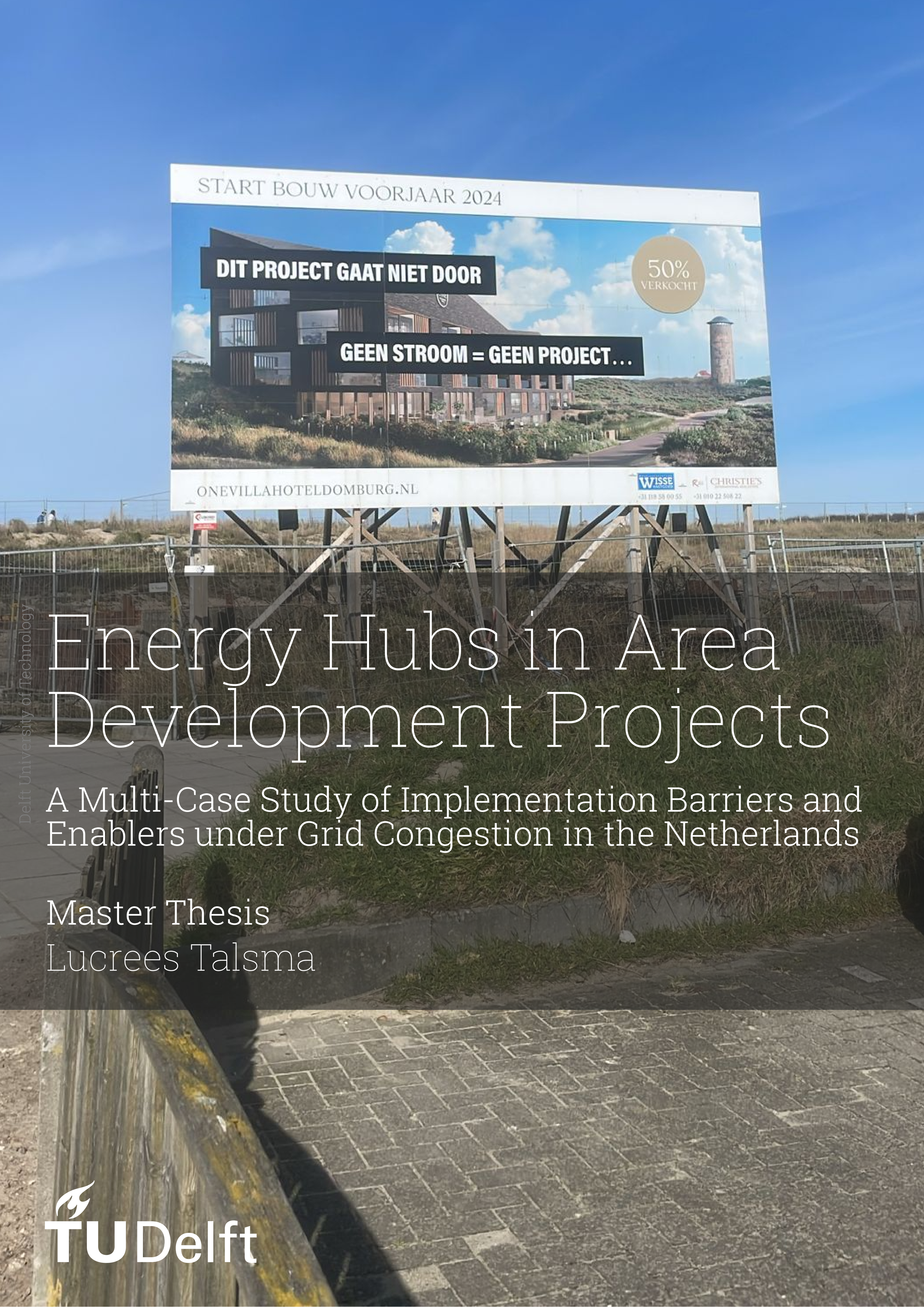


Delft University of Technology

# Energy Hubs in Area Development Projects

## A Multi-Case Study of Implementation Barriers and Enablers under Grid Congestion in the Netherlands

Master Thesis

Lucrees Talsma

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by

Lucrees Talsma

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# Preface

A day I once thought impossible has finally arrived: my last time sitting in the library of TU Delft. It is a strange and surreal feeling. This is a moment I have looked up to my entire life, both with admiration and a fair share of doubt.

In my family, the track record for completing a master's thesis is, let's just say, creatively timed. That is why I am proud to say I completed mine in one continuous effort. A sprint that, at times, felt more like a ultra-marathon. My father, who sadly is no longer with us, would have been incredibly proud. Graduating was his own long and winding journey (it took him 13 years), and one of his greatest fear was that his children might follow in those particular footsteps. Today, I hope I have made him proud.

Many thanks to my TU Delft supervisors, Prof. Dr. Korthals Altes and MSc. van den Bragt, for their guidance, patience, and critical insight throughout this process. Having such steady support made all the difference.

I would also like to thank Fakton Energy, and especially Benny Roelse, for your generous and consistent support. The learning experience was invaluable, and I truly appreciated the many calls and mini-lectures along the way. And of course, I must mention the coffee machine, which quickly became a highlight. After many hours of practice and countless lessons, I am proud to say I finally mastered the art of making foam. A personal goal I can now check off.

This graduation would not have been possible without my friends and family. Thank you for listening to all my stories, for always checking in, and for believing in me even when I did not. A special thank you to my roommate Pien, for your pep talks, for enduring my late nights during our move, and for being by my side through it all, especially during our emotional support walks through the Vondelpark.

Lucrees Talsma<br>Delft, June 2025

# Summary

This thesis explores the role of Energy Hubs (EHubs) in enabling area development projects in the Netherlands under conditions of electricity grid congestion. As the country faces a significant housing shortage and rising electricity demand, the capacity of the existing grid infrastructure to support new urban developments has become a critical bottleneck. EHubs are studied as a potential response to this challenge. These decentralised, multi-energy systems integrate local generation, storage, and demand management, and rely on coordination across multiple stakeholder groups. The research aims to deepen understanding of what EHubs are, how they are configured and implemented in practice, and to identify the technical, legal, governance, and financial conditions that enable or constrain their implementation.

The literature review shows growing academic and policy interest in decentralised energy systems, often described under terms such as Smart Energy Hubs, Local Energy Systems, and Multi-Energy Carrier Systems. Although these concepts differ in technical scope and institutional framing, they share key characteristics: local integration of energy technologies, flexible operation, and multi-actor governance. However, the review also reveals a gap in empirical evidence and conceptual clarity regarding the implementation of such systems in spatial planning contexts. In particular, there is limited insight into the governance models, legal arrangements, and business cases that support real-world EHub development in area development projects

To address this gap, the research applies the Multi-Level Perspective (MLP) on socio-technical transitions as a theoretical lens. Within this framework, EHubs are positioned as niche innovations navigating the constraints of the dominant energy regime, while responding to landscape-level pressures such as climate policy, electrification, and infrastructure bottlenecks. The MLP enables a systemic analysis that incorporates both technological configurations and institutional dynamics.

Methodologically, the study follows a qualitative, critical case sampling approach. Three Dutch pilot projects: Merwedekanaalzone (Merwede), Schoonschip, and Republica, serve as empirical case studies. These projects vary in scale, ambition, and governance, but all integrate the EHub concept within area development initiatives. Data collection included desk research and nine semi-structured interviews with technical advisors, legal and policy experts, distribution system operators (DSOs), and other key stakeholders. A thematic coding approach was applied to analyse technical, legal, organisational, and financial dimensions.

The cross-case analysis revealed a set of recurring enablers: early involvement of technical advisors, regulatory flexibility (via instruments such as the Experimentation Decree and Group Transport Agreement), access to public funding, and strong collaborative governance. Common barriers included limited technical standardisation, fragmented institutional responsibilities, uncertainty around long-term financing, and legal ambiguity about operational models.

This thesis contributes to both academic understanding and professional practice by identifying the conditions under which EHubs can transition from isolated pilots to more institutionalised infrastructure. While EHubs present a promising and adaptable approach to managing local energy systems under grid constraints, their long-term success depends on systemic alignment across technical, legal, financial, and governance domains. The findings suggest that EHubs are most effective when embedded early in the planning process and supported by regulatory flexibility, collaborative governance, and innovative financing mechanisms. For EHubs to scale and influence the dominant energy regime, structural changes in policy, planning, and market frameworks will be necessary to mainstream these decentralised energy solutions.

# Contents

# Abbreviations

| Acronym | Definition |
|---|---|
| **ACM** | Autoriteit Consument en Markt |
| **ATES** | Aquifer Thermal Energy Storage |
| **ATO** | Aansluit- en Transport Overeenkomst |
| **BESS** | Battery Energy Storage System |
| **CBC** | Capaciteit Beperkend Contract |
| **CEC** | Citizen Energy Community |
| **DHC** | District Heating and Cooling |
| **DSO** | Distribution System Operator |
| **EHub** | Energy Hub |
| **EMS** | Energy Management System |
| **EZK** | Ministerie van Economische Zaken en Klimaat |
| **GTO** | Groeps Transport Overeenkomst |
| **GVB** | Grootverbruikers |
| **ICE** | Internal Combustion Engine |
| **KGG** | Ministerie van Klimaat en Groene Groei |
| **KVB** | Kleinverbruiker |
| **LAN** | Landelijk Actieprogramma Netcongestie |
| **LOHC** | Liquid Organic Hydrogen Carrier |
| **MES** | Multi-Energy System |
| **MKGG** | Ministerie van Klimaat en Groenegroei |
| **NBNL** | Netbeheer Nederlands |
| **NP RES** | Nationaal Programma Regionale Energiestrategie |
| **NPE** | Nationaal Plan Energiesysteem |
| **PEM** | Proton Exchange Membrane |
| **PEMFC** | Proton Exchange Membrane Fuel Cell |
| **RE** | Renewable Energy |
| **REC** | Renewable Energy Community |
| **RES** | Regionale Energie Strategie |
| **RVO** | Rijksdienst voor Ondernemend Nederland |
| **SOEC** | Solid Oxide Electrolysis Cell |
| **SOFC** | Solid Oxide Fuel Cell |
| **SQ** | Sub-question |
| **Trafo** | Powergrid Transformer Substation |
| **TSO** | Transmission System Operator |
| **VNG** | Vereneging van Nederlandse Gemeenten |

# 1 Introduction

The Netherlands is currently facing a pressing housing crisis. With a structural shortage of over 400.000 dwellings, the country is struggling to meet the housing needs of a growing and urbanizing population. In response, the national government has set the ambitious goal of constructing 900.000 new homes by 2030, supported by a €5 billion investment (Ministerie van Algemene Zaken, 2023). However, the realization of this target is increasingly hindered by a range of challenges. These include spatial constraints, complex regulatory procedures, and a more recent and rapidly escalating new problem: grid congestion.

Grid congestion refers to a situation where the electricity grid has reached its maximum capacity and can no longer accommodate additional energy supply or demand (RVO, 2025b). The grid is essentially ‘full’. This condition arises when the demand for connections to the grid surpasses its technical transport capacity, especially during peak loads or in regions where infrastructure upgrades lag behind development needs.

In the Netherlands, grid congestion is affecting both the high-voltage and medium-voltage grids, making it particularly challenging for large electricity consumers to obtain new or upgraded grid connections. These consumers include entities with a demand exceeding > 3x80 amperes, such as schools, supermarkets, mobility hubs, and other essential non-residential facilities.

In contrast, individual dwellings are still able to connect to the low-voltage grid (for now [1]). Residential units typically have relatively low capacity requirements, allowing most new homes to be connected without immediate large-scale grid reinforcement. Moreover, grid operators and local authorities often prioritize residential connections due to their essential societal function and alignment with national housing objectives. As a result, while housing units can still be connected in most locations, broader area developments are increasingly being delayed or obstructed. The inability to connect critical supporting non-residential functions, such as e.g. schools, shops, and charging infrastructure for mobility, undermines the functional and financial viability of new neighborhoods. In some cases, these delays are projected to stretch beyond a decade (NOS, 2024), posing a serious threat to the realization of national housing targets and climate policy ambitions.

Notably, grid congestion has only recently emerged as a systemic constraint in the Netherlands, becoming a nationwide concern within the past five years The timeline in Figure 1.1 highlights the key developments, policy shifts and technical milestones that have contributed to the current situation, emphasizing the rapid escalation of this issue.

The implications of grid congestion on spatial development are profound. Traditional urban development practices, predicated on reliable access to energy infrastructure, are no longer guaranteed, as electricity becomes the primary energy carrier for heating, mobility, and industrial processes, the pressure on existing grid infrastructure will only intensify. This emerging bottleneck not only threatens the feasibility of planned housing projects but also jeopardizes the goals of the Dutch energy transition, including the phase-out of natural gas and the electrification of buildings and transport.

[1] This capacity is also predicted to reach its limits within the coming 2–5 years (Pato, 2024).

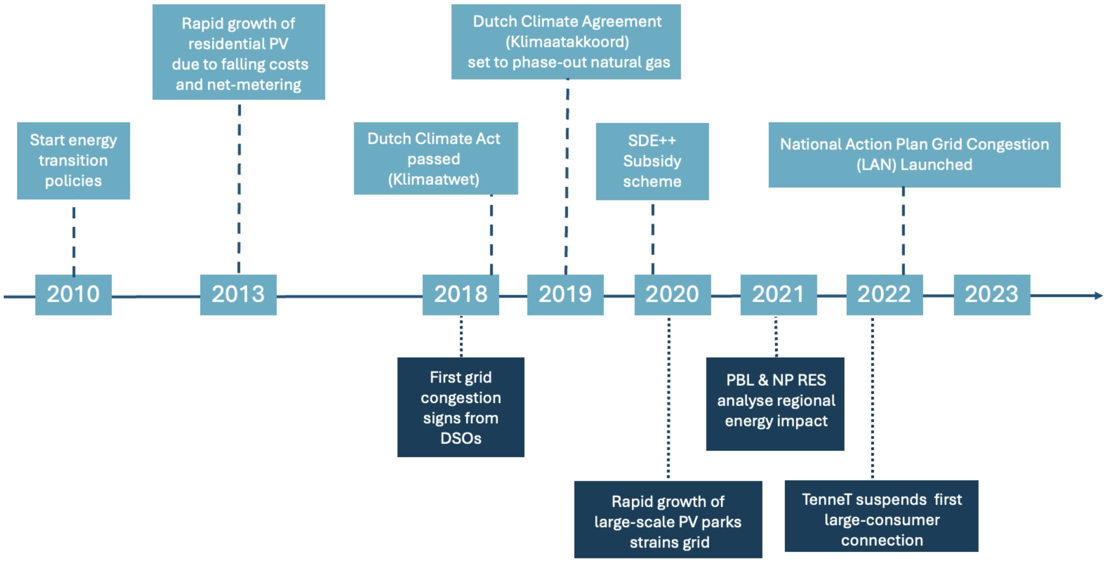


**Figure 1.1:** Grid congestion in the Netherlands: Key events and drivers (Author)

A concrete illustration of this issue can be seen in Amsterdam, where several major investment projects have been halted due to insufficient grid capacity. In the Sloterdijk area, for example, a large-scale housing development has experienced delays. The residential units were able to connect to the grid, however the non-residential functions such as schools, shops, and mobility infrastructure were not. According to the municipality, the inability to realise these supporting facilities compromises the viability of the entire neighbourhood. As noted by the alderman for Spatial Development and Sustainability, without the ability to deliver a fully functioning urban environment, proceeding with the residential component alone is not feasible (NOS, 2022).

The current Dutch energy system operates largely in silos, with different energy carriers (electricity, gas, heat) planned and managed independently. In response to increasing spatial constraints and limited grid capacity, there is growing attention and demand for more integrated, flexible, and decentralised approaches that aim to align energy infrastructure more closely with the spatial dynamics of area development. An example of such an approach is the use of multi-energy carrier systems, where energy flows across different vectors, such as electricity, heat, and storage, are coordinated and optimised at the local or district level. These systems aim to increase flexibility and efficiency by managing supply and demand across multiple energy carriers simultaneously. Particularly under current conditions of grid congestion and fragmented planning, this approach may offer a viable way to enable continued development where grid reinforcement is either delayed or insufficient.

A promising concept embodying this multi-energy approach is the Energy Hub (EHub). An EHub is a locally organized system in which multiple stakeholders collaborate to manage the generation, conversion, storage, distribution, and consumption of energy across various carriers. EHubs provide an approach for managing complex energy systems at the district or area level. By balancing local supply and demand, they can help mitigate grid congestion, increase resilience, and accelerate the transition to renewable energy.

The potential of EHubs as part of the national strategy for grid flexibility is increasingly recognized. The Dutch National Grid Congestion Action Programme (Landelijk Actieprogramma Netcongestie, LAN) explicitly highlights EHubs as a key enabler for increas flexibility of grid users, see Figure 1.2. However, despite this growing attention, the practical implementation of EHubs in the Dutch context remains in its early stages. Limited empirical research exists on how EHubs are currently configured, what barriers they face, and how they might contribute to overcoming grid congestion in area development projects.

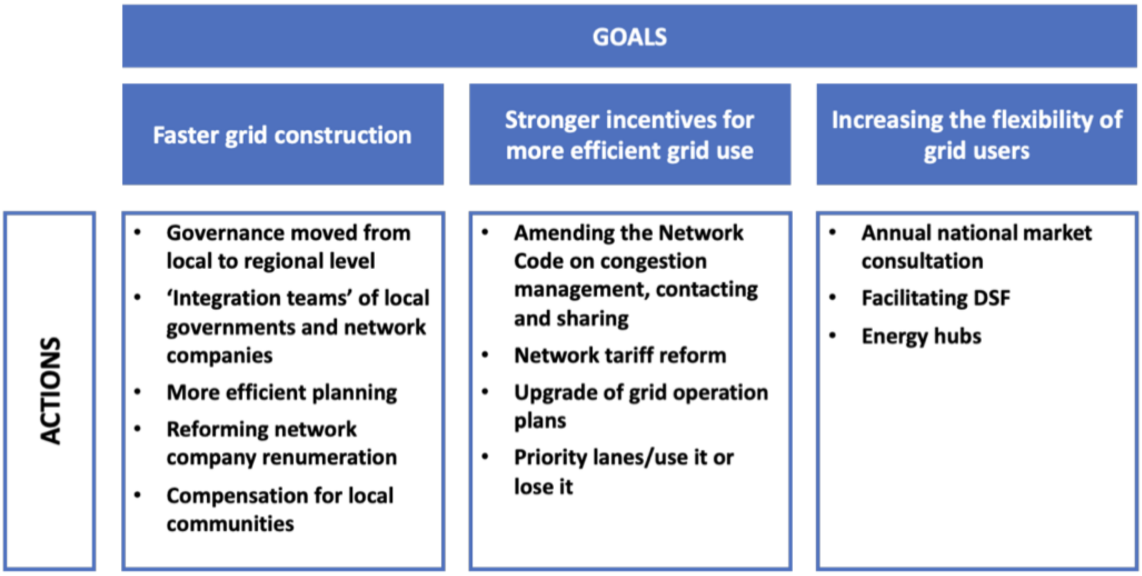

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**Figure 1.2:** Objectives of the Dutch National Grid Congestion Action Programme (LAN) (Source: Pato, 2024)

Given this background information, this thesis aims to contribute to the emerging field of integrated energy and spatial planning by examining the role of EHubs in facilitating area development under conditions of grid congestion in the Netherlands. Positioned at the intersection of a deepening housing shortage and growing pressure on the electricity grid, the research explores how EHubs are defined and configured in both theory and practice. It investigates the technical, legal, organisational, and financial conditions that influence their implementation. Through three empirical case studies, supported by semi-structured interviews with key stakeholders, the study identifies enabling and constraining factors that shape the implementation of EHubs within current planning and energy contexts.

Framed through the Multi-Level Perspective (MLP), EHubs are approached as niche innovations: small-scale pilots that have the potential to change or reform the dominant ways energy and spatial planning are currently organized. In doing so, the study contributes to academic discussions on decentralised energy systems as system innovations, while offering practical insights for stakeholders aiming to build area development projects within a constrained energy infrastructure. Rather than prescribing definitive solutions, the study aims to clarify the conditions under which EHubs might support more adaptive and integrated approaches to urban development in contexts where infrastructure capacity is limited.

## 1.1. Problem Statement

The Netherlands is currently confronted with two pressing systemic challenges: a persistent and intensifying housing shortage, and a rapidly escalating constraint of electricity grid congestion. While the housing crisis in the Netherlands has evolved over decades grid congestion has only recently emerged as a structural barrier to spatial development. Its effects are already disrupting planning trajectories and halting new area development projects across the country.

The accelerated electrification of heating systems, mobility, and industrial processes, coupled with rising residential electricity demand, has placed unprecedented pressure on the Dutch electricity grid. This increasing strain has resulted in significant delays and, in many cases, the complete suspension of spatial and economic developments due to grid capacity constraints (NOS, 2022). The implications of this problem are profound. Project timelines can be extended up to a decade; municipalities are under growing social and political pressure to deliver on housing commitments; and the broader energy transition is jeopardized by the limited flexibility of the existing energy infrastructure.

This situation exposes fundamental shortcomings in current planning and energy governance frameworks. These frameworks tend to operate in siloed, single-carrier paradigms that fail to reflect the increasingly interconnected nature of spatial and energy systems (Stoeglehner, 2020) . As a result, there is a persistent misalignment between policy development, infrastructure planning, and the urgency required for the energy transition.

Despite the urgency, there is currently no coherent institutional or technical framework guiding the integration of spatial development and energy system design in the context of grid congestion. One potential solution lies in the deployment of integrated Multi-Energy Systems (MES), which coordinate and optimise multiple energy carriers (such as electricity heat and gas) at a local scale. Within this context, Energy Hubs (EHubs) have emerged as a promising concept. An EHub can dynamically balance generation, conversion, storage, and consumption across different energy carriers in real time, potentially reducing peak loads on the electricity grid, makes better use of local energy resources, and is designed to lower dependency on the national grid.

