go to ensure fairness.

Question 9: What mechanisms are in place to ensure stakeholders adhere to agreements, and how is this monitored?

Answer 9:
Technical parties monitor usage and compliance, and contracts outline responsibilities and consequences for non-compliance. Liability is a significant issue, currently being addressed with new regulations.

Question 10: What conflicts arise between stakeholders, and how are they resolved?

Answer 10:
Conflicts are anticipated in contracts, with clear exit strategies and terms for rejoining the grid if needed. We've also discussed how to handle liability and ensure fair compensation.

Question 11: How do power dynamics affect the collaboration within the hub?

Answer 11:
We strive for equal partnership, though larger entities like Stedin have significant influence. The goal is to balance power by fostering cooperation and mutual dependence.

Question 12: What role do you play in facilitating collaboration and coordination among stakeholders?

Answer 12:
My role involves bringing stakeholders together, informing them, and stimulating cooperation. It’s about turning ideas into actionable projects and ensuring everyone stays aligned and motivated.

Question 13: What challenges do you face in coordinating efforts and sharing information among stakeholders?

Answer 13:
Funding is a major challenge, as initial phases are often underfunded. We rely on subsidies and support from entities like the Rabobank and the province to keep projects moving forward.

Question 14: How do you see the collaboration evolving in the future?

Answer 14:
The hub is expected to become a significant entity, requiring professional management and strategic decisions to involve the right stakeholders and expand effectively.

Question 15: What steps are necessary to improve collaboration within the hub?

Answer 15:
Improving collaboration involves more sharing of information and experiences, both at the initiative level and within the cooperative. Enhanced communication and support from entities like EZK are also essential.

Question 16: How do you handle contract development and stakeholder involvement in this process?

Answer 16:
Contract development is a collaborative effort, involving feedback from all stakeholders and ensuring that everyone’s concerns are addressed. It’s a continuous process of negotiation and adjustment.

Appendix B

Table 3

Definition and Operationalization of the Theoretical Constructs

Theoretical Construct	Definition	Operationalization
Trust	The belief among stakeholders that others will act in the group's best interest.	Measured by interview questions about stakeholders' willingness to share detailed information, confidence in other stakeholders' reliability, and commitment to long-term cooperation.
Reciprocity	Mutual exchange of benefits and support among stakeholders.	Assessed through questions about the extent stakeholders perceive mutual support and benefits, and their willingness to return favours or support received from other stakeholders.
Incentives	Rewards or benefits that motivate stakeholders to contribute to collective efforts.	Evaluated by asking stakeholders about perceived benefits of participating in the energy hub, such as cost savings, improved energy reliability, and access to innovative energy solutions.
Free-Rider Problem	The challenge of individuals benefiting from resources or efforts without contributing to them.	Investigated through questions about observed instances of stakeholders benefiting from the hub's resources without making proportional

		contributions, and measures in place to prevent such behaviour.
Commitment	The degree to which stakeholders are dedicated to the collective goals.	Measured by stakeholders' involvement in hub activities, participation in meetings and decision-making processes, and adherence to agreed-upon commitments.
Inclusiveness	The extent to which all relevant stakeholders are involved in the decision-making process.	Measured by stakeholders' participation in decision-making processes, diversity of stakeholders involved, and the degree to which different voices are heard and considered.
Transparency	Openness in communication and information sharing among stakeholders.	Assessed through questions about frequency and quality of information shared among stakeholders, availability of documentation, and perceived openness of communication channels.
Shared Decision-Making	Processes that allow for joint decision-making among stakeholders.	Evaluated by the extent stakeholders participate in decision-making meetings, mechanisms for joint decision-making, and perceived fairness and effectiveness of these processes.
Accountability	Mechanisms to hold stakeholders responsible for their contributions and actions.	Investigated by asking about systems in place to monitor and report on stakeholder contributions, presence of accountability measures, and stakeholders' perceptions of effectiveness of these measures.