However, a significant knowledge gap exists in understanding how EHubs can be effectively deployed as a solution to grid congestion in area development projects. While the EHub concept is gaining recognition in both academic literature and industry discourse, empirical insight into their real-world application remains limited. There is no clear understanding of how EHubs are currently defined, configured, and managed within real-world area development projects, nor of the technical, legal, organisational, and financial conditions under which they can effectively function as a structural solution to grid congestion.

This research addresses this knowledge gap by critically examining the role of EHubs in Dutch area development projects under the condition of grid congestion, with the aim of identifying enabling and constraining factors, and drawing lessons from existing pilot projects to inform future spatial and energy planning practices.

## 1.2. Scientific Relevance

This research contributes to academic understanding of EHubs as socio-technical innovations situated within the challenges of grid congestion and urban development. By integrating the Multi-Level Perspective (MLP) with thematic analysis and in-depth case studies, it provides a comprehensive view of the technical, legal, organisational, and financial configurations that define EHubs. In addition, it identifies key barriers and enabling conditions that influence their implementation. Adopting a cross-case, system-level perspective, the thesis captures the complexity of embedding EHubs into existing planning frameworks and energy regimes.

## 1.3. Societal Relevance

In the face of increasing pressure on both the housing market and the electricity grid, the Netherlands must find integrated solutions that enable continued urban development. This research investigates how decentralised energy systems, specifically EHubs, can be implemented in new area developments despite these infrastructural constraints. Through an analysis of three pilot projects, the study identifies practical barriers and enablers, offering actionable insights for municipalities, developers, DSOs, and policymakers. It supports more effective planning, advances sustainable development, and contributes to building future-proof energy systems in the built environment.

## 1.4. Research Questions

### 1.4.1. Main Research Question

To guide this research, the following main question has been formulated:

*"How are Energy Hubs defined and configured in area development projects facing grid congestion in the Netherlands, and what lessons can be learned from technical, organisational, legal, and financial barriers and enablers identified in current pilot projects to inform future practice?"*

### 1.4.2. Sub-Question

To address this main question, the following sub-questions have been formulated.

**SQ1:** *"How can an Energy Hub be defined?"*

**SQ2:** *"How are Energy Hubs configured in existing literature in terms of technical, organisational, and legal dimensions?"*

**SQ3:** *"How are Energy Hubs configured in current pilot projects in terms of technical, organisational, and legal aspects?"*

**SQ4:** *"What technical, organisational, legal, and financial barriers and enablers affect the implementation of Energy Hubs in these pilot projects?"*

**SQ5:** *"What cross-case lessons can be drawn from these barriers and enablers to inform the future practice of Energy Hubs in area development projects under grid congestion?"*

## 1.5. Research Scope

The scope of this research defines the boundaries within which the study will be conducted. It ensures a clear focus on the key elements that directly relate to answering the research question. The scope is structured around five domains: subject, geographical context, spatial scope, temporal scope, and legal scope.

- **Subject:** The core subject of this research is Energy Hubs, defined as local collaborations between multiple stakeholders aimed at coordinating energy production, transport, storage, conversion, and consumption within a specific area. These collaborations are formalized through agreements. This research focusses on specifically on EHubs in area development projects.
- **Geographical Context:** The research is conducted within the Netherlands, a country undergoing significant energy transitions driven by its commitment to climate neutrality by 2050 as stipulated in the Dutch Climate Agreement (2019). The Netherlands faces acute challenges in balancing its energy transition with pressing area development needs, including a housing crisis and widespread grid congestion. The Dutch context offers a valuable setting for studying EHubs, as their implementation aligns with national efforts to decentralize energy systems and enhance local sustainability.
- **Spatial Scope:** This study focuses on residential and mixed-use area development projects, where EHubs play a critical role in balancing the energy demands of housing, mobility and/or supporting commercial facilities such as supermarkets, schools, and community spaces. These area developments are characterized by high-density energy needs, complex stakeholder dynamics, and significant potential for integrating renewable energy systems. The area must be a locally bounded site, typically defined by formal planning or zoning documents.
- **Temporal Scope:** The research takes a temporal focus on the beginning of year 2025, reflecting the immediate need to address challenges such as grid congestion and delays in housing projects. This time-frame allows for an analysis of the current state of EHubs. It also ensures that the findings and recommendations are actionable within the short term, aligning with the urgency of the energy transition and area development goals in the Netherlands.
- **Legal Scope:** The study is limited to the laws and regulations in effect before may 2025, which govern energy systems, area development, and stakeholder collaborations in the Netherlands. This includes national and regional policies that impact the implementation of EHubs, such as zoning laws and the Energy Act. The research evaluates how these legal frameworks enable or hinder the development of EHubs in residential and mixed-use areas, ensuring that the recommendations align with the existing regulatory landscape.


**Figure 1.3:** Research Scope Visualisation (Author)

This scope ensures that the findings are contextually relevant, practical, and aligned with the pressing challenges facing the Netherlands in 2025. For a visualisation of the research scope see figure 1.3.

## 1.6. Goals and Objectives

The goal of this research is to develop and document knowledge and insights into the implementation of EHubs in area development projects. By analyzing three different pilot cases, the study aims to understand how this key innovation is being applied in practice and to critically examines its potential contribution, and limitations, in building legitimacy within the broader socio-technical transition of the energy system.

The findings aim to contribute to the broader academic understanding of EHubs in area development projects. In addition, they are intended to support decision-makers involved in spatial planning and energy infrastructure by offering practical lessons and reflective insights into the feasibility of integrating EHubs into area development projects in the Netherlands. Finally, the research seeks to inform area developers about potential strategies to enable continued construction, even in the face of ongoing grid congestion challenges.

## 1.7. Personal Study Targets

The initial personal study targets formulated in November of 2024 were:

- Understand the concept of net congestion.
- What is net congestion and why are we dealing with it?
- Identify solutions to mitigate net congestion in housing projects.
- Understand the organisational structure of the electricity grid.
- Develop expertise in energy management and governance.

While these targets provided a valuable foundation at the outset of the research, the exploratory nature of the study led to a refinement of focus over time. As the research progressed, the study evolved to concentrate more specifically on the role of Energy Hubs in area development under conditions of grid congestion, resulting in a partial divergence from the initial learning objective

## 1.8. Thesis Outline

A visual representation of the thesis outline is shown in figure 1.4.
This thesis begins with a theoretical framework that draws on Geels' (2006) Multi-Level Perspective (MLP) from transition studies. Rather than applying the MLP as a full analytical model, the framework

is used to conceptualize EHubs as niche innovations within the broader socio-technical energy system. This approach allows the research to examine the developmental stage of EHubs and to identify the structural conditions, both enabling and constraining, that influence their potential to scale and integrate into mainstream area development practices.

Introducing the MLP early on allows for a deeper understanding of where EHubs are situated within the wider energy and planning systems, and how they interact with institutional, technical, and political structures. By introducing the MLP early on, this research is grounded in a theory that not only frames the complexity of the problem, such as grid congestion and fragmented planning, but also guides the formulation of research questions and the structure of the analysis. This sequence ensures conceptual clarity and coherence throughout the thesis, from theory to empirical findings.

Following the theoretical chapter, the research presents a literature review that establishes a working definition of EHubs and explores existing configurations across technical, legal, and organizational dimensions. This review helps clarify how EHubs are currently understood in academic and policy literature, and identifies key variables to be examined in the empirical research.

The empirical component of the thesis consists of three in-depth case studies of Dutch EHub pilot projects: Merwedekanaalzone, Schoonschip, and Republica. These cases are analyzed to understand how EHubs are configured in practice and to identify the practical barriers and enabling factors encountered during their development.

The thesis concludes with a cross-case analysis that synthesizes the key findings from the three pilots. This includes lessons learned regarding the institutionalisation and future scaling of EHubs, and reflections on their potential to transition from niche experiments to embedded components of the dominant energy and spatial planning regimes. To reinforce the theoretical contribution, the findings are related back to the MLP framework, deepening the research's link to transition studies and system innovation literature.

As a closing reflection, the discussion connects the thesis findings back to a broader perdpective within the field of Management in the Build Environment. Using the 5P's model (People, Process, Place, Product, and Power), offering a multidimensional perspective on how EHubs can be more effectively embedded in future area development practices.

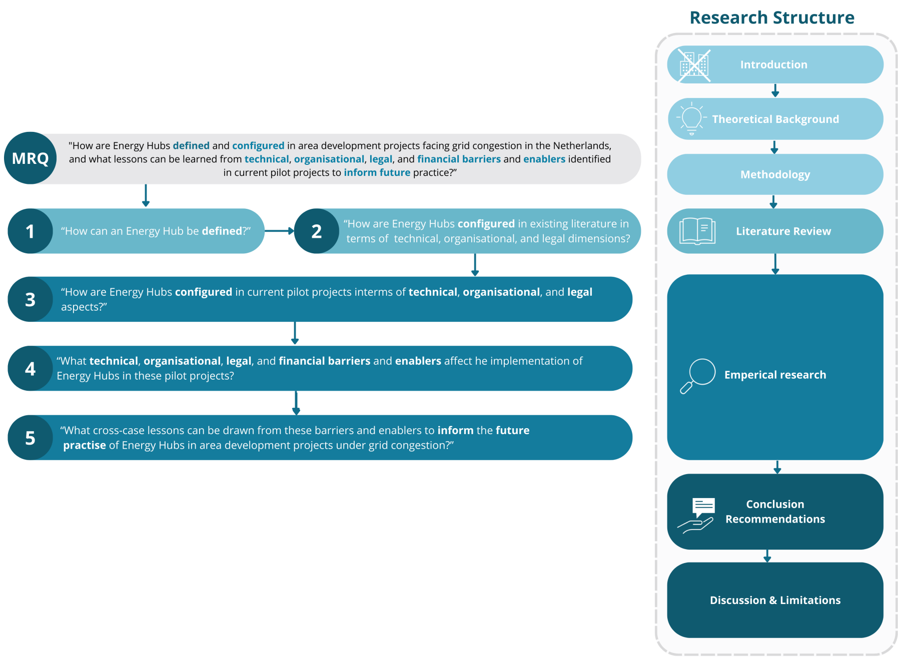


**Figure 1.4:** Thesis Outline (Author)

# 2
# Theoretical Background

The growing pressures of housing development and electricity grid congestion in the Netherlands expose a structural misalignment between spatial planning and energy infrastructure systems, particularly under conditions of rapid electrification and urban expansion (Koelman et al., 2024). Historically, these domains have developed in parallel in the Netherlands with limited institutional or operational integration. Today, this disconnect is visible as housing targets clash with grid limitations, underscoring the need for planning approaches that align spatial development with energy system capacity. While technical solutions such as grid reinforcement offer temporary relief, they do not resolve the deeper systemic fragmentation. Addressing this challenge requires not only technological interventions but also institutional innovation in governance, coordination, and planning practices.

To adequately analyse EHubs, not merely as a technological solution, but also a socio-technical innovation, this study draws selectively on the Multi-Level Perspective (MLP) from transition theory (Geels, 2006). The MLP offers a conceptual framework for understanding how innovations emerge, evolve, and potentially scale within complex systems.

Since its introduction by Geels (2006), the Multi-Level Perspective (MLP) has been widely used to study how major changes happen in systems like energy, transport, or housing. One example is the work of Verbong and Geels (2007), who used the MLP to analyse how the Dutch electricity system has changed over time. Their research shows how new technologies often start small, in protected spaces like pilot projects, but whether they grow depends on how they interact with existing rules, institutions, and external pressures like climate policy or market liberalisation.

The use of MLP in empirical studies has helped explain why some innovations remain locked in pilot phases, while others gain traction and reshape existing regimes, making it a fitting tool to explore the developmental and institutionalization challenges of EHubs in the Dutch context.

In this research, the MLP is not used as a full analytical model, since such an approach would exceed the scope and empirical capacity of this study. Instead, the MLP is used selectively as a conceptual lens to situate EHubs within the broader context of socio-technical change. The MLP is used to understand in what stage of development EHubs are, and to reflect on the structural conditions that may enable or constrain their institutionalisation. It is not used to structure the empirical case analysis, but rather to frame the relevance and systemic nature of the research focus.

As illustrated in Figure 2.1, the MLP distinguishes between three interacting levels of socio-technical change. The landscape level (macro), encompassing developments such as climate targets, energy crises, and societal pressures. The regime level (meso), which includes dominant infrastructures, regulations, and organizational routines. Finally, the niche level (micro) refers to protected spaces where radical innovations, such as EHubs, are developed and tested, often in the form of pilots or experimental projects.

In line with the MLP framework, EHubs are conceptualized as niche innovations because they operate in protected spaces, such as pilot projects, where they can be developed and tested outside the dominant energy regime (Geels, 2006). These protected environments offer shelter from direct market or regulatory

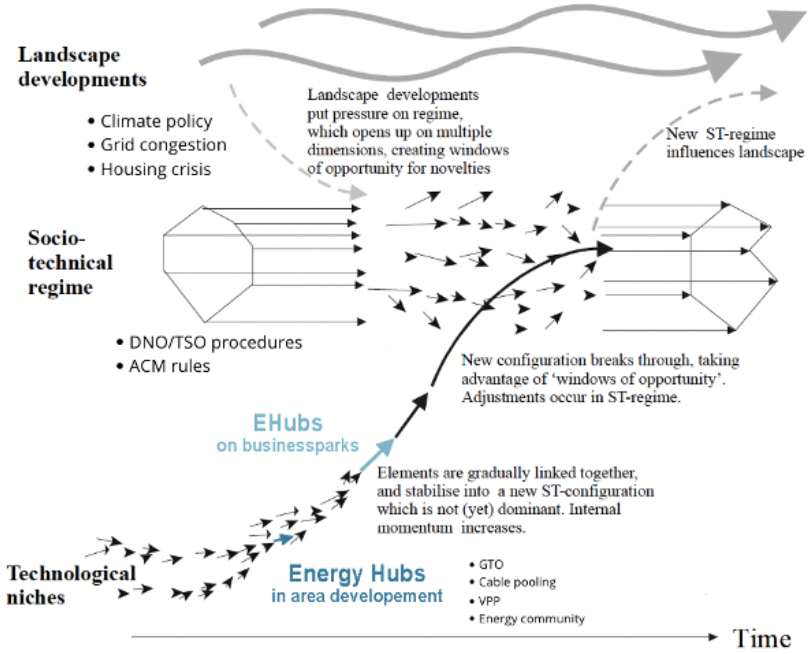


**Figure 2.1:** Multi-Level Perspective Framework adapted to EHubs (Author; adapted from Geels, 2006 )

pressures, allowing novel configurations of technology, governance, and stakeholder cooperation to take shape. Their current reliance on local initiative, project-based funding, and the absence of an integrated regulatory framework underscores their status as early-stage innovations. The development and potential upscaling of EHubs are influenced by landscape-level pressures, including climate policy, the energy transition and the increase of grid congestion, as well as by regime-level barriers, such as fragmented governance and siloed infrastructure planning. By enabling coordinated management of multiple energy carriers within local context, EHubs offer not only technical functionality, but also institutional and organizational innovation.

As shown in Figure 2.1, for niche innovations to mature and ultimately influence or integrate into the dominant socio-technical regime, three key internal and external processes must occur (Geels, 2006):

1. Alignment and stabilization of core elements into a coherent configuration or "dominant design";
2. Strengthening of internal momentum, including the development of shared expectations, supportive actor networks, and investment flows;
3. Strategic interaction with the existing regime, through which the innovation either becomes embedded within or disrupts incumbent rules, norms, and infrastructures.

Together, these processes illustrate that the scalability of EHubs depends not only on technical viability, but also on their ability to stabilise organisational models, mobilise support networks, and engage with existing institutional frameworks. Without such integration, even promising innovations risk remaining isolated experiments.

Applying the MLP framework allows this research to go beyond evaluating *what* EHubs are or *how* they work. It enables a deeper exploration of *why* they emerge, *under what conditions* they may succeed or fail, and *how* they interact with existing planning and energy systems. This perspective frames EHubs not as isolated technical solutions but as part of broader systemic change

Ultimately, the MLP positions EHubs within a socio-technical transition context, highlighting the need for conditions under which they might evolve from pilot projects to institutionalised components of urban development. The following chapters will explore the current role of EHubs in Dutch area development projects.

# 3
# Methodology

This chapter outlines the research methodology employed to investigate how Energy Hubs (EHubs) are defined, configured, and implemented in the context of area development projects facing electricity grid congestion in the Netherlands. Given the exploratory nature of this study and the relative novelty of EHubs in both academic and practical domains, a combination of a literature review is complimented with a qualitative, case study–based approach for the empirical part of the research. The aim of the research is to generate in-depth empirical insights into the technical, legal, organizational, and financial dimensions of EHub implementation. To achieve this, three Dutch pilot projects were selected for comparative case analysis: Merwedekanaalzone, Schoonschip, and Republica. These cases provide a diverse but relevant sample of early-stage EHubs operating under different spatial and institutional conditions.

The methodology chapter begins by presenting the overall research design and justifying the choice for a qualitative multi-case study design. It then details the case selection criteria, data collection methods (including semi-structured interviews, document analysis, and project materials), and the thematic coding approach used for analysis. Particular attention is given to how validity and reliability were ensured throughout the research process.

By combining conceptual insights from the Multi-Level Perspective (MLP) with grounded empirical data from pilot projects, this methodological framework supports a comprehensive exploration of the barriers and enablers shaping the role of EHubs in current and future spatial development under grid-constrained conditions.

## 3.1. Research Design

This research adopts a qualitative multiple-case study approach with an exploratory and comparative design. It aims to generate in-depth insights into the implementation of EHubs as a potential solution to enable area development under conditions of grid congestion in the Netherlands. In addition, it seeks to document and formalize implicit knowledge on this topic, thereby contributing to the broader knowledge base. This effort is particularly relevant, as knowledge development and diffusion are widely recognized as core functions of innovation systems and essential to effective policy-making.

The study combines a semi-structured expert interviews and desk research, integrating stakeholder perspectives with documentary evidence to explore how technical, legal, and organizational configurations influence implementation outcomes.

Due to the limited availability of detailed public documentation on the selected pilot projects, semi-structured interviews with key stakeholders were conducted. These interviews served not only to explore perceived barriers and enabling factors, but also to help construct the case narratives themselves. Interview participants primarily included technical advisors ans Distribution System Operators (DSOs), all of whom were directly involved in the implementation of each EHub.

The interviews served two purposes, they provided empirical insights into the technical, organizational and legal configurations of each case, information often not publicly available in written sources.

Secondly, they formed the basis for thematic analysis of barriers and enablers related to energy hub implementation across these dimensions. The dual role of interviews, both descriptive and analytical, ensured the context-sensitive and actor-informed understanding of each project, consistent with an interparticle case study approach.

The findings are analyzed thematically using a framework focused on identifying key barriers and enabling factors across the case studies. Thematic coding was applied both to the case study data and to the analysis of barriers and enablers. To strengthen the credibility of the findings, interview data were triangulated where possible with desk research, including policy documents, project reports, and information provided by involved parties.

## 3.2. Theoretical Research

Theoretical research covers the first two sub-questions. The theoretical background is explored through an extensive literature review and explorative interviews.

## 3.3. Empirical Research

### 3.3.1. Thematic Analysis Using Barriers and Enablers

To analyse the conditions under which EHubs may contribute to solving grid congestion in area development, this research applies thematic coding across four dimensions:

- Technological
- Organisational
- Legal
- Financial

The thematic coding followed the approach outlined by Braun and Clarke (2006). This process involves sex key phases:

1. Familiarizing yourself with the data
2. Generating initial codes
3. Searching for themes
4. Reviewing themes
5. Defining and naming themes
6. Producing the report

This structured, step-by-step process was adopted to ensure consistency, transparency, and analytical depth throughout the thematic analysis

Following a systematic literature review on the concepts and configurations of EHubs in area development projects, as well as participation in multiple expert events and numerous discussions with professionals in the field, three key thematic categories emerged: technical, organisational, and legal configuration.

Semi-structured interviews were conducted to develop a deeper understanding of the selected cases. The interviews were subsequently guided by the identified themes in order to explore the key barriers and enablers influencing the implementation of the pilot projects within these areas.

The following deductive codes were used to review the transcripts of the interviews in Atlas.ti:

**Deductive codes:**

- Theme: Technical
  - Barriers
  - Enablers
  - Description

- Theme: Organisational
  - Barriers
  - Enablers
  - Description
- Theme: Legal
  - Barriers
  - Enablers
  - Description

These themes represent the key barriers and enabling conditions for implementation as reported by stakeholders.

During the coding process, the financial dimension emerged as being a key barrier or enabling factor for the implementation and development in EHubs in area development projects.

**Inductive codes**

- Theme: Financial
  - Barriers
  - Enablers

After the coding process, an overview of the key barriers and enabling factors will be developed for each thematic category. Following this, each case will be described individually, outlining its technical, organisational, and legal configuration. This structured presentation serves as the foundation for a cross-case analysis, which will examine recurring technical configurations across multiple cases and provide a holistic overview of their characteristics.

A cross-case analysis will then be conducted to identify patterns, similarities, and differences across the pilot projects, providing insight into whether certain barriers or enablers are context-specific or systemic in nature. Key lessons from each case will be documented. Finally, these findings will be related back to the Multi-Level Perspective (MLP) to reflect on how the identified barriers and enablers interact across niche, regime, and landscape levels.

### 3.3.2. Case Study Selection and Criteria

Grid congestion has become an increasingly urgent challenge in the Netherlands, emerging alongside the country's rapid progress in the energy transition. With high population density and ambitious climate-neutrality targets, the Netherlands now faces structural bottlenecks in electricity grid capacity. As noted by the International Energy Agency (Kvarnström et al., 2025), the country is a striking example of how grid congestion can hinder clean energy deployment and threaten climate goals. In this context, the demand for innovative, scalable local energy solutions has become both critical and policy-relevant.

Given the novelty of this issue and the limited availability of comparable international examples, this research adopts a critical case sampling strategy. As Flyvbjerg (2006) argues, such an approach is particularly valuable in exploratory research where cases can serve as strategically important examples. Critical cases are selected not for representativeness, but for their potential to offer deep, context-specific insights that may be transferable to other settings. The aim here is not statistical generalisation, but to develop a nuanced understanding of how EHubs function within residential area developments under grid-constrained conditions.

To support cross-case learning and contrastive analysis, the three selected cases vary in terms of scale, governance structure, spatial characteristics, and implementation progress. However, to ensure analytical coherence and relevance to the research questions, all selected cases must meet the following general selection criteria:

- The initiative must involve an operational or developing EHub within an Area Development project in the Netherlands;

- The development must be residentially driven, even if it contains mixed-use components.

Due to the absence of a universally standardized definition of an EHub, a limitation that will be further elaborated in the following subchapter, a clear operational scope is required to guide the case selection of this research. A set of criteria has been defined to delimit which initiatives are considered relevant and representative of an EHub within the framework of this study:

**Spatial Characteristics:**

- Residential Density: All three case studies selected for this research must primarily consist of residential developments. While mixed-use elements such as commercial or community facilities may be present, the dominant function of each area should be housing. This focus ensures that the study specifically addresses the challenges and opportunities related to large-scale residential development in the context of grid congestion.
- Local Operation: The EHub must operate within a clearly defined local geographical area.

**Development Scale:**

- Project Size: The development should involve multiple buildings or a master-planned area, distinguishing it from individual projects such as single homes or small complexes.

**Stakeholder Involvement:**

- Multi-Stakeholder Collaboration:The development must involves collaboration between various stakeholders, such as municipalities, developers, and residents.

**Legal:**

- Participants in the EHub are collectively represented through a single legal entity.

**Energy Hub Criteria:**

- Local Energy Production: The EHub in question must involve local production, conversion, distribution, storage and use of energy.
- The EHub must integrate multiple energy carriers, such as electricity, heat, cool, hydrogen, and biofuels, to enhance system efficiency.

The primary objective of the EHub should be to maximize the integration and utilisation of locally generated renewable energy sources (RES) within the system. This approach will ensures compliance with national and international climate obligations, including the Dutch Climate Act and the European Union's broader decarbonisation targets. By prioritising renewable energy uptake, the EHub contributes directly to the transition toward a low-carbon energy system, as mandated under the Climate Act (Ministerie van Economische Zaken en Klimaat, 2019).

### 3.3.3. Desk Research

Desk research was conducted to gather contextual and supporting information relevant to each case study. This included the review of publicly available project documentation, policy papers, regulatory frameworks, and official case reports. The aim of this desk research was twofold: first, to triangulate and verify the data obtained from interviews; and second, to enhance the overall understanding of the institutional, legal, and technical landscape surrounding EHub implementation. Where available, planning documents, public reports, and governmental communications were also consulted to provide additional depth to the analysis.

### 3.3.4. Semi-structured Interviews

To gain deeper insight into the implementation processes, barriers, and enabling factors associated with EHubs in area development projects, a total of nine semi-structured interviews were conducted with key stakeholders. Interviewees used for empirical research primarily included technical advisors, representatives from Distribution System Operators (DSOs), and policy makers directly involved in or knowledgeable about the pilot projects. These interviews served both a descriptive and analytical purpose: they provided detailed case-specific information and contributed empirical data for the thematic analysis.

All interviews were conducted in accordance with ethical research standards. Participants were informed of the research objectives, their rights, and how their data would be handled. The data management plan, informed consent form, and the HREC (Human Research Ethics Committee) checklist are included in Appendix.

The data management plan, informed consent form and HREC checklist are included in appendix.

## 3.4. Data Analysis and Data Plan

This research employs a qualitative analysis approach to address the research questions and derive actionable insights. The analysis focuses on identifying recurring themes, comparing critical cases, and building an understanding of stakeholder dynamics and collaboration models.

Interview data will be analyzed using a thematic coding approach in Atlas.ti. This research combines both deductive and inductive coding approaches to analyze the interview data thematically.

• **Deductive coding**: is a theory-driven approach, where codes are predefined based on existing literature, theoretical frameworks, or research questions.

In this study, deductive codes were derived from key themes identified in the literature and initial expert engagement.

• **Inductive coding**, by contrast, is a data-driven approach, where codes emerge organically from the content of the data itself without being predefined.

During the analysis, inductive coding revealed the financial dimension as an additional key theme, which was not initially part of the coding structure but emerged consistently across interviews as a significant factor influencing project feasibility.

The combination of both approaches allows for a structured yet open-ended analysis, ensuring that the coding process remains grounded in theory while remaining responsive to new insights arising from the empirical data.

According to Fereday and Muir-Cochrane (2006) , using a hybrid approach that integrates both deductive and inductive thematic analysis "allows researchers to capture rich, nuanced findings while ensuring alignment with predefined research objectives".

## 3.5. Synthesis and Validation

To ensure the validity of the data, triangulation will be employed as a key methodological approach (Saunders et al., 2019). Triangulation involves gathering data from multiple sources to enhance the reliability and robustness of the findings. In this study, data from case studies was supplemented with additional information sourced from internet-based resources to provide a comprehensive perspective.

To further ensure accuracy, the anonymised findings will be shared with participants for review. Participants will be invited to evaluate the content and provide feedback or corrections where necessary. This iterative validation process ensures that any misinterpretations are identified and addressed, thereby enhancing the overall quality and credibility of the research outcomes.

## 3.6. Ethical Considerations

Ethical considerations will be integral to this research. Measures include:

1. **Informed Consent Form:** All participants will receive detailed information about the purpose of the study, their role, and their rights before agreeing to participate. Written consent will be obtained before any data collection begins.

2. **Pseudonymisation and Confidentiality**: Participant identities will be anonymised in all reports and publications. Coded and anonymised data will be securely stored on TU Delft's OneDrive environment. Any personally identifiable information will be stored separately to ensure confidentiality is maintained at all times.
3. **Data Handling and Deletion:** All data collected during the study, including interview recordings and transcripts, will be stored securely on the encrypted "Project Data Storage (U)" platform. To further ensure privacy, all raw data will be permanently deleted one month after the completion of the research. Only aggregated and anonymized insights will be retained for future use.
4. **Transparency with Participants:** Participants will have the opportunity to review and approve interview transcripts upon request. They may also withdraw their consent at any point during the study and are informed about these rights in the signed consent form.
5. **Institutional and Legal Compliance:** The research will adhere to the ethical guidelines of the Delft University of Technology and comply with the General Data Protection Regulation (GDPR) in the Netherlands.

The informed consent form is included in appendix g.

# 4

# Defining an Energy Hub (EHub)

The concept of the Energy Hub (EHub) has gained significant attention in recent years as a means to enhance the efficiency, flexibility and sustainability of energy systems. However, there is no single, universally accepted definition of an EHub in literature (Sadeghi et al., 2019). Interpretations vary depending on the context, scale, and purpose of implementation.

Broadly, an EHub serves as a central unit where multiple energy carriers, such as electricity, natural gas, and heat, are produced, converted, distributed, and stored to meet various energy demands. This integrated approach facilitates optimized energy management, contributing to the advancement of sustainable energy infrastructures. In contrast to “classical” energy systems, where energy carrier systems are treated separately or independently (Mancarella, 2014), EHubs promote a holistic and interconnected approach.

The variability in definitions of the EHubs reflects its diverse applications across different sectors, ranging from industrial and urban energy systems to decentralized renewable energy solutions. This research focuses on macro-scale EHubs, particularly in mixed-use and residential area development projects, as a potential solution to challenges such as grid congestion and the transition to low-carbon energy systems.
The term ‘Energy Hub’ is used in various ways. The following subsections will explore the different definitions found in academic literature and in practice, ultimately establishing the scope of the term ‘Energy Hub’ for this research.

## 4.1. Origin of the Ehub Concept

The EHub concept was first introduced by a research group from ETH Zurich in a project titled A Vision of Future Energy Networks (VoFEN) (Geidl et al., 2007). The aim of this project was to conceptualize long-term future energy systems (30 to 50 years ahead). The EHub was initially defined as the interface between consumers, producers, storage devices, and transmission devices, either directly or via conversion equipment, handling one or several energy carriers. This concept involved the management of Multi-Energy Systems (MES). The first conceptualization of the EHub is visualized in Figure 4.1.

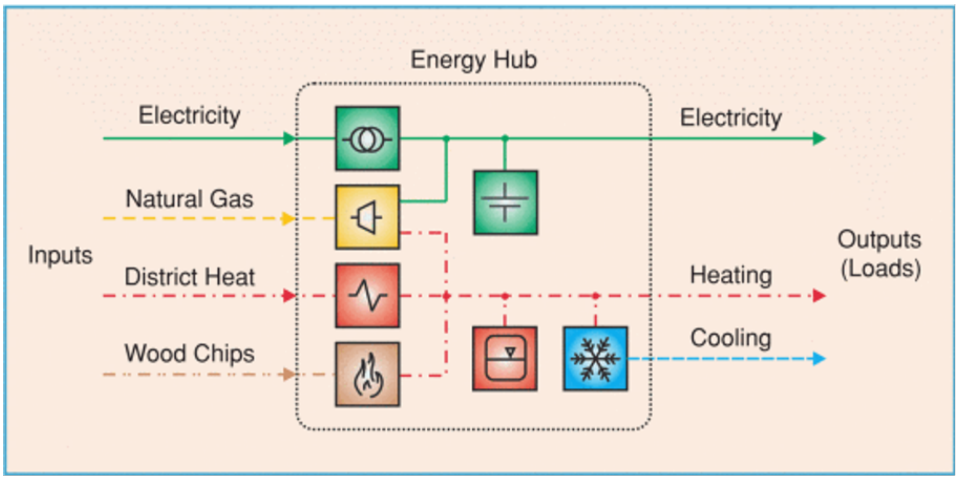


**Figure 4.1:** First visualization of the Ehub concept (Geidl et al., 2007)

The diagram presented by Geidl (2007) provides a comprehensive visualization of the EHub as an integrated system for managing multiple energy carriers. The EHub receives a variety of energy carriers as inputs, processes and converts them to meet specific energy demands, and distributes the processed energy to various end-users. Advanced conversion technologies within the Hub enable the transformation of input energy carriers into usable forms. By balancing inputs and outputs, the Hub optimizes energy use, reduces waste, and minimizes reliance on external energy sources. This integrated approach enhances system efficiency and supports the transition to sustainable and decentralized energy systems.

## 4.2. Fragmentation of the Energy Hub concept

During the literature review, it became apparent that a significant challenge in researching EHubs is the inconsistency in terminology and definitions across various studies. Many researchers use different terms to describe what is fundamentally the same concept. To establish a clearer understanding of the existing body of work, an overview has been compiled that categorizes the diverse terminologies used to refer to the EHub concept. This was done by backwards snowballing on Scopus as well as Google Scholar.

**Table 4.1:** Overview of Terminology Used in Energy Hub Literature

| **Citation Key** | Energy Hub | Smart Energy Hub | Multi-Energy Carrier System | Residential Energy Hub | Smart Multi-Commodity Energy System | Local Energy System | Local Multi-Energy Community | Smart Energy Community | Energy Community | Energy Cooperation |
|---|---|---|---|---|---|---|---|---|---|---|
| (Geidl et al., 2007) | ✓ | | ✓ | | | | | | | |

**Table 4.1 – continued from previous page**

| Citation Key | Energy Hub | Smart Energy Hub | Multi-Energy Carrier Hub | Residential Energy Hub | Smart Multi-Commodity Energy System | Local Energy System | Local Multi-Energy Community | Smart Energy Community | Energy Community | Energy Cooperation |
|---|---|---|---|---|---|---|---|---|---|---|
| (Krause et al., 2011) | ✓ | | ✓ | | | | | | | |
| (Mancarella, 2014) | ✓ | | ✓ | | | ✓ | | | | |
| (Mohammadi et al., 2017) | ✓ | ✓ | | | | | | | | |
| (Howell et al., 2017) | | ✓ | | | | ✓ | | ✓ | | |
| (Sadeghi et al., 2019) | ✓ | ✓ | ✓ | | ✓ | | | | | |
| (Maroufmashat et al., 2016) | ✓ | ✓ | | ✓ | | ✓ | | | | |
| (Topsector Energie, 2021) | ✓ | ✓ | | | | ✓ | ✓ | | | |
| (Rodhouse et al., 2023) | | | | | | ✓ | ✓ | | ✓ | ✓ |
| (Wiertsema et al., 2024) | ✓ | | | ✓ | | ✓ | ✓ | | | |
| (de Graaf et al., 2024) | ✓ | | | | ✓ | ✓ | ✓ | | ✓ | |

Throughout the literature, various terms are used interchangeably or in close relation to the Energy Hub concept. From Table 4.1 most notably Smart Energy Hub, Local Energy System, and Multi-Energy Carrier System. While these concepts are often applied within similar technical and spatial contexts, they differ subtly in emphasis.

**Smart Energy Hub**: Refers to an EHub enhanced with automation technologies such as smart grids and optimization algorithms, enabling real-time energy management.

**Local Energy System**: Highlights the geographically bounded, community-focused dimension of energy coordination, often involving local governance and stakeholder collaboration.

**Multi-Energy Carrier System**: Emphasizes the technical infrastructure that enables the integration and conversion of different energy vectors, such as electricity, gas, and heat, within a single system.

In this context, an energy vector is a specific form of energy that can be transferred, stored, or converted. The ability of an EHub to manage several vectors simultaneously is known as multi-vector integration. Despite these nuances, all three concepts share the core principle of multi-vector integration and decentralized optimization. In this research, the term Energy Hub is used as an umbrella concept, while acknowledging that these related terms reflect important functional or organizational variations within the broader framework. This choice is a deliberate effort to enhance the discoverability and accessibility of the research.

### 4.2.1. Academic Definition and Definition found in practice

Since the first introduction of the concept, the EHub has been interpreted and adapted in various ways by different organizations and researchers. To establish a commonly used definition for the term an extensive literature review has been deployed.

The process of defining the term 'Energy Hub 'is complicated by a two-fold problem. Firstly, a variety of terms are used in the literature to describe what is essentially the same concept. This inconsistency in terminology makes it difficult to establish a clear an unified understanding of the concept.

Secondly, even if the term Energy Hub is used, the definitions can still differ across studies. Some emphasize the physical infrastructure that interconnects various energy carriers (such as electricity, heat, and gas), while others focus on the control and optimization aspects of multi-energy systems, or the role of Hubs in regional and national energy systems.

Together, this diversity in terminology and conceptual interpretation creates ambiguity and hinders the development of a standardized definition. Therefore, a clear overview of how the term 'Energy Hub' is used across the literature is necessary to clarify its meaning and scope.

In recent years organizations such as CE Delft, TopSectorenergy and Royal HaskoningDHV and the Rijkdiens voor Ondernemend Nederland (RVO) also have explored the application of EHubs in the context of sustainable urban development in Netherlands. These interpretations often emphasize the role of energy hubs in enhancing local energy resilience and supporting the transition to low-carbon energy systems. The RVO (2024) uses the following definition for an EHub:

*"An Energy Hub is a local collaboration between several parties in the field of energy. These parties coordinate generation, storage, conversion and consumption. They often make agreements on cooperation. There is also a legal entity or natural person representing the parties. This has a legal status and acts on behalf of the cooperating group."*

The emphasis on collaboration between parties and a legal entity that acts on behalf of the cooperating group is new to the orginal definition by Geidl et al. (2007) and is unique to the Dutch context and their understanding of concept. This must therefore be taken into account for this research.

**Table 4.2:** Comparison of Energy Hub Definition Components in Literature and Practice

| **Source** | Multi-energy carrier integration | Conversion of energy carriers | Energy storage | Decentralized/local operation | Optimization / Efficiency | Smart control / ICT | Stakeholder collaboration | Legal structure / entity | Formal agreements between parties |
|---|---|---|---|---|---|---|---|---|---|
| Geidl et al., 2007 | ✓ | ✓ | ✓ | | ✓ | | | | |
| Krause et al., 2011 | ✓ | ✓ | ✓ | | ✓ | | | | |
| Mancarella, 2014 | ✓ | ✓ | ✓ | ✓ | ✓ | | | | |
| Mohammadi et al., 2017 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| Sadeghi et al., 2019 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | | |
| Wiertsema et al., 2024 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Topsector Energie, 2021 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ |
| de Graaf et al., 2024 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| RVO, 2024 | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **This research** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

## 4.3. Scope for this research

Following Table 4.2 and multiple iterations, the scope outlined below has been selected to guide the direction of this research. The definition has been altered to fit the existing pilots for EHubs in the built environment in the Netherlands (this will be further elaborated on later):

*"An Energy Hub is a **locally demarcated collaboration** among **multiple stakeholders** within the energy domain. These stakeholders coordinate the **generation, storage, conversion, and consumption** of energy. A defining characteristic of an Energy Hub is the presence of **formal agreements** that structure the cooperation between the involved parties. Additionally, an Energy Hub is represented by a **legal entity** or a designated natural person who acts on behalf of the collaborating parties. This representative has a legal status, enabling them to engage in contracts, comply with regulatory frameworks, and ensure accountability within the hub."*

The EHub concept represents a modern approach towards energy management, offering the potential to enhance system efficiency, flexibility, and sustainability across various contexts. As the energy landscape continues to evolve, the continued exploration and adaptation of EHub models will be crucial in addressing the multifaceted challenges associated with the global transition to sustainable energy systems.

# 5
# Characterization and Implementation of EHubs

This chapter outlines the various typologies of Ehubs, their technical configurations, the stakeholders involved, and the legal and regulatory frameworks governing them. It aims to offer a holistic understanding of how energy hubs are conceptualized and implemented in practice.

## 5.1. Typologies of Energy Hubs

### 5.1.1. Classification by Scale

In academic literature, EHubs are often classified according to their physical and functional scale. Mohammadi et al. (2017) introduces a distinction between micro and macro Ehubs. Micro EHubs typically operate at the building or neighbourhood level and can be further categorized into residential, commercial, industrial, and agricultural variants, depending on their primary function and energy demand profiles.

On the other hand, macro EHubs represent networks of interconnected micro hubs, coordinated to achieve system-level optimization. These may include larger infrastructures such as industrial zones, energy-positive districts, or entire cities, managed through integrated control systems and governance structures. This scale-based typology is particularly useful for analyzing EHubs from a systems engineering or network optimization perspective.
This research will focus on micro EHubs.

### 5.1.2. Functional Classification: Energy Hub Families

Within the Dutch context different parties have also tried to categories of EHubs from a functional point of view. According to a research performed by Royal Haskoning DHV (de Graaf et al., 2024), EHubs in the Netherlands can be divided into 4 categories or as the research calls them 'families'. The categorisation is based on their dominant application area and stakeholder composition:

**Built Environment**
This family encompasses hubs that integrate residential, commercial, and mobility elements within the built environment. Depending on the specific context, the hub functions as a sponge or an island. It facilitates the sustainable electrification and heat transition of urban areas while minimizing strain on grid capacity.

**Mobility**
This family focuses on mobility across road, water, and rail networks. The hub does not act as a primary energy source but instead operates as a sponge or part of an island. By integrating various energy carriers for transportation, often with storage solutions, it enables sustainable mobility within a broader geographical region.

**Business parks**
This family consists of hubs located in business parks, often linked to industrial activities. It can act as a source where it supplies energy to surrounding areas, or it can also absorbs surplus renewable energy from nearby sources.

**Cluster 6**
Cluster 6 refers to stand-alone industrial companies that operate independently from larger energy systems or industrial clusters. These entities often have high energy demands and generate residual heat as a by-product of their processes (e.g. Friesland Campina). While not inherently integrated into broader energy networks, Cluster 6 companies have the potential to contribute to local energy systems by supplying excess heat to surrounding areas. This residual heat can be utilized particularly in the built environment, for example through district heating networks, thereby enhancing overall energy efficiency and sustainability.

This classification enables a more applied, stakeholder-centric analysis of energy hubs, facilitating comparison across real-world implementations in the Netherlands. This thesis will exclusively focus on ehubs within the Built Environment. By narrowing the scope to this specific family, the research will provide new insights on this understudied topic.

## 5.2. Technical Configurations

Consumers demand many different forms of energy, each provided by different infrastructures. Until now, due to the centralised set up of the energy system in the Netherlands, all infrastructures operate independently. However, the flexible combination of different energy carriers using conversion and storage technology offers a powerful approach for various system improvements. Energy cost and system emissions can be reduced, security and availability of supply can be increased, congestion can be mitigated, and overall energy efficiency can be enhanced (Geidl et al., 2007.)
An EHub serves as an interface between different energy infrastructures and/or loads. The EHub concept enables the design of multi-energy carrier systems, integrating inputs from electricity, gas, and heat networks to provide required energy services such as electricity, heating, and cooling. Within the hub, energy is converted and conditioned using technologies such as combined heat and power (CHP) systems, transformers, power-electronic devices, compressors, and heat exchangers (Geidl et al., 2007).

### 5.2.1. Basic Structure of an Energy Hub

A simplified version of an EHub system is illustrated in figure 5.1.