Mutual Benefit	The degree to which collaborative efforts provide benefits to all participating stakeholders.	Measured by stakeholders' perceptions of benefits they receive from collaboration, balance of benefits among stakeholders, and perceived fairness of benefit distribution.
Resource Dependency	The extent to which stakeholders depend on the common resource.	Assessed by level of reliance on shared energy resources, criticality of these resources to stakeholders' operations, and perceived impact of resource availability on their activities.
Governance Structures	The rules and regulations governing the use and management of the resource.	Evaluated by presence and clarity of governance rules, stakeholders' understanding and adherence to these rules, and perceived effectiveness of governance structures.
Sustainability Practices	Practices aimed at maintaining the resource over time.	Investigated through questions about sustainability measures in place, stakeholders' commitment to sustainable practices, and perceived long-term viability of resource use.
Conflict Resolution	Mechanisms to resolve disputes among stakeholders regarding resource use.	Measured by presence of conflict resolution mechanisms, stakeholders' experiences with these mechanisms, and perceived effectiveness in resolving disputes.
Monitoring and Enforcement	Systems in place to ensure compliance with agreed-upon rules and practices.	Assessed through questions about monitoring systems used, frequency and accuracy of enforcement, and stakeholders' perceptions of compliance and enforcement effectiveness.

Coordination	The process of organising stakeholder activities and efforts.	Measured by presence of coordination roles or bodies, frequency and effectiveness of coordination meetings, and stakeholders' satisfaction with coordination efforts.
Information Sharing	The exchange of information among stakeholders.	Evaluated by channels and frequency of information exchange, relevance and usefulness of shared information, and stakeholders' perceptions of information sharing practices.
Interdependency	The mutual reliance among stakeholders for resources and support.	Assessed by extent of resource and support exchanges, perceived criticality of these exchanges, and stakeholders' views on their interdependence.
Network Density	The number and strength of connections among stakeholders.	Measured by number of stakeholder interactions, strength and quality of these relationships, and stakeholders' perceptions of network connectivity.
Facilitative Leadership	Leadership that promotes cooperation and guides the network toward common goals.	Evaluated by stakeholders' views on presence and effectiveness of leadership roles, actions taken by leaders to promote cooperation, and overall impact of leadership on network activities.

Table 4

Empirical Support for the Expectation

Expectations	Empirical Support from Interviews
Expectation 1: Increased trust and the provision of incentives will lead to higher commitment of stakeholders to collective actions.	Interviewees emphasised the importance of trust among stakeholders, highlighting that trust facilitates information sharing, cooperation, and long-term commitments. For example, trust is deemed essential for companies to share detailed information and commit to long-term cooperation.
Expectation 2: Greater reciprocity among stakeholders will reduce free-riding.	One participant mentioned that businesses that initially refuse to join often want to participate later, indicating the challenge of free-riding. Strong agreements were suggested as a partial mitigation strategy, but it's difficult to predict whether free-riding can be fully prevented.
Expectation 3: Mutual benefits from collaboration encourage greater inclusiveness among stakeholders, and higher inclusiveness in decision-making processes will improve the quality and acceptance of decisions.	The interview results show that involving a small group of core stakeholders initially and gradually expanding encourages inclusiveness. Mutual benefits were cited as a driving force for inclusiveness in decision-making, leading to better-quality decisions and greater acceptance.
Expectation 4: Greater transparency in communication and information sharing will lead to higher accountability.	Several parts of the interview results highlight the role of transparent communication and information sharing in building trust and ensuring accountability. Structured monitoring during operational stages and collaborative contract development were specifically mentioned.
Expectation 5: Increased dependency on common-pool resources and strong monitoring and enforcement systems lead to better sustainability practices.	The interviews discuss the role of governance structures and monitoring mechanisms in managing conflicts and ensuring compliance with sustainability practices. While dependency and monitoring are important, sustainability is also influenced by broader regulatory and operational factors.

Expectation 6: Robust governance structures enhance the effectiveness of conflict resolution among stakeholders.	Various parts of the interview results mention the importance of clear governance structures and resolution mechanisms in managing conflicts effectively. One participant discussed conflicts anticipated in contracts with clear strategies for resolution.
Expectation 7: Effective coordination, increased information sharing, and facilitative leadership have a positive effect on the network density.	The interview results describe the role of the Director or Manager in facilitating collaboration and coordination among stakeholders, indicating the importance of effective leadership and coordination.