$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_n \end{bmatrix} \begin{bmatrix} C_{11} & C_{12} & \dots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ C_{m1} & C_{m2} & \cdots & C_{mn} \end{bmatrix} = \begin{bmatrix} L_1 \\ L_2 \\ \vdots \\ L_m \end{bmatrix}$$

**Figure 5.1:** Simplified Energy Hub system (Mohammadi et al., 2017)

In an extensive literature review conducted by Papadimitriou et al. (2023) , different configurations of EHubs were analyzed. The study identifies electricity as the primary or "backbone" energy carrier within integrated energy systems. This dominant role is further emphasized by its frequent coupling with other carriers, including natural gas, heating, cooling, hydrogen, and domestic hot water. The most common combinations found in the reviewed literature involve electricity paired with heating and cooling systems, highlighting their central role in multi-energy system configurations Papadimitriou et al., 2023.

### 5.2.2. Functional Blocks of an Energy Hub

An EHub typically integrates four key functional blocks:

- **Input**: Energy sources such as electricity from the grid, natural gas, renewable energy (solar PV, wind), and district heating.
- **Conversion**: Technologies that transform energy from one form to another (e.g., CHP, heat pumps, electrolyzers for hydrogen production).
- **Storage**: Systems that store excess energy for later use (e.g., batteries, thermal storage, hydrogen tanks).
- **Output**: Final energy services (electricity, heating, cooling).

These blocks are interconnected via a system control layer, which optimizes energy flows based on demand, cost, and environmental constraints (Papadimitriou et al., 2023).The efficiency of an EHub therefore not only depends on its physical components but also on its control and optimization strategies. Advanced energy management systems (EMS) use real-time data and predictive algorithms to balance supply and demand while minimizing costs and emissions (Mohammadi et al., 2017).

### 5.2.3. Common Energy Hub components

A comprehensive table has been compiled to catalogue key components commonly associated with Energy Hubs, as identified in the literature. These components were subsequently reviewed and validated by domain experts to establish a foundational framework for EHub configurations. The optimal combination of components depends largely on the specific context in which the EHub is implemented, particularly the local energy demand and system needs.

**Table 5.1:** EHub components with academic literature

| Category | Components | Literature References |
|---|---|---|
| **Input [I]** | | |
| Wind | Onshore/offshore turbines | (Gielen et al., 2019; Papadimitriou et al., 2023) |
| Grid Energy | Electricity import/export | (Geidl et al., 2007) |
| Micro-hydro | Small-scale hydropower | (Manders et al., 2016; Paish, 2002) |
| Solar Energy | PV panels, Solar thermal | (Gielen et al., 2019; Jäger-Waldau, 2021; Papadimitriou et al., 2023) |
| Waste Heat | Industrial process recovery | (Calvillo et al., 2013; Papadimitriou et al., 2023) |
| Geothermal | Ground-source heat extraction | (Gielen et al., 2019;Lund et al., 2018; Chen et al., 2024)) |
| Aquathermal | Water-body thermal energy | (Kruit et al., 2018) |
| Biomass | Solid organic matter | (Gielen et al., 2019; Papadimitriou et al., 2023; Sansaniwal et al., 2017) |
| Biofuel | Liquid/gas biofuels | (Gielen et al., 2019; Bauer et al., 2020) |

*(continued on next page)*

| Category | Components | Literature References |
|---|---|---|
| **Conversion Technologies [C]** | | |
| P2X | Power-to-hydrogen/heat | (Gielen et al., 2019) |
| Heat Pump | Air-/ground-/water-source | (Staffell et al., 2012) |
| Electric Boiler | Resistance heating | (Papadimitriou et al., 2023) |
| CHP | Combined Heat & Power | (Calvillo et al., 2013; Papadimitriou et al., 2023) |
| Electrolyser | PEM/Alkaline/SOEC | (Götz et al., 2016; Papadimitriou et al., 2023) |
| Fuel Cell | SOFC /PEMFC | (Chien et al., 2011; Papadimitriou et al., 2023) |
| Combustion Engine | ICE generator | (Alanne and Cao, 2019) |
| Absorption Chiller | Heat-driven cooling | (Kayfeci and Keçebaş, 2019; Papadimitriou et al., 2023) |
| **Storage Systems [S]** | | |
| Battery Storage | Li-ion/Na-ion batteries | (Koohi-Fayegh and Rosen, 2020; Papadimitriou et al., 2023) |
| V2G | Vehicle-to-grid | (Kempton and Tomić, 2007) |
| Thermal Storage | Hot water tanks | (Koohi-Fayegh and Rosen, 2020; Papadimitriou et al., 2023; Pereira da Cunha and Eames, 2016 ) |
| Hydrogen Storage | Compressed gas/ LOHC | (Papadimitriou et al., 2023; Preuster et al., 2017) |
| CAES | Compressed Air Energy Storage | (Papadimitriou et al., 2023; Wang et al., 2017) |
| Molten Salt | Thermal storage | (Papadimitriou et al., 2023;) |
| Cold Storage | Phase-change materials | (Papadimitriou et al., 2023) |

A technical visualisation of the EHub system is shown in Figure 5.2, highlights the different energy flows within the system. It was inspired by the scheme made by (Papadimitriou et al., 2023) but adapted to an EHub in the built environment, and within the Dutch context.

Main changes include:

- Only focussing on RE,
- Removing Hydro due to local context of EHubs in the built environment,
- Adding grid electricity as an input due to the ehub in the built environment.

Figure 5.2 presents a schematic overview of all energy streams within an EHub. It is provided to given an overview of all possible configurations of carriers, assets and outputs an EHub can have.

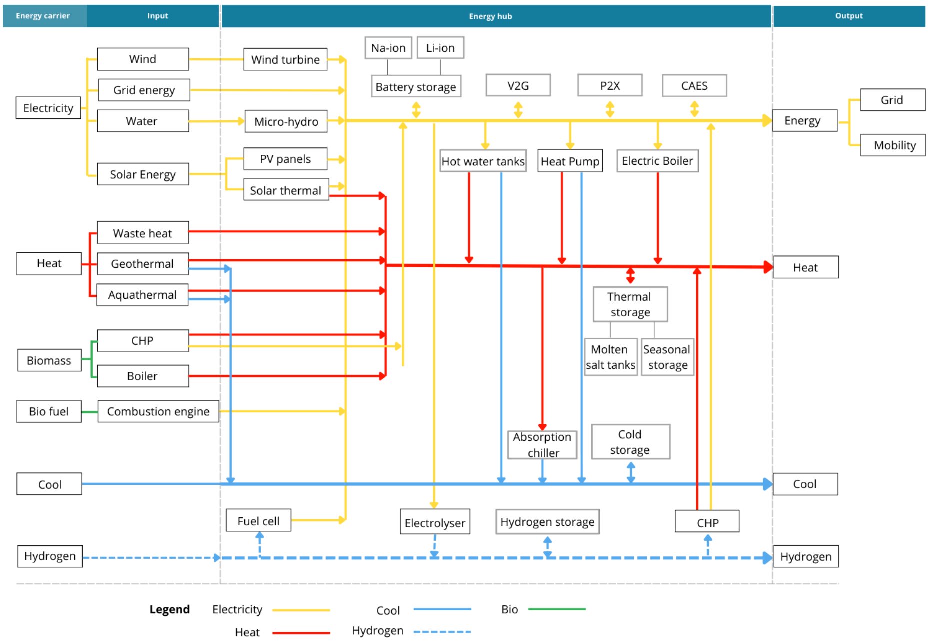


**Figure 5.2:** Schematic overview technical configuration Ehub (adapted from: Papadimitriou et al., 2023 * )

* See appendix for a larger visualisation.

## 5.3. Stakeholders

To provide a foundation for identifying the key actors involved in the development and realisation of an EHub within the built environment, insights were drawn from a broad review of relevant academic and grey literature. This was complemented by findings from exploratory interviews and observations from professional events related to the topic. A table with all identified stakeholders can be viewed on page 26.

| Stakeholder Category | Stakeholders | Role / Responsibility |
|---|---|---|
| **Regulators and Authorities** | European Commission<br>Ministry of Climate and Energy<br>ACM<br>Municipalities | Develop policy and legislation; issue permits; create incentives and subsidies; oversee market rules and local planning frameworks. |
| **Grid Operators** | Transmission System Operator (TSO)<br>Distribution System Operators (DSOs) | Manage national and regional grid infrastructure, oversee connections, system reliability, and congestion management. |
| **Project Developers** | Urban developers<br>Energy developers | Design and implement spatial and technical components of the area and EHub; coordinate stakeholders and delivery phases. |
| **Technology and Energy Service Providers** | Energy Service Companies (ESCOs)<br>EMS providers<br>PV/heat pump/battery installers<br>ICT firms | Provide, install, and maintain energy technologies; manage smart systems for load balancing and local optimization. |
| **Thermal and Mobility Operators** | WKO BVs<br>Mobility BVs | Operate local thermal grids (e.g., heating/cooling) and shared mobility services; coordinate energy flows with EHub systems. |
| **Consumers and Users** | Residents<br>Building owners<br>Housing associations | Use and co-invest in local energy infrastructure; shape demand profiles and system flexibility; participate via cooperatives. |
| **Financial Actors** | Banks<br>Private investors<br>Public subsidy providers | Fund infrastructure, share investment risk, evaluate viability of business models. |
| **Advisory and Legal Experts** | Consultants<br>Legal advisors<br>Strategic planners | Provide expertise on governance, legal frameworks, contracting, and compliance with energy regulation. |
| **Research and Knowledge Institutions** | Universities<br>Applied research institutes | Support modelling, technical validation, and policy-relevant knowledge production for scaling and innovation. |

**Table 5.2:** Overview of Stakeholder Categories, Key Actors, and Responsibilities in Energy Hubs (Author)

## 5.4. Life Cycle of an Ehub

The life cycle of an EHub follows a structure process to ensure the viabilaty. The process is shaped according to the following 4 phases (EIGEN, 2023) and is also used by the RVO (RVO, 2024) to explain the lifecycle of an EHub:


2

**Figure 5.3:** Life-cycle of an Ehub

1. **Exploration phase**
The first phase involves a preliminary assessment of the feasibility of establishing an Energy Hub. Key activities in this stage include stakeholder identification, preliminary data collection, opportunity assessment, and the preparation of a decision document. The goal is to determine whether the conditions and interests are suitable to proceed with development.

**2. Development phase**
Following the initial exploration, stakeholders collaboratively move into the development phase. This stage focuses on designing the technical and organizational structure of the EHub. It involves a detailed analysis of the local context, the development of multiple scenarios, and the formulation of a business case to assess financial and operational viability..

3. **Realization phase**
The realization phase encompasses the physical construction and commissioning of the EHub. Key activities include the deployment of infrastructure such as renewable energy systems, storage technologies, and grid connections. This phase also includes system testing and validation (e.g., interoperability and safety checks), as well as ensuring regulatory compliance and acquiring necessary permits.

4. **Exploitation phase**
The final phase focuses on the long-term operation, monitoring, and continuous improvement of the EHub. It includes asset management (such as performance tracking and maintenance), contract administration (including energy supply agreements and off-taker contracts), and ongoing optimization through strategies like demand response and efficiency enhancement.

## 5.5. Legal and Regulatory Context

### 5.5.1. European Legislation

**The Clean Energy Package (CEP)**
In November 2016 the European Commission initiated the 'Clean Energy for all Europeans' initiative. The package comprises eight individual regulations and directives that establish more ambitious targets for 2030 and introduce new mechanisms for energy efficiency, the use of renewable energy sources, and the functioning of the electricity market (van der Valk, 2019).

In 2019 the EU revised its energy policy framework to this new CEP to help move away from fossil fuels and more specifically, to deliver the EU's Paris Agreement commitments for reducing greenhouse gas emissions (European Commision, 2019c).

After the political agreement between the EU Council and the European Parliament was finalized in May 2019, and the new EU rules came into effect, member states were given 1 to 2 years to incorporate the new directives into their national laws through their National Energy and Climate Plans (NECPs).

The most relevant parts of the CEP for EHubs are listed:

1. Active participation of Consumers and Local Energy Sharing

   Directive (EU) 2019/944 on common rules for the internal market for electricity introduces the concept of the active consumer (also known as "prosumer"), defined as an end-user who not only consumes but also produces, stores, or sells electricity, either individually or collectively. Article 15 explicitly affirms the right of active consumers to operate in the market without being subject to disproportionate barriers or discrimination by network operators or suppliers (European Commision, 2019a).

2. Renewable Energy Communities

   The revised Renewable Energy Directive (EU) 2018/2001 (RED II) further strengthens the legal basis for local energy collaboration by introducing the concept of renewable energy communities (RECs). Article 22 of RED II grants RECs the right to produce, consume, store, and sell renewable energy, and to access all electricity markets on equal terms with traditional suppliers (Directive (EU) 2018/2001, 2018). Member states are required to establish enabling frameworks that remove regulatory and financial barriers for such communities.

3. Flexibility and Grid Integration

   A third key area relevant to energy hubs is flexibility provision. Regulation (EU) 2019/943 on the internal electricity market introduces a market framework for flexibility services, including demand response, storage, and distributed generation. Articles 6 to 13 outline requirements for non-discriminatory access to markets for all resources that can provide such services, regardless of size (European Commision, 2019b).

4. National Implementation and Legal Certainty

   The CEP obliges Member States to align national energy laws with its provisions, thereby structurally embedding previously experimental activities such as energy sharing and community-based generation, into the regular legal framework.

   For the Netherlands, this has led to the development of a new Energy Act (Energiewet), replacing the outdated Electricity Act of 1998. This legal shift removes the need for temporary pilots (e.g., the "experimentenregeling").

Under this new law one of the core innovations is the introduction and recognition of active consumers and energy communities. This is particularly relevant for the development of EHubs, which rely on active participation and local coordination of energy flows. The CEP promotes decentralized energy systems, which is a core feature of EHubs.
Furthermore, it can enable consumers to participate actively in the energy market, for instance by generating and trading renewable energy locally.

### 5.5.2. Dutch Legal Context

At the national level, the legal and regulatory framework in the Netherlands is undergoing significant transformation in response to the Clean Energy Package (CEP). The provisions outlined in the CEP, particularly those related to active consumers, renewable energy communities, and flexibility services, require Member States to align domestic legislation accordingly.

In the Netherlands, this has triggered the development of a new, integrated Energy Act (*Energiewet*), which will replace the outdated Electricity Act of 1998 (*Elektriciteitswet 1998*) and the Gas Act (*Gaswet*). This legislative reform signals a broader shift from a centrally organised, fossil-based energy system toward a more decentralised, participatory, and flexible energy landscape. It eliminates the need for temporary experimental frameworks, such as the experimentenregeling, by formally embedding previously pilot-based activities like energy sharing and community-led generation into the national legal structure.

This evolving regulatory environment is particularly relevant for EHubs, which typically operate at the intersection of multiple legal domains, including energy law, spatial planning, data governance, and consumer protection. EHubs depend on a coherent and enabling legal framework that supports decentralised energy production, peer-to-peer trading, and active participation by end-users.

The following section outlines the key Dutch legal instruments that govern, facilitate, or constrain the development and operation of EHubs in the built environment.

**The Energy Act (2024)**
The foundation of the Dutch energy market used to be the Electricity Act 1998 (NL: Elektriciteitswet 1998) and the Gas Act (NL: Gaswet). However, the Dutch government is currently in the process of replacing these acts by one single integrated Energy Act (NL: Energiewet). This reform reflects the need for increased flexibility and sustainability in the Dutch legislation (Tweede Kamer, 2023).

The former legal framework was developed in a context of centralized fossil-based energy production. However, with the rapid growth of renewable energy sources, local energy initiatives, storage technologies, and the emergence of new market actors (e.g., prosumers and aggregators) these laws have become outdated and fragmented. The new Energy Act aims to modernize and integrate the regulatory framework to better support a future-proof, sustainable, and reliable energy system.
Some of the key changes that are relevant for this research are:

1. Legal recognition of new collective energy models
2. Role of a legal entity
3. Legal grid flexibility and congestion management
4. Energy sharing and collective use
5. Data access and transparency.
6. Alignment with spatial planning and sustainability goals

**The Climate Act (Klimaatwet)**
In the Climate Act the Netherlands has registered that by 2035 the Netherlands must emit 49 percent less greenhouse gasses, compared to 1990 levels. By 2050 this number must be down by 95 percent. By writing it down as a law every kabinet must adhere to this goal (Rijksoverheid, 2019).

Under the Climate Act, the government is obliged to publish an annual Klimaatnota and a Climate Plan every five years, which increasingly reference the role of decentralized energy systems. Municipal and regional governments, via the Regionale Energie Strategieën (RES), are explicitly encouraged to support local energy innovation, including EHubs.

**Experimentation decree (Experiment regeling)**
In 2015 the Dutch government adopted a Crown decree for experiments with decentralized renewable electricity generation (Experimentation Decree) with the aim to generate insights on how to adjust the legal framework to enhance innovation in the legal framework to facilitate more innovation in the energy sector.

The scope of the project permitted experimenting with:

- Local energy trading (peer-to-peer electricity markets),
- Renewable energy collectives (exemptions from grid fees for cooperatives),
- Hybrid energy systems (e.g., integrating solar PV with battery storage).

The project ended in 2018, and the findings from the experiments informed the Dutch Energy Act (Elektriciteitswet 1998) amendments in 2018, which:

- Formalized rights for energy communities
- Simplified grid connection for decentralized projects

However, there are still legal barriers in the new Energy Act limiting the participation of households in EHubs.

**Light Licensing Scheme in the New Dutch Energy Act**
In response to the increasing role of citizen-led energy communities in the Dutch energy transition, the upcoming Dutch Energy Act (Energiewet) introduces a light licensing framework for local energy initiatives. This regulatory provision is intended to lower administrative and legal barriers for renewable energy communities and energy cooperatives, enabling them to supply electricity to their members without the need for a full supplier license.

According to the legislative draft (Tweede Kamer, 2023), cooperatives may be exempted from the supplier licensing obligation under the following conditions:

- The electricity supplied must be limited to what the cooperative itself generates within a given year.
- Delivery may only occur to members or shareholders of the cooperative.
- Recipients must have a small-scale connection </= 3×80 A, typically corresponding to residential or small commercial use.

This approach aligns with the European Union's Clean Energy Package, particularly Directive (EU) 2019/944, which mandates that Member States facilitate the development of energy communities and allow them to engage in energy supply, generation, and sharing (European Commision, 2019c). By implementing a lighter regulatory path, the Netherlands aims to promote greater participation in the energy transition while maintaining system reliability and consumer protection.

The legislative process for the Energy Act is ongoing, and the final conditions of the light licensing regime may be further refined. However, its inclusion in the draft marks a significant shift towards institutional recognition of community-based energy models within the national energy framework.

### 5.5.3. Incentives and Subsidies

**The Dutch Energy Hubs Incentives Programma (Stimuleringsprogramma Energiehubs)**
In 2024, the Dutch government launched the Energy Hubs Incentives Programme with a budget of €166 million to accelerate the development of local and regional energy hubs. The programme aims to foster a more decentralized, sustainable and flexible energy system by supporting collaborative projects that align local energy supply and demand through storage, conversion, and smart grid technologies (Ministerie van Economische Zaken en Klimaat, 2024).

The programme is structured across two levels:

- 15 percent of funds are allocated to national coordination, knowledge sharing, and strategic tools (e.g., the Energy Hub Roadmap).
- 85 percent supports local project development and capacity building in the regions.

Implementation is coordinated by multiple actors, including the Ministry of Climate and Green Growth (MKGG), regional governments (VNG), grid operators (NBNL), and development agencies (ROMs), with formal agreements outlined in the 2024–2030 parliamentary framework.

### 5.5.4. Legal frameworks for EHubs

The Netherlands holds a few legal structures for EHub implementation. An overview of the different types of contracts and collaboration models is made:

**Energy coöperation (Energie coöperatie)** A member-driven organization prioritizing local renewable energy generation and distribution (Bauwens et al., 2022). Governed under the Dutch Cooperative Act (Cooperatieve Wet), these cooperatives adopt democratic governance, where each member holds equal voting rights, and profits are reinvested into community projects (Bauwens et al., 2022).

**Collective Capacity Limiting Contract (Collectief Capaciteit Beperkend Contract - C-CBC)** This contract type offers a contractual mechanism for demand flexibility. Under this agreement, Ehubs commit to reducing peak-time energy consumption, thereby alleviating grid strain and avoiding costly infrastructure upgrades (Liander, n.d.). Grid operators like Liander and Stedin provide financial incentives for participation, making C-CBCs particularly attractive for industrial Ehubs (Autoriteit Consument Markt (ACM), 2022). This model highlights the growing role of contractual flexibility in balancing energy supply and demand in congested networks .

**Group Transport Agreement (Groeps-Transportovereenkomst, Groeps-TO)** A Group Transport Agreement (GTO) is a new type of contract that is currently under review with the Dutch Authority for Consumers and Markets (ACM) in their new grid code.

The contract is an arrangement between a group and the Distribution System Operator. The contract defines the collective transmission capacity of the group, known as the Group Transmission Volume (*NL:Gecontracteerd Transport Vermogen* - GTV). The group can then internally decide how to flexibly allocate that capacity throughout the day. The model is being explored to address grid congestion and support decentralized energy systems (RVO, 2024).

It is important to note that only large consumers can as of now be part of the GTO (so no residents). Moreover the GTV limit of the group is actually lower than the combined individual capacities of each participant as it is based on historical profiles (the GTV will represent between 60 and 80 percent of the total sum of the original individually contracted capacities. In exchange for this lower capacity the participants are allowed to use the capacity of the other participants at certain times. This arrangement is particularly beneficial for companies with limited individual capacities, which allows them to exceed their own limits as long as the overall group capacity is not exceeded (Wampack, 2024).

**Cable pooling**
Cable pooling is a concept introduced under the new Energy Act, enabling multiple energy installations to share a single grid connection. This typically involves the integration of various renewable energy sources, such as solar farms, wind farms, and battery storage systems. By combining these installations behind one grid connection, peak load moments can be mitigated, thereby allowing a greater amount of sustainably generated electricity to be fed into the grid (Autoriteit Consument & Markt (ACM), 2025).

The Dutch (ACM) actively supports this development, emphasizing that cable-pooling offers several key benefits. It optimizes the use of existing grid infrastructure, reduces connection and operational costs for participants, and accelerates the broader energy transition.

Specific conditions apply to these arrangements. A shared connection must have a minimum capacity of 100 kilovolt-amperes (kVA) and may include no more than four participants, each corresponding to a distinct property tax object (WOZ-object). These limitations are defined within the Energy Act and the accompanying Energy Decree (Autoriteit Consument & Markt (ACM), 2025).

The ACM is implementing these provisions in advance of the formal adoption of the Energy Act Autoriteit Consument & Markt (ACM), 2025. Additionally, the legislation requires that participants in a cable pooling arrangement act collectively as a single grid-connected entity. In practice, this is often facilitated through the ACM's framework known as Multiple Suppliers on One Connection (MLOEA), under which participants make internal agreements regarding the management of the shared connection and their access to the grid. The ACM explicitly provides regulatory space for such contractual arrangements.

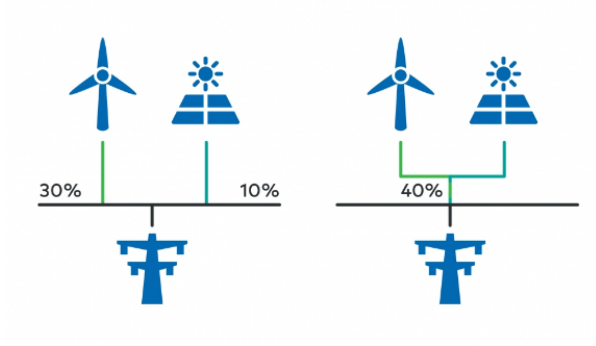


**Figure 5.4:** Cable-Pooling (Source: van de Vegte, 2021; Ines Cabral de Noronha e Menezes, 2025)

## 5.6. The Current Status of Energy Hubs in the Netherlands

In 2025 there were approximately 100 active EHubs in the Netherlands, many of which are situated on business parks (RVO, 2025a). This spatial distribution is not coincidental but rather a result of both regulatory flexibility and economic motivations. Businesses located in these areas face strong incentives to secure and expand their energy access in light of increasing grid congestion. By developing localized energy exchange systems such as Ehubs, companies can bypass the grid limitations set by ENO's and maintain their operational growth.

Deploying EHubs on business parks is generally less complex from a legal and regulatory perspective than an Ehub in the Built Environment. This is largely because they do not involve residential consumers, who under Dutch law must retain the freedom to choose their own energy supplier (Eerste Kamer, 2003). As soon as households are involved in an Ehub configuration, stricter regulatory frameworks apply to ensure consumer rights, such as supplier choice and consumer protection standards, which significantly increase the legal and technical complexity of implementation. Due to this, most Ehubs to date that reach the exploitation phase are implemented in industrial and commercial zones, where collective energy management faces fewer institutional barriers.

## 5.7. Conclusion

This chapter has offered a structured classification of micro-level EHubs, with particular attention to mixed-use EHubs, which form the focal point of this study. The analysis identified key stakeholders involved in the organization and operation of such hubs and examined a range of collaborative models as outlined in the existing literature. In addition, the chapter explored the life-cycle of EHubs, highlighting the dynamic processes involved from initiation to exploitation.
An important part of the analysis of EHubs in the Netherlands is the switching regulatory environment. With the new energy act that was accepted at the end of 2024 this creates a whole new legal landscape. This legislative shift redefines the organisational and operational parameters of energy hubs, thereby enhancing the relevance of this research within the context of emerging energy governance structures. The chapter concludes with an assessment of the current status of energy hubs in the Netherlands, offering a perspective of the practical realities, challenges and opportunities the development of EHubs are currently experiencing. This lays the necessary foundation for the rest of the study.

# 6
# Case study

This chapter presents three in-depth case studies on EHubs in area development projects:

- Merwedekanaalzone (Utrecht),
- Schoonschip (Amsterdam),
- Republica (Amsterdam).

These cases were selected for their diversity in scale, governance structure, development stage, and technical ambition. Offering a rich comparative lens on the implementation potential of EHubs under grid congestion conditions in the Netherlands.

To systematically analyse the cases, this research applies a thematic framework that focuses on four core dimensions: technical, organisational, legal and financial. Each of these dimensions plays a distinct and interrelated role in shaping the feasibility, performance, and replicability of EHubs in urban area development.

The technical configuration refers to the physical and digital design of the energy system, including the energy carriers used, the level of local generation and storage, the role of energy management systems (EMS), and the system's ability to balance loads within the neighbourhood. It directly affects the flexibility, scalability, and grid compatibility of the project.

The organisational configuration concerns how responsibilities, roles, and decision-making are distributed among stakeholders such as municipalities, developers, DSOs, and resident groups. It provides insight into coordination mechanisms, stakeholder alignment, and governance resilience, all of which are critical for long-term operational success.

The legal configuration focuses on the institutional arrangements and contractual structures that enable or constrain EHub implementation. This includes liability distribution, grid connection rights, cooperative models, and regulatory compliance. Legal clarity is often a prerequisite for risk acceptance and investment.

Finally, financial consideration was added inductively during the coding process. This is crucial for understanding the economic feasibility of EHubs. They include investment models, cost-sharing mechanisms, subsidies, and developer willingness to carry upfront risk. Given the inductive nature of this research, the financial dimension was not predefined as a core analytical category. However, it emerged consistently across the cases and is therefore addressed as a complementary theme, though not explored with the same depth or structural focus as the technical, organisational, and legal configurations.

Each case is first described through these three core dimensions. Providing a structural overview of the systems design, governance and regulatory context. This is followed by a cross-case analysis of these configurations to identify recurring elements and contextual differences. Following the case descriptions, the identified barriers and enablers are thematically grouped and listed per case. The chapter concludes with a cross-case comparison of these barriers and enablers, highlighting shared challenges, enabling conditions, and key lessons learned to inform the future design and implementation of EHubs in grid-congested area development projects.

## 6.1. Configuration of EHubs in Pilot Projects (SRQ3)

This subchapter addresses Sub-Research Question 3:

*"How are Energy Hubs configured in current pilot projects in terms of technical, organisational, and legal aspects?"*

The analysis begins with a case-by-case overview and then examines how each project adapts to its context across three key dimensions: technical infrastructure, organisational governance, and legal framework. The subchapter concludes with a cross-case synthesis, highlighting both shared features and context-specific configurations.

### 6.1.1. Case I - Merwedekanaalzone

**Figure 6.1:** Location Merwedekanaalzone (Author)

**Case overview**
The Merwedekanaalzone (commonly referred to as Merwede) is a large-scale urban transformation project located in Utrecht, the Netherlands. Subarea 5, the focus of this case, involves the redevelopment of a former industrial site into a mixed-use, high-density urban district. The project aligns with Utrecht's strategic goal of urban densification rather than spatial expansion.

The development will provide approximately 4,250 new homes and 65,000 m² of commercial and social facilities. Core design features include extensive greenspaces, car-free mobility infrastructure, and a high level of sustainability integration. The project began its planning phase in 2020, with construction expected to commence in 2025 and initial occupancy anticipated by 2027. Although still in development, it has progressed into the realization phase, offering valuable insights into integrated energy and mobility planning under grid constraints.

A key challenge the project faced was heavy grid congestion in the FGU-area (Flevoland, Gelderland and Utrecht). This resulted in the exploration of different solutions to grid congestion problems

**Data sources**
This case study is based on:

- Urban planning documents from the Municipality of Utrecht
- Internal technical and legal documents
- Semi-structured expert interviews with the technical advisor and DSO of this project.

**Technical configuration**
Merwede incorporates a district-wide EHub. The interlinked technologies used are:

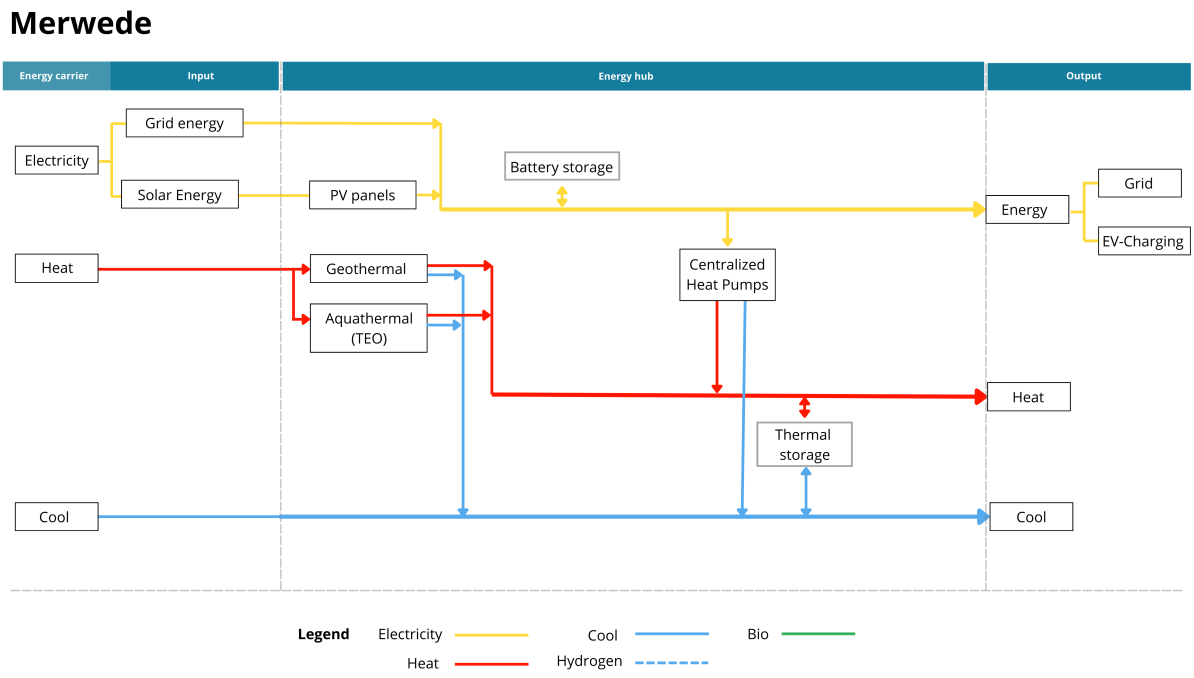


**Figure 6.2:** Technical Configuration Merwede (Author)

| | |
|---|---|
| Thermal grid | A low-temperature district heating and cooling system (DHC), based on aquathermal and geothermal sources (ATES), distributes energy across buildings. The system operates on ectogrid principles, allowing for intra-district energy exchange (Essent, n.d.). |
| Heat Pumps and Buffers | Eight central heat pump installations are supported by thermal storage tanks that shift heat production to off-peak hours. |
| Smart Electricity Use | Rooftop PV installations, smart EV charging hubs, and a district battery (BESS) enable demand-side flexibility. A central Energy Management System (EMS) coordinates generation, consumption, and storage in real-time. The system maximizes on-site generation and smart distribution of electricity. |
| Grid-Aware Load Management: | The design limits grid load to 5.2 MW, calculated based on a benchmark of 1.23 kW per dwelling. Large consumers (GVBs) are integrated into a shared-use arrangement via a pilot Group Transport Agreement (GTO). Their peak load under normal circumstance would already be 10MW. |

**Table 6.1:** Technical Configuration Merwede

Notably, peak loads from EV charging are shifted to off-peak hours (e.g., 4:00–10:00 PM cutoff), and vehicles may even return energy to the grid (V2G). This flexible configuration was critical given the severe grid congestion in the Utrecht regio.

**Organizational configuration**
Merwede demonstrates a hybrid governance model in which private developers and public actors, coordinated through a formal area development organization, collaborated from an early stage, prior to the emergence of grid congestion issues. This early partnership enabled the integration of mobility and energy systems into the district's spatial and technical design, laying a strong foundation for later coordination on energy resilience and grid-aware planning.

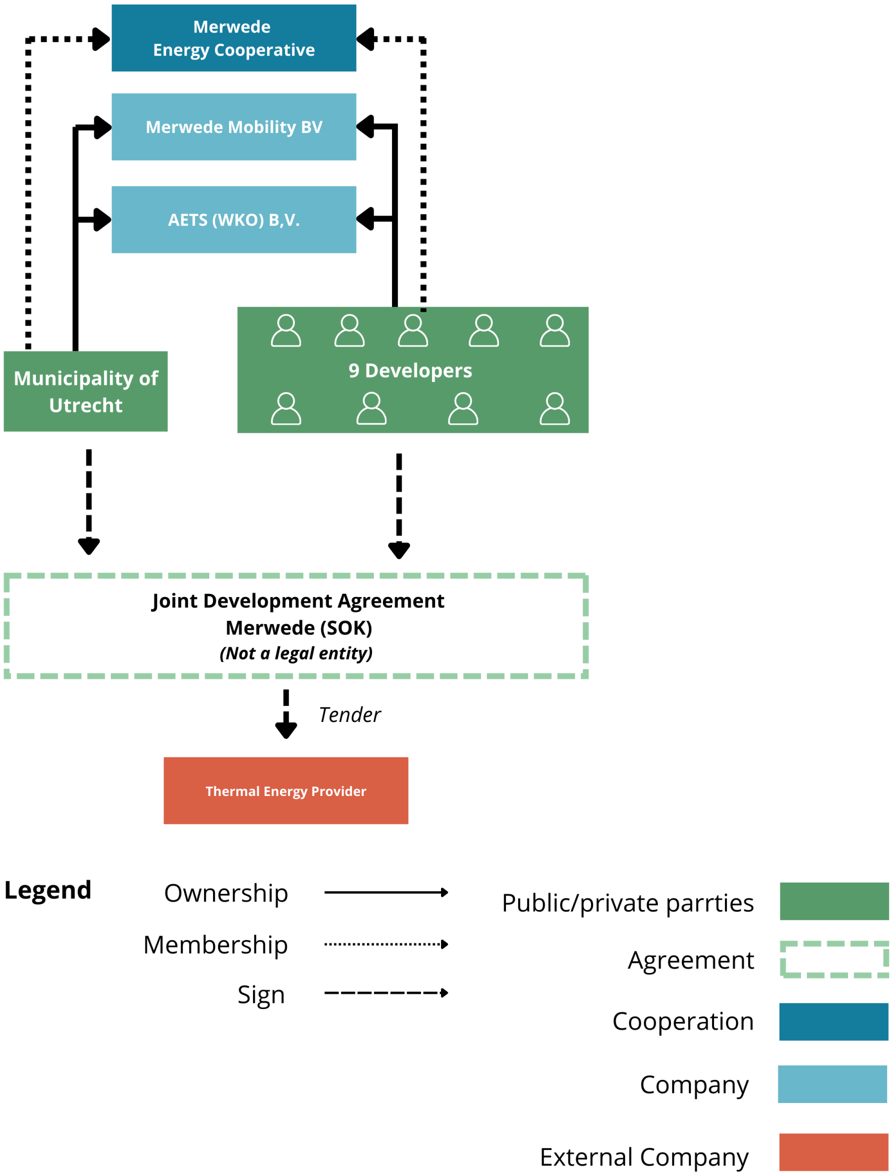


**Figure 6.3:** Overview Organisational Structure Merwede (Author)

**Key features include:**

Developer Cooperation: Nine private developers jointly manage energy and mobility infrastructure planning.

Municipal Facilitation: The City of Utrecht coordinates overarching energy and mobility goals but does not own the land. It plays a steering role by issuing spatial and energy guidelines (e.g., soil implementation plan, district heating plan).

Third-Party Actors: An array of technical, legal, and service partners are involved, including Essent (energy), a Congestion Service Provider (EMS), a Battery Service Company, and the DSO (Stedin).

A dedicated project lead was appointed by the municipality to manage the complex coordination challenges around energy systems and grid limitations.

**Legal and Policy framework**

The legal structure of Merwede centers on a pioneering use of the Group Transport Agreement (GTO). This mechanism allows large consumers to temporarily access unused grid capacity allocated to small consumers. Although small consumers are not parties to the agreement, their load profiles define available residual capacity.

**Key legal-political elements include:**

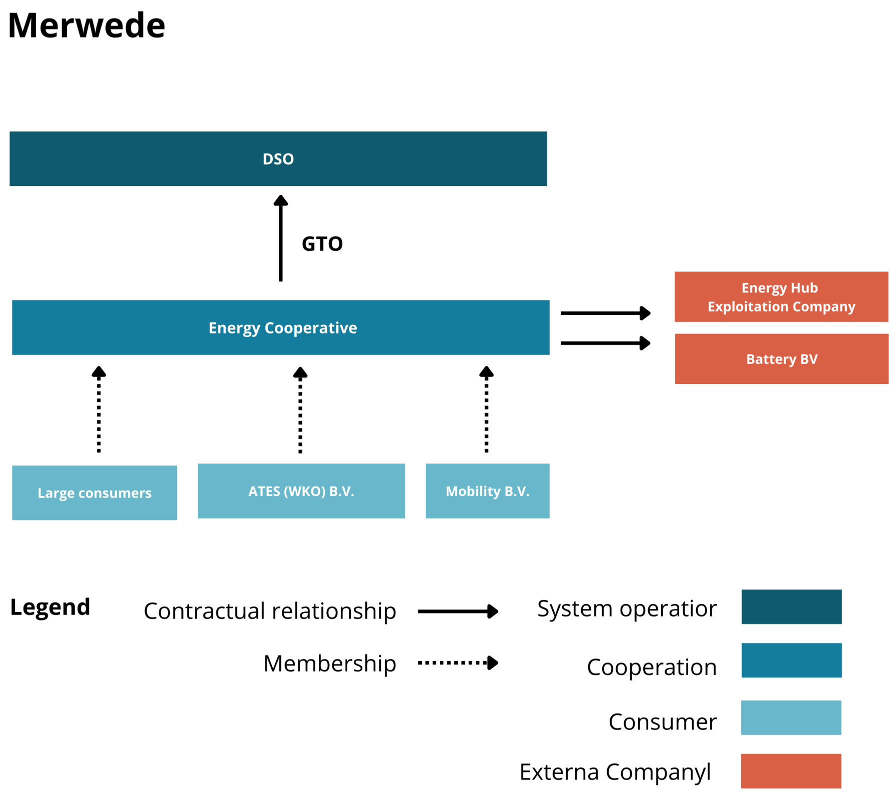


**Figure 6.4:** Legal Configuration Merwede (Author; Inspired by (Núna Energy, n.d.)

Municipal Co-Ownership in AETS B.V.: Dutch law requires municipalities to hold majority shares in local heat utilities. Utrecht holds equity in the WKO Merwede BV, enabling it to set operator requirements.

Contractual Innovation: The GTO represents a novel approach to managing grid congestion and is seen as a transferable model for other urban developments.

Policy Instruments: Predefined "energy principles" were integrated early into zoning and permitting to ensure grid-conscious development.

The municipality in cooperation with the developers also prioritized interventions along a "ladder of preferred solutions": 1. Energy efficiency

2. Load shifting (demand-side management)
3. Seasonal energy storage
4. Day-scale storage of local renewables

Non-preferred:

5. Fossil-based generation
6. Connecting to the HT/MT heat grid
7. Use of gas generators
8. Postponing development

**Case-specific insights:**
Grid Congestion as a Trigger for Innovation: Regional and national DSOs lacked capacity for new large-scale connections. This constraint led to systemic innovation in area energy planning.

High-Level Collaboration: A pre-existing cooperative structure among developers, aided by municipal coordination, enabled early-stage decisions on collective energy and mobility infrastructure.

Scalable Legal Frameworks: The GTO pilot has sparked national interest as a model for shared energy contracting under constrained grid conditions.

Systemic Design Decisions: Assigning each dwelling a fixed peak demand budget created technical boundaries that all developers had to design within. This enforced energy-aware architectural and engineering decisions from the outset.

### 6.1.2. Case II - Schoonschip

**Figure 6.5:** Location Schoonschip (Author)

**Case Overview**
Schoonschip (Dutch for "Clean Ship") is a pioneering all-electric floating neighborhood located on the Johan van Hasseltkanaal in Buiksloterham, Amsterdam North. The project transformed a disused industrial canal into a 47-household water-based residential community, designed with sustainability, energy self-sufficiency, and circularity at its core. Initiated in 2010 by a group of future residents and officially completed in 2021, Schoonschip is widely regarded as one of the most advanced residential micro-grid communities in Europe.

Schoonschip's layout consists of houseboats moored around a central jetty, which physically integrates critical infrastructure for electricity, water, and waste. Despite national regulations prohibiting private grid ownership, Schoonschip operates under the Dutch Experimentation Decree, allowing legal exemptions for innovative energy projects. This enabled the development of a private smart grid owned and operated collectively by the community.

**Data Sources**
This case study draws on:

- Technical documentation from the project team and energy trading partners
- Policy and legal analyses related to the Experimentation Decree
- Interviews with Technical Advisor and lawyer
- Publicly available project reports and academic publications

**Technical Configuration**
Schoonschip's energy system exemplifies decentralized, smart-grid design. An overview of the technical configuration is shown in Figure 6.6.

Key technical features include:

## Schoonschip

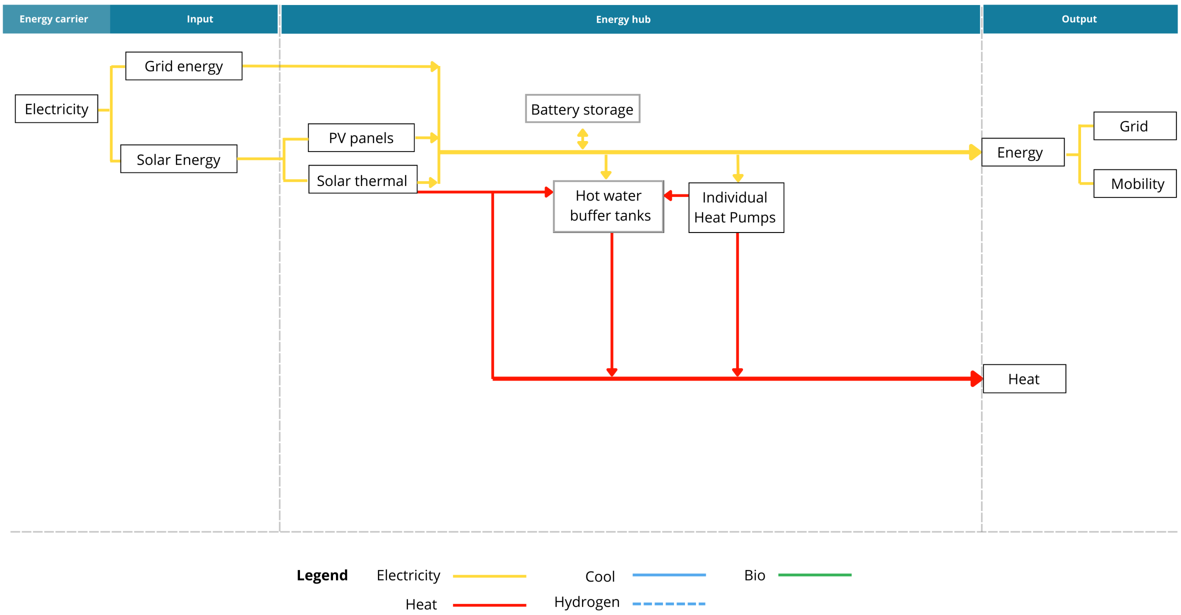


**Figure 6.6:** Technical Configuration Schoonschip (Author)

| | |
|---|---|
| Solar Photovoltaics (PV) | Over 500 solar panels installed across rooftops generate the primary electricity supply. |
| Battery Storage | 30 household-level battery systems provide storage and support energy balancing. A plan for a single central battery was initially considered but later replaced with a distributed design for improved autonomy and control. |
| Heat Pumps & Solar Thermal | Each home uses a water-source heat pump for space heating and passive summer cooling. Solar thermal collectors preheat domestic hot water, reducing the electricity load on heat pumps. |
| Smart Grid Infrastructure | All homes are connected to a private internal electricity network with a single external grid connection, enabling real-time peer-to-peer energy exchange within the community. |
| Energy Management System (EMS) | The EMS coordinates generation, storage, and consumption. It includes forecasting algorithms and adaptive control systems to shift consumption based on solar availability and price signals. |
| Virtual Power Plant (VPP) | Since January 2025, the neighborhood operates as a VPP, actively participating in the day-ahead, intraday, and national imbalance markets. Batteries are aggregated and bid into the grid's flexibility mechanisms through a third-party energy trader. |

**Table 6.2:** Technical Configuration Schoonschip

The EMS implements seasonally adaptive strategies. In winter, priority is given to peak shaving; in summer, the system maximizes on-site consumption. The smart grid is capable of throttling or curtailing PV output to avoid micro-grid overload, while surplus solar energy can be exported or stored for strategic use.

The system also supports energy arbitrage, whereby electricity is purchased from the national grid when prices are low and discharged when prices are high. This capability not only supports household demand but also generates revenue for the cooperative through frequency regulation and real-time balancing services.

**Organizational Configuration**
Schoonschip's governance was initiated from the bottom up. A group of future residents formed the Schoonschip Foundation and later a housing corporation to plan and manage the development. The initial vision was collective self-building, though this proved too complex, and each household eventually hired its own contractor. Despite this, shared systems and governance mechanisms were maintained.

A key organizational actor is the VvE Schoonschip (homeowners' association), which acts as the internal energy supplier and grid operator. This entity manages metering, billing (via monthly invoice spreadsheets), and contracts with external technical advisors. The Schoonschip Energy cooperative works closely with the EMS operator, who oversees real-time system control and optimization.

**Key project actors:**

- Municipality of Amsterdam
- Distribution System Operator (DSO)
- Architecture firm: Space & Matter
- Technical manager/EMS operator
- VvE Schoonschip (residents' cooperative)
- Stichting Schoonschip (foundation)
- Third-party energy trader (imbalance market participation)

**Legal and Policy Framework**
Schoonschip operates under the Dutch Experimentation Decree, which allows temporary legal exceptions to energy regulations for innovative pilots. This exemption made it legally permissible for the community to establish a private internal electricity network, despite national prohibitions on grid ownership by non-licensed parties. The configuration between residents, the community, and the DSO can be seen in Figure 6.7.

Further legal characteristics include:

Energy Community Model: Schoonschip functions as an energy community under emerging EU-aligned Dutch frameworks, emphasizing citizen-led generation and use.

VvE as Supplier: The VvE is formally registered as the internal energy supplier, handling both operational and commercial aspects of the system.

Public Subsidy Dependency: The project was heavily reliant on public funding, as it was not backed by a profit-driven developer. Subsidies were essential to offset the costs of infrastructure, R&D, and coordination.

The project also serves as a legal and policy learning site, demonstrating the potential for citizen-led, microgrid-based developments under evolving energy law.

**Case-Specific Insights**
Early Adoption of Peer-to-Peer Trading: Schoonschip implemented decentralized electricity trading and household-level storage years ahead of national regulation.

Flexibility as a Revenue Stream: Participation in the imbalance market through battery aggregation represents a novel financial model for residential communities.

Legal Innovation Through Experimentation Decree: The ability to legally operate a private grid highlights the importance of regulatory sandboxes for urban energy innovation.

Citizen Governance and Bottom-Up Planning: While the self-build model was eventually decentralized, the project retained a high degree of resident engagement and ownership, which proved critical to its long-term coherence and adaptability.

Since 2024, all solar inverters, batteries, and heat pumps in the neighborhood are centrally coordinated through a Virtual Power Plant (VPP). The VPP enables real-time load balancing, market participation, and local congestion management.

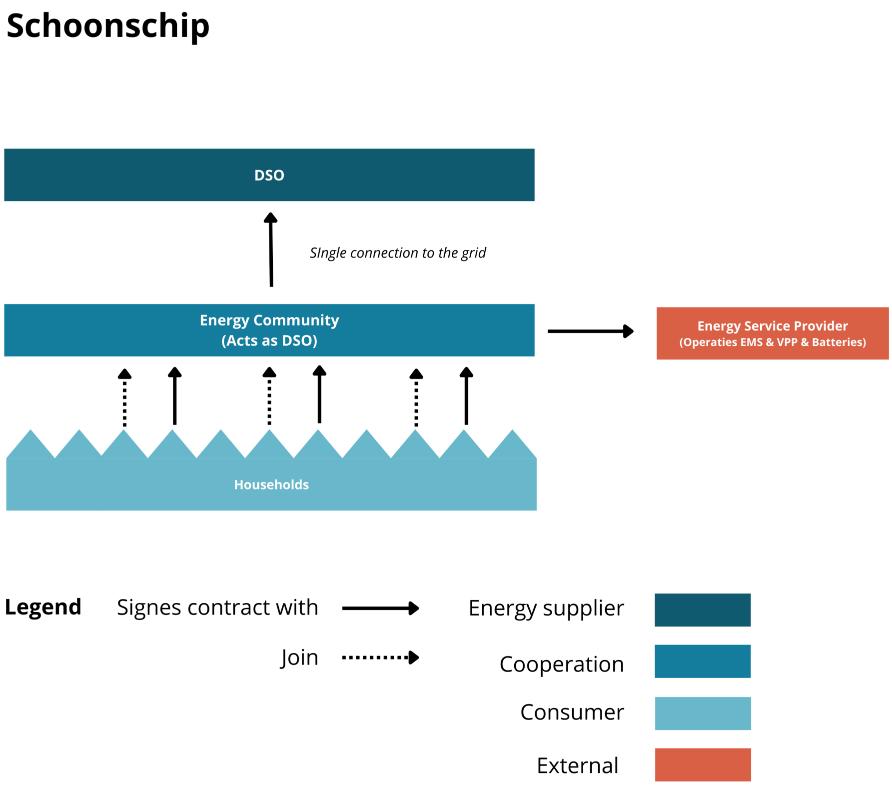


**Figure 6.7:** Legal Configuration Schoonschip (Author)

### 6.1.3. Case III - Republica

**Figure 6.8:** Location Republica (Author)

**Case overview**
Republica is a mixed-use urban development located in Buiksloterham, Amsterdam North. It is one of two designated Positive Energy Districts (PEDs) in the city under the EU Horizon 2020 project ATELIER (Atelier Positive Energy Districts, 2024). Republica exemplifies the ambition of PEDs: to generate more renewable energy annually than is consumed on-site. Situated in a district known for experimentation with sustainability and circularity, the Republica complex includes six buildings that combine 74 residential units with commercial functions such as office spaces, a hotel, and hospitality venues, totalling over 20,000 m².

Construction began in 2021 (following delays due to the COVID-19 pandemic) and was largely completed in 2024. From the outset, Republica encountered a key infrastructural challenge: limited grid connection capacity. The local DSO could initially only offer 1.5 MW of connection, though the calculated peak demand was closer to 2.0 MW. This limitation catalyzed an integrated design approach that included smart controls, on-site generation, thermal storage, and battery-based flexibility, enabling the entire district to function within the 1.5 MW limit.

Republica operates a private micro-grid and acts as its own internal energy supplier, managing power distribution and supply within the site. Despite this, the system is not fully peer-to-peer but centrally managed through a cooperative tied to the building ownership structure.

**Data Sources**
This case study is based on:

- Technical reports from ATELIER and Republica partners
- Design documents from the developer and energy consultants
- Interviews with the technical advisor.
- Regulatory documentation concerning Dutch energy law and grid contracts

**Technical Configuration**
An overview of the multi-energy carrier system for Republica is show in Figure 6.9.

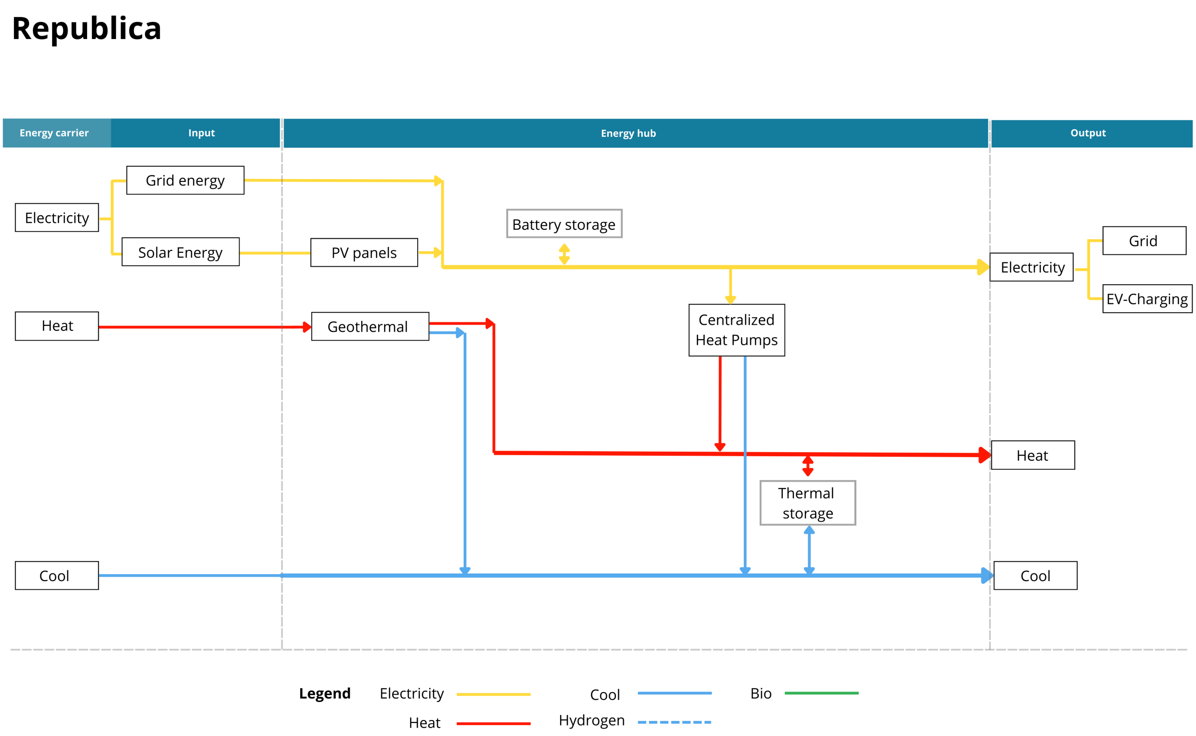


**Figure 6.9:** Technical Configuration Republica (Author)

Republica's energy system integrates multiple technologies into a microgrid-enabled PED architecture:

| | |
|---|---|
| Solar PV Panels | Installed on most rooftops, supplying renewable electricity to the site. Some roofs also serve as green infrastructure or host HVAC systems. |
| Microgrid | All six buildings are linked by a private electricity network with a few points of common coupling to the public grid. This design allows for local balancing and resource sharing, including collective use of the battery and solar generation. |
| Battery Storage | A 1,2 MWh stationary battery located in the basement of one building provides peak shaving, load shifting, and energy market participation. A second smaller battery is installed for added flexibility. |
| Seasonal Thermal Storage | An integrated ATES (WKO) system enables seasonal balancing of thermal demand. Low-temperature groundwater is used to cool buildings in summer and preheat space heating in winter. Heat pumps upgrade this thermal energy to usable levels for domestic hot water and space heating. |
| Energy Management System (EMS) | The EMS oversees all generation, storage, and consumption. At the building level, local building management systems (BMS) manage HVAC, thermostats, ventilation, and EV charging. The EMS can send commands to modulate loads (e.g., pre-cooling offices or shifting EV charging). |
| Demand Response: | The EMS includes smart algorithms to align building consumption with generation and market price signals. This helps maintain the 1.5 MW cap while enabling participation in dynamic pricing schemes. |

**Table 6.3:** Technical Configuration Republica

The system is also designed to support future participation in congestion management programs, making it adaptable to national regulatory changes or grid service opportunities.

**Organisational Structure**
The development of the EHub in Republica followed a top-down, developer-driven approach, contrasting with grassroots projects like Schoonschip. The energy strategy was embedded early in the real estate development phase, ensuring integration of energy infrastructure into the financial and legal structure of the project.

**Key organizational features:** Energy Cooperative: Established to manage the energy system, the cooperative acts as both micro-grid operator and energy supplier to residents and tenants. While Dutch law allows residents to opt for a different external supplier, most remain within the system.

Technical Service Company: Handles billing and EMS functionality. Metering is performed externally by specialists.

Developer Role: The project developer prioritized innovation as a market differentiator but also faced challenges due to limited energy expertise, lack of coordination, and underestimated system complexity.

Market Participation Constraints: Although the system technically supports local energy exchange, the operator often prioritizes feeding excess solar energy back to the grid when financially advantageous, resulting in underutilization of the battery and limited internal sharing.

**Key project actors include:**

- Real estate developer
- Municipality of Amsterdam
- Local energy cooperative (internal supplier and grid operator)
- Technical advisors and EMS operator

- DSO (grid connection contract holder)
- National regulator (ACM)
- Energy services provider for battery operation and market interface
- Commercial tenants (hotel, restaurant, offices)

**Legal and Policy Framework**
Republica operates within conventional Dutch energy law but leverages creative interpretations to function as a semi-autonomous energy district.

Key legal elements include:

Private Grid Operation: The site functions as a private electricity network with internal supply arrangements, avoiding the need for separate grid connections for each building.

Energy Cooperative: Legally structured to represent property owners and manage supply, billing, and maintenance. Residents have the legal right to opt out but typically remain within the cooperative structure. The relation between the Cooperation and the DSO, Consumers and External Energy Service provider is show in Figure 6.9.

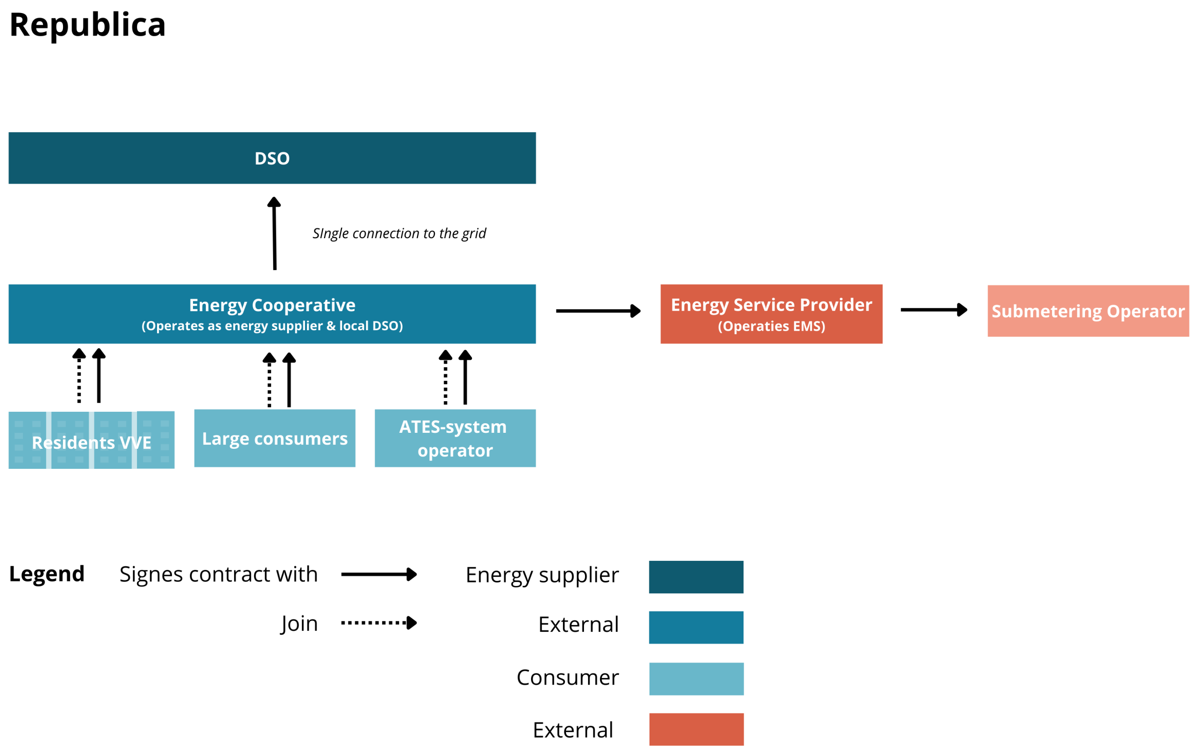


**Figure 6.10:** Legal Configuration Republica (Author)

Grid Connection Strategy: The site maintains a single connection contract with the DSO. The cooperative holds this contract, with all internal metering and energy balancing managed internally.

Despite technical capabilities, energy exchanges within the system do not yet qualify as peer-to-peer under current regulation. Instead, all flows remain under a central supply contract.

**Case-specific Insights**
Grid Constraint as Design Driver: Republica's energy system was shaped by a restrictive 1.5 MW grid cap. This encouraged early integration of thermal storage, battery systems, and building-level demand flexibility.

Developer-Led Integration: Energy was embedded into Republica's real estate and financial model from the outset, ensuring alignment between building function and energy system performance.

Institutional Simplicity with Trade-Offs: A single internal supplier simplifies operations but constrains experimentation with peer-to-peer trading and user autonomy.

Battery Utilization Gaps: While technically capable, the battery systems was underused.

Scalable Lessons: Republica demonstrates that positive energy and grid-conscious design is feasible in commercially driven real estate projects, but requires early coordination, technical expertise, and appropriate regulatory conditions.

## 6.2. Cross-case Analysis Configuration(SRQ3)

To answer Sub-Research Question 3 :

*"How are Energy Hubs configured in current pilot projects in terms of technical, organisational, and legal aspects?"*

A cross-case analysis was conducted across the three case studies.
This analysis begins by comparing the key technological components across the projects to identify recurring elements that may constitute the foundational configuration of an EHub in urban developments.

**Table 6.4:** Cross-Case Comparison of Key Energy Technologies (Author)

| Technology Category | Merwede | Schoonschip | Republica |
|---|---|---|---|
| Solar PV | ✓ | ✓ | ✓ |
| Battery Storage | ✓ | ✓ | ✓ |
| ATES | ✓ | x | ✓ |
| Ectogrid | ✓ | x | ✓ |
| Heat Pumps | ✓ | ✓ | ✓ |
| EMS | ✓ | ✓ | ✓ |
| VPP | x | ✓ | x |
| Smart EV Charging | ✓ | x | x |
| Shared Mobility | ✓ | ✓ | ✓ |

All three cases make use of: Solar PV, Battery storage, Heat pumps (centralised or per home), EMS, Shared mobility.

The comparison shows that all three projects employ a consistent core of technologies: solar PV, battery storage, heat pumps, energy management systems (EMS), and shared mobility solutions. These appear to be foundational for the technical realization of Energy Hubs in area-based development and can be considered baseline components for replicability.

Table 6.5 presents a cross-case comparison, compiled by the author, that integrates key organisational, legal, and implementation characteristics. This comprehensive overview highlights enabling and constraining factors across the different cases.

### 6.2.1. Conclusion

The cross-case analysis of Merwede, Schoonschip, and Republica highlights how EHubs are configured through the interplay of technical systems, organisational arrangements, and legal frameworks, each adapted to the context-specific opportunities and constraints of the project.

Technically, all three pilots share a common core configuration comprising solar PV, battery storage, heat pumps, and energy management systems (EMS). These technologies form the backbone of Energy Hub functionality, enabling self-generation, flexibility, and real-time load coordination. Organisationally, the governance models diverge substantially. Legally, innovation was necessary in all cases to allow collective or private grid operation. These legal instruments proved essential in overcoming structural regulatory barriers.

**Table 6.5:** Summary Comparison of Urban Energy Innovation Cases (Author)

| Attribute | Merwede | Schoonschip | Republica |
|---|---|---|---|
| Scale | Large distric-scale<br>4250 households, 65.000m² commercial/social) | Small-scale<br>47 households | Medium-scale<br>74 households, 20.000m² commercial/social |
| Governance Model | Hybrid public-private, Energy cooperative with GVBs | Bottom-up energy cooperative initiated by residents | Developer-led cooperation with VvE & utility partnerships |
| Legal Framework | Group Transport Agreement (GTO), municipal co-ownership in DHC | Experimentation Decree (private grid ownership) | Experimentation Decree (private microgrid and internal supplier) |
| Grid Constraint Strategy | Load budgeting per dwelling; 5,2 MW cap;<br><br>EMS that coordinates heating, mobility, battery systems to stay within contracred capacity; Load shifting V2G | Strict 130 kW cap;<br><br>High local self-generation (solar PV), distributed home batteries, and a smart EMS that enables real-time load balancing, demand response, and participation in energy markets via a Virtual Power Plant (VPP). | 1.5 MW cap;<br><br>Managed by combining a local microgrid, centralized battery storage, thermal energy exchange (ATES), and building-level EMS control to balance loads, maximize on-site consumption, and reduce peak demand. |
| Market Participation | Limited/planned | Active (day-ahead, imbalance) | Limited; Underutilized potential |
| Replicability | Moderate<br>(scalable under similar conditions) | Low<br>(unique governance/legal setup) | Moderate<br>(scalable under similar conditions) |

The three pilot projects demonstrate that EHubs are configured through a combination of technical flexibility, governance alignment, and legal adaptability. While all projects share core technologies (e.g., solar PV, heat pumps, EMS), their implementation is shaped by the organisational model and legal possibilities. Hybrid, cooperative, and developer-driven models each offer viable paths depending on the planning context. Importantly, early integration of energy considerations in urban design, backed by enabling legal frameworks, appears to be a decisive factor in successful Energy Hub implementation.

EHubs in these pilot projects are configured as context-specific combinations of core technical systems (solar PV, EMS, storage, and heat pumps), tailored organisational structures (public-private, cooperative, or developer-led), and enabling legal frameworks (GTO or Experimentation Decree). While the core technology is similar across all cases, the governance model and legal arrangements fundamentally influence how Energy Hubs are planned, operated, and scaled. The analysis demonstrates that successful Energy Hub implementation requires not only technological innovation but also early-stage institutional alignment and legal adaptability.

## 6.3. Thematic coding - Data analysis (SRQ 4)

This section presents the results of the empirical data analysis addressing Sub-Research Question 4:

*SRQ 4: What technical, organisational, legal, and financial barriers and enablers affect the implementation of Energy Hubs in these pilot projects?*

To answer this question, a series of semi-structured expert interviews were conducted across three selected Energy Hub pilot projects. The interviews were thematically coded using a hybrid framework that combined deductive categories drawn from the literature with an inductively added theme. In addition, codes for descriptive insights and lessons learned were included to capture contextual richness and forward-looking reflections.

| **Actor** | **Merwede** | **Schoonschip** | **Republica** |
|---|---|---|---|
| Technical Advisor | ✓ | ✓ | ✓ |
| DSO | ✓ | – | - |
| Legal Advisor | - | ✓ | ✓ |

**Table 6.6:** Experts interviewed per case

The analysis aims to identify the barriers that constrain implementation and the enablers that support it, as perceived by those directly involved in the projects. Given the novelty of Energy Hubs in the Dutch spatial and energy planning context, this approach enables a grounded understanding of what factors matter most in practice, beyond abstract design principles.

Each case is analysed in a dedicated subsection, with barriers and enablers grouped thematically. Although the financial configuration was not predefined as a core category, it emerged consistently across the interviews and is therefore discussed as a complementary theme. The findings are supported by visual summaries and concluded with key takeaways from each interview.

This structure allows for a clear, case-based insight into the dynamics of EHub implementation and sets the stage for the cross-case comparison in the following section.

### 6.3.1. Case 1: Merwede - Barriers and Enablers

The Merwede development presents a technically and institutionally complex case, in which multiple stakeholders aim to implement a highly integrated and sustainable energy system. The project applies an Energy Hub model that combines collective electricity, thermal, and mobility systems within a dense urban environment.

The barriers and enablers in Figure 6.11 were identified from the interviews. A more broad description of every barrier and enabler is added in appendix B.

**Technical Dimension**

The technical challenges at Merwede were primarily related to the unpredictability and rigidity of the energy system design due to the scale and phased nature of the development. A key barrier was forecasting uncertainty, where demand projections across a 10-year construction timeline complicated accurate system sizing and infrastructure planning. In addition, large-scale energy users, such as supermarkets and student housing, were identified as difficult to shift or steer, thereby reducing the system's flexibility.

Another challenge was the lack of access to real-time grid data, which limits DSOs' and developers' ability to model and adapt system design to actual grid performance. Furthermore, strict capacity limits (e.g., the 5.2 MW ceiling for the area) posed operational risks and required complex balancing interventions.

Despite these constraints, Merwede benefited from several enabling factors. The centralised thermal energy system, designed for heating and cooling, created a predictable and high-load profile, simplifying system coordination. Combined with thermal storage, this allowed for effective peak shaving. Similarly, high-density residential profiles offered more predictable energy usage patterns, improving modelling accuracy. The deployment of automated monitoring and control systems (EMS) further enabled responsive management of grid load, while new

**Organisational Dimension**

| Themes | Type | Label |
|---|---|---|
| Technical | Barrier | Forecasting_uncertainty |
| | Barrier | Inflexible_large_consumers |
| | Barrier | No_grid_data_acces |
| | Barrier | Grid_capacity_limit |
| | Enabler | Centralised_solution |
| | Enabler | Predictable_profiles |
| | Enabler | EMS |
| | Enabler | Regulatory_support |
| Organisational | Barrier | Complex_stakeholder_coordination |
| | Barrier | Late_involvement_technocal_adviso |
| | Barrier | Stakeholder_dependency |
| | Barrier | Slow_Development |
| | Enabler | Stakeholder_collaboration |
| | Enabler | Cooperation |
| | Enabler | Joined_procurement |
| | Enabler | Win_win_framing |
| | Enabler | Technical_advisor |
| | Enabler | DSO_recignition_nonresidential |
| | Enabler | Willingness_DSO |
| Legal | Barrier | Legal_liability_risk_DSO |
| | Barrier | Legal_liability_risk_Developer |
| | Barrier | Lack_of_legal_instrument |
| | Enabler | Cooperation |
| | Enabler | Obligation_connecting_dwellings |
| | Enabler | Pre_contracted_load |
| | Enabler | Pilot |
| Financial | Barrier | High_upfront_investment |
| | Barrier | Stakeholder_dependency |
| | Barrier | Stakeholder_dependency |
| | Enabler | Pre_contracted_load |
| | Enabler | Commitment_stakholders |
| | Enabler | Flexibility |

**Figure 6.11:** Merwede - Barrier & Enablers (Author)

Organisationally, Merwede had to coordinate a large number of actors, which led to complex stakeholder coordination and difficulties in maintaining shared commitment over the course of the lengthy development process (slow development). The late involvement of technical experts due to siloed institutional practices further weakened early energy system decisions. Moreover, there was high dependency on a small number of key stakeholders (e.g., municipality and mobility provider), which made the project vulnerable to strategic withdrawal.

The case also demonstrated enablers. The presence of a pre-existing area organisation facilitated joint procurement of heating and mobility infrastructure and allowed for the coordinated use of a Group Transport Agreement (GTO). Close cooperation between the municipality and developers contributed to shared commitment and scale. A pivotal enabler was the early involvement of a technical advisor with project management experience, who helped frame a win-win narrative and align technical ambitions with broader development goals. Additionally, the DSO demonstrated both recognition of the need to include non-residential loads (such as supermarkets) and willingness to enable the pilot, both of which were crucial to unlocking the GTO contract structure.

**Legal Dimension**

Legally, Merwede faced multiple uncertainties. A key barrier was the lack of legal clarity regarding liability in shared grid configurations, which caused risk aversion among DSOs. Additionally, the developer consortium faced contractual liability if energy usage exceeded contracted capacity, a significant risk in a system where peak demand is distributed and hard to predict. The absence of specific legal instruments for EHubs prior to the ACM's policy changes also created early ambiguity.

Yet these legal risks were counterbalanced by strong enabling conditions. The creation of a legal cooperative allowed shared responsibility and clear contractual arrangements among stakeholders. The legal obligation of DSOs to connect residential dwellings ensured a baseline level of infrastructural commitment. Importantly, the pre-contracting of capacity for the area provided legal and operational certainty, avoiding the typical waiting-list issues. Finally, the municipality's willingness to support legal experimentation through a pilot arrangement enabled the project to proceed in the absence of a complete regulatory framework.

**Financial Dimension** Financially, Merwede encountered typical barriers associated with large-scale

innovation. The project required high upfront investments for infrastructure and energy storage while grid connection rights were still pending. Furthermore, there was financial dependency between

stakeholders, particularly regarding shared infrastructure and investment risks, increasing overall coordination complexity.
Nevertheless, proactive steps were taken to mitigate these risks. The GTO framework allowed for early contracting of grid capacity, which reduced long-term uncertainty. The developer consortium's willingness to invest upfront—with one party (Leaf) financing the battery system—demonstrated strong project commitment. Finally, the design's emphasis on load flexibility was seen as critical for future affordability, giving users the option to strategically time energy use and reduce peak charges.

**Key takeaways:**

- Strong organisational foundation was a success factor. Merwede had a high level of institutional organisation early on, which enabled joint procurement and aligned ambitions, key to making the EHub viable.
- Technical foresight and integration of EMS and thermal systems provided crucial load management benefits.
- The role of a skilled and trusted technical advisor was central—one who not only brought technical expertise but could also coordinate between parties, frame shared value, and drive implementation.
- DSO engagement was unusually proactive, demonstrating that innovation is possible within traditional institutions when aligned with broader spatial and political priorities.
- Legal risk remains a concern, particularly around liability and lack of established frameworks. However, regulatory progress (e.g. ACM policy changes) shows institutional learning is occurring.
- Financial commitment depended on early certainty. The GTO reduced risk and enabled pre-investment in systems like batteries, which was essential given long timelines and uncertain returns.

### 6.3.2. Case 2: Schoonschip - Barriers and Enabler

| Themes | Type | Label |
|---|---|---|
| Technical | Barrier | Lack_of_standardization |
| | Barrier | Small_scale_implimentation |
| | Barrier | Decentralize_solutions |
| | Enabler | EMS_integration |
| | Enabler | EMS_refinemens |
| Organisational | Barrier | Unclear_Roles |
| | Barrier | User_autonomy_design |
| | Barrier | Time_intensive_support |
| | Enabler | Stakeholder_collaboration |
| | Enabler | Early_enagement_technical_advisor |
| | Enabler | Residents_ technical_knowledge |
| | Enabler | Close_collaboration |
| Legal | Barrier | Future_legal_uncertainty |
| | Barrier | Permitting_constrain |
| | Enabler | Cooperation |
| | Enabler | VPP |
| Financial | Barrier | Decentralized_solutions |
| | Barrier | Limited_scalability |
| | Enabler | Subsidies |
| | Enabler | Innovation_added_value |

**Figure 6.12:** Schoonschip - Barriers & Enablers (Author)

**Technical** Schoonschip's technical configuration faced several challenges rooted in its decentralised setup.

The absence of standardisation across residential installations led to inconsistent system integration and maintenance complications. Initial restrictions on placing a central battery forced the use of decentralised storage solutions, which were less efficient. This also led to technical complaints, such as battery noise near bedrooms, placing a burden on the EMS operator (Spectral).

Despite these issues, the project succeeded in testing new configurations. Battery systems were integrated with the EMS (energy management system), enabling optimised local solar usage and grid relief. Furthermore, the project became a real-world laboratory for refining EMS software, which may contribute to broader learning in future implementations.

**Organisational** The decentralised and experimental character of Schoonschip also created organisational friction. Diffuse role divisions and the lack of a clear project coordinator resulted in inefficiencies. Moreover, the high involvement of 40+ households required intensive communication and technical support, creating unsustainable workloads for project partners.

Nevertheless, strong engagement from the energy cooperative and early involvement of a technical advisor were crucial enablers. Resident technical expertise and close collaboration between the cooperative and Technical Advisors supported adaptive project management, even in the face of mounting complexity.

**Legal**

On the legal front, Schoonschip operated under the Dutch experiment regulation (2015–2018), allowing for temporary deviations from standard grid rules. However, the termination of this arrangement now introduces legal uncertainty regarding long-term operation. Additionally, permitting constraints initially blocked the deployment of a central battery, affecting the design's efficiency.

Still, the cooperative structure provided a viable legal entity for collective ownership and governance. The legal and technical possibility to participate as a Virtual Power Plant (VPP) in the future opens up opportunities for additional income and better system integration, offering a promising outlook for replication under evolving regulatory conditions.

**Financial**

Financially, the small scale and decentralised nature of the project posed barriers. Duplication of infrastructure and non-standard design choices increased costs, while the limited scalability of such setups reduced commercial viability. However, public subsidies were instrumental in making the pilot financially feasible. Furthermore, the EMS provider gained valuable practical experience, increasing its technological maturity and market credibility.

**Key Takeaways from Interview**

- Scalability remains a challenge: The project's decentralised configuration, while innovative, is not easily scalable due to high transaction costs and design inconsistencies.
- Technical friction impacted EMS provider: Spectral struggled with user-specific complaints and maintenance responsibilities, exposing the limits of decentralised autonomy.
- Future legal uncertainty: The expiration of the experimental legal regime raises questions about the long-term viability of the current setup.
- Commitment and flexibility as enablers: Resident commitment and early technical support were critical for making the system work despite its complexity.
- VPP potential offers new directions: The legal capacity to act as a VPP may transform the cooperative into a more integrated part of the broader energy system.

Next, we will explore the barriers and enablers in the Republica case.

### 6.3.3. Case 3: Republica - Barriers and Enablers

**Technical**

Technically, Republica benefitted from a well-engineered and standardised energy system. The use of a central battery reduced system complexity and facilitated smoother integration with rooftop PV. Furthermore, metering and monitoring were outsourced to a professional energy services firm, reducing the risk of data mismanagement or disputes.

However, the system's potential was not fully realised. The battery was not optimally used for local balancing, and excess solar production was often fed back into the grid at low market prices. This limited both the system's resilience and the financial return on investment.

| Themes | Type | Label |
|---|---|---|
| Technical | Barrier | No_local_balancing |
| | Enabler | Standardized_design |
| | Enabler | Centralised_solutions |
| | Enabler | EMS_integration |
| Organisational | Barrier | EMS_refinemens |
| | Barrier | Lack_of_expertise |
| | Enabler | Developer_innovation_motive |
| | Enabler | Early_involvement |
| | Enabler | Single_developer |
| Legal | Enabler | Pilot |
| | Enabler | Cooperation |
| Financial | Barrier | No_local_balancing |
| | Enabler | Subsidies |
| | Enabler | Innovation_added_value |

**Figure 6.13:** Republica - Barriers & Enablers (Author)

### Organisational

Organisationally, Republica stood out due to its simplicity: one developer, one decision-making body, and fewer actors to coordinate. This streamlined governance contributed to fast decision-making and implementation.

Still, this simplicity came at a cost. Residents were largely unaware that they were part of an experimental pilot, and as a result, their behaviour remained unchanged. This lack of awareness limited opportunities for behavioural alignment, the process by which end-users adapt their routines, expectations, and energy use in response to the design and objectives of an energy system. In practice, this meant that residents did not shift their energy consumption to off-peak hours, respond to real-time pricing signals, or actively engage with energy-saving opportunities. As a result, the potential benefits of decentralised energy technologies, such as peak shaving or load balancing, remained underutilised.

Nonetheless, the developer's motivation to brand the project as a sustainability showcase provided strong internal drive and legitimacy to invest in new technologies. The early involvement of technical advisors also ensured system stability and coherence from the outset.

### Legal

Republica operated under a designated pilot status, which gave the project more legal flexibility in implementing a cooperative-based energy structure. The formation of an energy cooperative allowed shared infrastructure ownership and management, creating a robust legal basis for the EHub's operation. Unlike Merwede and Schoonschip, Republica faced fewer legal barriers, likely due to its simpler structure and limited interdependencies. No major legal frictions were reported during the development phase.

### Financial

From a financial perspective, the project benefitted from EU-level subsidies through the PED framework, which covered part of the innovation cost. However, the underutilisation of storage systems led to lower-than-expected returns. With limited national or municipal financial support, this weakened the overall business case.

Despite this, the developer regarded Republica as an innovation pilot and was willing to accept a lower return in exchange for reputation value and learning. This perspective was crucial for enabling upfront investment in novel energy infrastructure.

### Key Takeaways

- Simple governance enabled fast delivery: Having a single developer eliminated coordination barriers seen in more fragmented projects.
- Underuse of flexibility tools limited impact: While the technology was in place, the lack of operational optimisation meant the EHub's potential wasn't fully unlocked.

- Residents remained uninvolved: Their minimal role in energy use or system design may have reduced opportunities for user-driven flexibility or education.
- Pilot status and cooperative model worked well: The project benefited from legal and institutional flexibility without encountering major compliance issues.
- Strategic framing mattered: The developer's view of Republica as a sustainability flagship helped justify higher upfront investments.

## 6.4. Cross-case analysis (SRQ 5)

**Cross-case Code Analysis Barrier and Enablers**
Across all three pilot projects, we found a set of recurring enablers and barriers themes despite their different scales and contexts.
Reoccurring Enablers:

- **Early involvement of technical advisor** Early technical expertise was cited as an *organisational enabler* in all cases, helping align design decisions with implementation feasibility.
- **(Public) Subsidies:** All three cases highlighted cooperation and joint governance as a clear *organisational enabler*. Strong coordination between developers, municipalities, or residents was crucial to aligning interests and mobilizing action.
- **Strong Collaboration:** All three cases highlighted cooperation and joint governance as a clear *organisational enabler*. Strong coordination between developers, municipalities, or residents was crucial to aligning interests and mobilizing action.
- **Pilot; exemption from regulations** All cases required some form of regulatory space to operate, such as the Group Transport Agreement (Merwede), the Experimentation Decree (Schoonschip), or Positive Energy District status /Experimentation Decree (Republica). These served as legal enablers that allowed deviation from conventional grid rules.
- **EMS integration with battery systems**: In both Schoonschip and Republica, the integration of battery systems with an Energy Management System (EMS) was considered a strong *technical enabler*, enabling peak-shaving and increased local self-consumption and allowing balancing to the grid. \begin{itemize}
    - Merwede also included an EMS and battery system in its design, which contributed to load balancing, though this was not prominently named as an enabling factor in the interviews.

Reoccurring Barriers:

- **Lack of standardization:** Cited as a *technical barrier* in both Schoonschip and Republica This recurring issue impeded installation and maintenance across small-scale projects.
- **Initial design restrictions:** Early planning decisions constrained flexibility in Schoonschip and Republica, resulting in suboptimal decentralised storage setups. Forming a recurring *technical barrier*.
- **Diffuse project responsibilities:** In both Schoonschip and Republica, there were *organisational barriers* tied to unclear roles and fragmented decision-making among stakeholders (Merwede experienced a similar challenge related to the involvement of many stakeholders and siloed responsibilities across technical and legal teams).
- **Uncertainty about long-term legal status:** All three cases raised concerns about transitioning from a pilot to permanent operation, reflecting a shared *legal barrier* rooted in unclear regulatory pathways for Energy Hubs.

Furthermore the cross-case comparison of barriers and enablers showed that larger, developer-driven hubs (e.g.Merwede, Republica) can leverage economies of scale and formal planning, whereas small community-led hubs (Schoonschip) depend on social capital and regulatory flexibility.
In all cases, innovative legal/regulatory measures (like the GTO or cooperative status) were needed to align the niche project with the regime.
Enabling conditions across cases include: strong actor collaboration (e.g. community or cooperatives), clear business/legal frameworks (grid contracts, billing structures), and financial/policy support to

offset high up-front costs. Barriers common to all include complexity in coordinating multiple users and assets, and uncertainty about transitioning out of pilot status into the mainstream regime.

### 6.4.1. Conclusion

This chapter analysed three pilot EHubs: Merwede, Schoonschip, and Republica, revealing a shared technical core of solar PV, batteries, heat pumps, and EMS. While these technologies have a certain base configuration, their implementation is shaped by context-specific governance models and legal frameworks.

Organisationally, approaches ranged from cooperative-led (Schoonschip) to developer-driven (Republica) and hybrid models (Merwede), each influencing system coordination and user involvement. Legally, all cases required regulatory flexibility, such as pilot exemptions or cooperative structures, to enable non-standard grid configurations.

Overall, EHub implementation depends not just on technology, but on early alignment of institutional roles, legal innovation, and financial certainty. EHubs are best seen as adaptable configurations of core technologies embedded in supportive organisational and regulatory ecosystems.

# 7

# Discussion & Limitations

This chapter discusses the findings of the research and its methods and outlines its limitations. Furthermore, placing them in the broader context of Management in the Built Environment through the 5 P's and reflecting backt to the MLP framework.

## 7.1. Discussion

This research set out to explore Energy Hubs (EHubs) as a response to distribution grid congestion in Dutch urban developments. By examining three pilot projects and interpreting the findings through the lens of the Multi-Level Perspective (MLP) on socio-technical transitions and the five P's of Management in the Built Environment (People, Planet, Profit, Process, Project), an attempt is made to draw broader insights beyond the individual cases. While the cases confirmed the potential of EHubs to integrate local renewables and add flexibility, they also underscored that EHub implementation requires more than technical solutions alone. Systemic change will depend on aligning human roles, sustainability goals, financial incentives, governance processes, and project-specific contexts. Below, the findings are discussed in terms of these five P's, followed by a reflection on how these niche innovations relate to the wider energy transition (MLP).

#### People – Roles, Collaboration, and Responsibility

A consistent theme across the cases was the unclear distribution of roles and responsibilities in planning and operating EHubs. In current area development practices, no single stakeholder is naturally tasked with integrating energy systems into the design; as a result, the energy component often becomes an afterthought. The case studies demonstrated that this gap can lead to misalignment in the design. For example, without an entity clearly in charge of the energy concept, early design decisions tended to ignore grid capacity constraints or flexibility options, forcing costly adjustments later on like in Merwede.

The case findings underscore the importance of introducing two complementary roles early in the development process. First, an "energy program manager" is needed, positioned within a municipality, developer consortium, or public-private partnership who can uphold the energy agenda, coordinate between actors, and ensure that energy requirements are structurally integrated into spatial and financial planning.

Second, a technical advisor with experience in both system design and real-world implementation is necessary. This role brings the practical expertise to model energy demand, assess grid constraints, and configure systems such as storage, heating, and controls in alignment with local context and development goals. While the energy program manager provides strategic coordination and alignment, the technical advisor ensures that the envisioned system is technically robust, feasible, and optimised for implementation.

Together, these roles bridge the gap between ambition and delivery. Ensuring that energy systems are not just technically sound, but also embedded within the organisational, spatial, and regulatory realities of urban development

Just as important as formal roles is the quality of collaboration. Early and proactive engagement between developers, technical experts, and the Distribution System Operator (DSO) proved to be a strong enabler in all three projects. When technical advisors and DSOs were brought in during the concept phase (as seen in Merwede's preparatory workshops and Schoonschip's initial design sessions), the projects could identify constraints and co-create solutions (like smart grid layouts or adjusted connection schemes) before problems escalated. This contrasts with conventional practice where utility planning occurs late and separately. The case studies highlight that communication, and trust were as crucial as the technologies themselves.

Another important "people" dimension concerns the role of residents in the functioning of EHubs. The pilot projects revealed contrasting approaches to user engagement. In the community-driven Schoonschip project, residents were highly involved from the outset, leading to a strong awareness of the system's functioning and a behavioural culture oriented toward active energy management, such as consciously shifting electricity use to periods of solar surplus. In Republica, by contrast, residents had little awareness of the EHub's presence, and energy behaviour largely remained unchanged.

Interestingly, all technical advisors interviewed recommended minimising active resident involvement in day-to-day system operation. This advice stems from the recognition that long-term user engagement tends to fade and that most users prefer seamless, automated systems over ones requiring continuous behavioural input. From this perspective, the absence of resident interaction is not necessarily negative, it may even improve long-term reliability and participation through passive, embedded flexibility.

Nonetheless, the divergent practices across cases suggest that the role of residents in EHubs need further investigation. Especially as user preferences, trust, and behavioural norms may shape the social acceptability and long-term viability of such systems. Future research should therefore explore under which conditions, and to what extent, residential engagement supports or hinders EHub performance.

**Planet – Systemic Sustainability through Local Innovation**

EHubs provide a decentralised model for balancing local supply and demand, aligning closely with national sustainability goals. However, their contribution to decarbonisation is contingent upon more than just the presence of renewable technologies. System effectiveness depends on early-stage modelling, clear understanding of temporal demand profiles, and the capacity to orchestrate flexibility across heating, electricity, and mobility.

All three case studies revealed that sustainability gains are maximised when design choices are supported by simulation tools (e.g., digital twins), and when flexibility mechanisms, like thermal buffers or smart charging, are sized and located according to specific contextual demand. Without such preparatory foresight, even well-intentioned technical solutions risk being oversized, underused, or grid-incompatible.

**Profit – Risk, Incentives, and Financial Models**

The financial viability of EHubs emerged as one of the most complex challenges. All three pilot projects encountered a well-known dilemma in sustainable innovation: high upfront capital investments coupled with considerable uncertainty regarding long-term returns. Key technologies such as community batteries, private micro-grids, or collective heating systems required significant investment before the anticipated benefits, such as lower grid fees or energy savings, could materialise.

While private actors were often willing to invest in these innovations, their willingness diminished when those investments were also tied to realisation risks. Uncertainties around planning procedures, permitting, or long-term coordination responsibilities makes it difficult to commit capital. Without mechanisms to capture and safeguard the value of future flexibility or efficiency gains, building a robust business case proved challenging.

To move beyond ad hoc arrangements, risk-sharing instruments, including performance-based subsidies, innovative tariff models (e.g., time-of-use pricing), and third-party service models such as energy-as-a-service. These tools could help align private incentives with public objectives and lower the perceived risk of participation.

Examples like Zero Bills™ housing models or dynamic congestion charges show how flexibility can be monetised in ways that appeal to both market actors and policy agendas. However, the Dutch regulatory and financial frameworks are still too fragmented to consistently support such mechanisms. This reflects a broader insight from the MLP: niche innovations like EHubs struggle to scale when regime-level institutions, particularly around financing and market organisation remain unchanged.

#### Process – Governance, Timing, and Regulation

A recurring limitation in all three cases was the lack of integration between energy planning and spatial planning. The findings suggest that energy tends to be "fitted in" rather than planned alongside core development decisions. This temporal mismatch, where technical system design follows rather than informs land use planning, limits both flexibility and feasibility.

Moreover, the regulatory framework for EHubs remains immature. Although the new Dutch Energy Act represents a step forward, EHubs are still not formally recognised as a legal planning category. As a result, municipalities and DSOs often lack clarity on responsibilities, permitting, and risk allocation. Temporary instruments like the Group Transport Agreement (GTO) and Experimentation Decree provide short-term workarounds, but not structural certainty.
Aligning governance with energy complexity requires policy innovation. This includes role clarity, standardised legal templates, and planning instruments that foreground energy from the outset. The MLP lens reinforces this conclusion: while local projects are innovating, they remain constrained by regime institutions that have not yet adapted to decentralised, multi-actor systems.

#### Project – Complexity, Automation, and Context-Specific Design

The heterogeneity of the case studies underscores that no single blueprint exists for successful EHub deployment (yet). Schoonschip thrived on bottom-up initiative and strong resident buy-in, while Republica succeeded through top-down simplicity. Merwede's scale and ambition introduced technical innovation but struggled with coordination. A key insight is that context shapes the design logic and feasibility of each EHub.

Scale is one context factor with a notable impact. Larger projects like Merwede (thousands of units) can exploit economies of scale and justify more complex infrastructure (such as a district thermal grid with aquifer storage), but they also face greater coordination challenges and slower timelines. Small projects like Schoonschip (just 47 households) can achieve very high degrees of self-sufficiency and community engagement, yet they may struggle with financial viability and technological redundancy (since each house ended up with its own systems). Medium-sized developments like Republica show a middle path: some integration is achieved, and the complexity is more manageable, but they may not reach the ideal scale for cost-effectiveness of certain technologies. This suggests that future EHub projects should carefully assess which scale and scope best fit their goals. For example, a cluster of 50–100 homes might focus on a shared electric system and simple heat pumps, whereas a 5000-home district could justify a multi-utility approach (heat, power, mobility) with advanced control systems. Recognizing these distinctions can prevent projects from being over-engineered or under-ambitious relative to their context.

#### Synthesis through the MLP lens

When interpreted through the MLP framework, the current EHub landscape in the Netherlands reflects a promising but incomplete niche innovation trajectory. Technically and organisationally, a dominant design is beginning to form, particularly around sector coupling, smart storage, and district-level control. Actor networks are expanding, and knowledge diffusion is visible through experimentation and policy dialogue.

However, regime alignment remains weak. Regulatory uncertainty, unclear financing mechanisms, and planning silos prevent EHubs from influencing mainstream development practices. Landscape pressures, such as climate targets and grid congestion continue to mount, but have not yet triggered structural shifts at the regime level. In this light, EHubs are best viewed as "protected spaces" for experimentation. Their survival and growth depend on whether these experiments can influence institutional reform.

In short, EHubs show that local, smart energy systems can work well but are still held back by policies and ways of working. Real progress can only happen if changes are made in all five areas: who is responsible (People), how sustainability is built into the design (Planet), how projects are financed (Profit), how planning and regulations support innovation (Process), and how projects are managed from idea to completion (Project). The three case studies reflect the bigger picture: innovative ideas are there, but the systems around them need to catch up. The next step is closing that gap.

## 7.2. Limitations

As an exploratory qualitative study situated within an evolving field, this research is subject to several limitations that inform both the interpretation and scope of its findings. These limitations primarily relate to the study's methodological choices, the stage of development of the studied innovations, and the availability of data.

First, the stakeholder sample was weighted toward technical advisors involved in the respective case studies. While these individuals offered critical insights due to their cross-cutting involvement in planning, design, and implementation, the limited inclusion of other actors, such as residents, developers, and public officials, means that certain perspectives may be underrepresented. This may have led to an emphasis on infrastructural and regulatory dimensions over social or political dynamics. Although interviewees were selected for their broad project oversight and familiarity with multiple stakeholder positions, future research would benefit from more balanced representation across the full spectrum of actors involved in EHub development.

Second, the study examines EHub initiatives that are either in early operational phases or still under development. As such, the analysis reflects a snapshot of conditions, intentions, and early implementation experiences rather than mature, long-term outcomes. While this limitation is inherent to researching emergent socio-technical innovations, it constrains the ability to assess the durability, scalability, and behavioural effects of these systems over time. To address this, the research focused on identifying perceived enablers and barriers in the early stages, with the goal of informing similar developments currently being considered or planned. Nevertheless, longitudinal follow-up studies would be essential to understand how these projects evolve and adapt beyond their initial implementation phase.

Third, the findings are highly context-dependent. Each of the three case studies exhibits unique spatial, institutional, and governance characteristics. These differences influence both the feasibility and form of EHub implementation, limiting the generalisability of conclusions to other developments. The use of a cross-case comparative approach helped to identify both shared patterns and case-specific dynamics. However, the variability among cases reinforces that there is no single EHub blueprint. Instead, the study offers indicative insights into what contextual conditions are likely to support or hinder implementation. The value of the research lies in its ability to highlight recurring themes and plausible strategies, rather than prescriptive solutions.

Fourth, the research does not employ longitudinal data. While retrospective interview techniques and document analysis provided some temporal context, the absence of real-time tracking limits the ability to evaluate how stakeholder relationships, governance structures, and technical systems evolve. EHubs are dynamic configurations subject to shifts in policy, market conditions, and technological performance. A longitudinal design would be necessary to fully capture these trajectories and their implications for long-term viability and institutionalisation.

Finally, limited access to internal project documentation, particularly regarding financial models, contractual arrangements, and decision-making processes, restricted the depth of analysis in certain areas. Some data remained confidential or proprietary, especially from private developers and Distribution System Operators. Where direct information was unavailable, inferences were made through interviews and secondary sources, with transparency regarding any assumptions. While triangulation strategies were employed to increase reliability, the absence of full documentation introduces a degree of uncertainty in the interpretation of key decisions.

Despite these limitations, the study provides a conceptually grounded exploration of EHubs as niche innovations within the Dutch energy and spatial planning context. By applying a cross-case qualitative approach and situating findings within a broader socio-technical transition framework, it offers a valuable foundation for both scholarly inquiry and practical application.

# 8 Conclusion & Recommendations

## 8.1. Conclusion

This thesis set out to explore how Energy Hubs (EHubs) are defined, configured, and implemented in the context of Dutch area development projects facing electricity grid congestion. The research sought not only to clarify the conceptual and technical underpinnings of EHubs but also to investigate the institutional, legal, organisational, and financial dynamics that shape their real-world application. Through a literature review, a theoretically informed framework using the Multi-Level Perspective (MLP), and an in-depth case study of three pilot projects: Merwede, Schoonschip, and Republica, this study provides a grounded understanding of the current potential and limitations of EHubs in urban development contexts.

The study was guided by the following Main Research Question:

*"How are Energy Hubs defined and configured in area development projects facing grid congestion in the Netherlands, and what lessons can be learned from technical,organisational, legal, and financial barriers and enablers identified in current pilot projects to inform future practice?"*

The first sub-question addressed how EHubs can be defined. Existing literature uses the term inconsistently, often highlighting either their technical integration or their organisational novelty, but rarely both. This thesis proposes a more comprehensive definition, grounded in Dutch planning practice: an EHub is a localized, multi-stakeholder system that coordinates the generation, conversion, storage, and use of multiple energy carriers within a development, under a shared legal and operational framework. This perspective foregrounds the dual nature of EHubs as both technical systems and socio-institutional arrangements.

The second sub-question examined how EHubs are configured in existing literature. While terminology varies, there is broad agreement that EHubs typically consist of four core technical components: local renewable inputs (often solar PV), conversion technologies, storage (both thermal and electrical), and an Energy Management System (EMS) for coordination. Organisationally, configurations range from cooperatives to public-private partnerships, while legal structures increasingly rely on special exemptions or sandboxing mechanisms due to the mismatch between EHubs and existing law. Still, empirical studies of EHubs remain scarce, and most literature lacks detailed insight into how these systems are embedded in planning and governance contexts.

The third sub-question explored how these dimensions manifest in practice across the three Dutch pilot projects. Despite differences in scale, ambition, and governance model, the projects shared a core technical toolkit: PV-panels, batteries, heat pumps, and an EMS, and all relied on some form of legal workaround to function. Yet their organisational configurations varied significantly: Schoonschip followed a bottom-up cooperative model, Merwede employed a hybrid public-private consortium, and Republica pursued a developer-led approach with cooperative elements. This variation suggests that while the technical design of EHubs may be increasingly standardized, their implementation remains deeply context-specific and highly dependent on local actor dynamics and regulatory space.

The fourth sub-question identified key enablers and barriers in each domain. Technically, pilots showed the feasibility of integrating distributed energy systems, though complexity and lack of standardisation posed challenges. Organisationally, unclear roles and coordination burdens hindered progress. Especially in more fragmented initiatives, whereas early involvement of technical advisors and a clearly mandated energy coordinator proved essential enablers. Legally, reliance on temporary exemptions like the Experimentation Decree and GTO highlighted the fragility of the current legal basis for EHubs. Financially, high upfront costs, uncertain revenue models, and risk aversion among stakeholders constrained scalability; nonetheless, public funding and economies of scale helped mitigate these risks in some of the cases.

Finally, the fifth sub-question asked what lessons could be drawn for future practice. Several recurring themes emerged. First, integrating the energy concept early in the planning process is critical. When left too late, technical and financial misalignments emerge, as seen in Merwede. Second, a core technical configuration seems to be forming across pilots, suggesting replicability is increasingly viable. Third, strong cross-sector collaboration and clear governance roles are foundational to project success. Fourth, legal experimentation is currently necessary but must evolve into permanent frameworks to enable scaling. And fifth, new financial models and flexibility markets must mature to support long-term viability. These lessons point to a need for holistic and adaptive planning processes that align technical ambition with legal, financial, and institutional feasibility.

Viewed through the Multi-Level Perspective (MLP), EHubs can be seen as niche innovations situated within a regime that is only partially accommodating their emergence. Landscape pressures like climate goals, urbanisation, and grid congestion, are creating fertile ground for change: however regime structures such as enhanced energy legislation, planning procedures, and standard financing models have yet to fully evolve. The pilots analysed here occupy a liminal space: they offer glimpses of a more integrated and resilient energy future, but rely heavily on exceptions, workarounds, and committed pioneers to succeed.

In conclusion, this research finds that EHubs represent a promising yet still fragile model for enabling sustainable urban development under grid constraints. Their success depends not only on technological readiness but also on institutional innovation, collaborative governance, and regulatory reform. While the cases studied here cannot offer universal solutions, they illustrate viable pathways and highlight the conditions under which EHubs can move from experimental exceptions to mainstream practice. For planners, policymakers, and developers navigating the complexities of the energy transition, EHubs offer not just technical solutions, but a compelling socio-technical vision for how energy can be re-embedded in the fabric of urban development.

## 8.2. Recommendations

The findings of this research show that EHubs can help address structural grid congestion in Dutch area development projects. At the same time, their implementation remains limited by regulatory, financial, organisational, and technical barriers. Based on cross-case insights, this chapter outlines recommendations for both policymakers and developers to support more widespread application of EHubs and for future research.

**For policymakers**

A first consideration relates to the role of supplier choice in decentralised energy systems. In the current legal framework, end-users are entitled to freely select their energy supplier—a principle firmly embedded in both Dutch and European legislation. However, findings from this research suggest that this model may not always align with the operational needs of area-based energy systems. In contexts where local energy infrastructure is collectively managed, and where balancing and optimisation rely on shared assets, full individual supplier freedom can create complexity and inefficiencies.

In practice, collective procurement or coordinated supply models may offer a more effective route for integrating flexibility services, limiting congestion, and facilitating local energy exchange. This creates a potential conflict with existing legal norms, particularly at the European level, where liberalised market access and consumer autonomy are central pillars. Nonetheless, as decentralisation advances, it may become necessary to reconsider whether current market principles can accommodate such locally embedded models. Introducing geographically or system-based exceptions could offer a pragmatic way forward, provided these are accompanied by clear rules to safeguard transparency, accountability, and consumer rights. While this would represent a departure from the uniform market logic of EU energy law, it may be a necessary evolution to enable more context-specific and system-efficient forms of energy governance.

Another key finding is that all three cases relied heavily on temporary regulatory exemptions, such as the Experimentation Decree or custom-made grid arrangements, to enable their implementation. While these instruments offer necessary flexibility for early-stage innovation, they offer limited legal certainty. Their case-by-case application creates ambiguity for developers and limits the scalability of EHubs. To move beyond the experimental phase, it is important that such mechanisms, particularly tools like the Group Transport Agreement (GTO) and collective contracting arrangements such as cable pooling, are embedded in structural legislation. Integrating these provisions into the Dutch Energy Act and spatial planning frameworks would provide a more stable and predictable legal foundation. This would enhance legal clarity, and enable broader replication of collective energy systems in future area developments.

A third issue concerns the limited availability of grid data. Stakeholders reported difficulties accessing reliable and timely information on local grid capacity and constraints. This lack of transparency hinders both investment and research. Without insight into where the grid is congested or nearing capacity limits, developers cannot make informed decisions about the feasibility or timing of new projects. Similarly, researchers and system designers are unable to test, model, or validate potential technical or organisational solutions without access to real-world data. As a result, promising innovations may not be deployed where they are most needed.

Currently, DSOs are reluctant to disclose detailed grid data due to concerns over privacy, cybersecurity, and commercial sensitivity, especially in decentralised systems where data may be traceable to individual households or shared infrastructures. While these concerns are legitimate, a lack of data access poses a significant barrier to resolving the very issues that grid operators are facing.

To address this, policymakers should explore the creation of a regulated data-sharing framework that enables structured access to local grid information under strict conditions. This could include aggregated or anonymised datasets at the neighbourhood or district scale, shared through secure platforms with appropriate oversight. Such a framework would not only support better planning and investment decisions but also facilitate targeted innovation and public research into congestion relief, flexibility services, and system integration. Without access to this data, both public and private actors will remain limited in their ability to contribute meaningfully to grid optimisation.

Finally, this research finds that EHubs often depend on collaboration between multiple actors. Yet, project coordination remains difficult due to a lack of standard tools. The development of a standard public-private partnership framework could help. Such a framework could include model contracts, governance structures, and guidance on cost-sharing and liability. While the RVO is currently working on this for EHubs on business parks, extending these tools to area development could support broader uptake and consistency in project delivery.

**For developers**

For developers, EHubs offer technical possibilities but also introduce new forms of complexity. This research shows that while EHubs are feasible, they require a different approach to planning and delivery. Energy must be considered from the start of a project, not as an add-on.

One insight from the cases is the importance of early involvement of a technically skilled energy advisor. These advisors translated stakeholder needs into system designs and helped prevent delays or poor decisions. Because energy systems are path dependent, late interventions can lead to higher costs or technical lock-in. In practice, we see that the role of the energy advisor is changing. Rather than a traditional technician or consultant, projects may benefit from someone who also has coordination and project management skills. This more integrated role could help bridge technical, legal, and organisational questions.

Another shared element across cases was the use of energy storage and EMS software. These systems helped balance loads, increase self-consumption, and support participation in energy markets. Integrating such technologies from the beginning of the design process could avoid the need for later retrofits. Some actors pointed to modular or s "as-a-service" deployment models as a way to reduce costs and investment risks. Developers may benefit from exploring such options early on and ensuring compatibility with existing and future regulation.

In addition, while most EHubs rely on a legal entity to represent users, this is not always enough. What matters is that the internal structure of such entities is clear and functional. Contracts should outline responsibilities, liability, and decision-making procedures. Without this clarity, collective contracting and engagement with DSOs becomes difficult. Developers could benefit from using standard legal templates, especially in projects where legal expertise is limited. Standardizing such frameworks could make future projects easier to coordinate and faster to set up.

Lastly, the Merwede case shows that grid constraints must be considered when phasing construction. Developing a timeline without coordination with the DSO can cause delays or make the project more expensive. Developers are advised to engage the DSO early and co-develop phased connection strategies. This makes it easier to align supply and demand and avoid bottlenecks during delivery. Where possible, such agreements should be documented to ensure continuity and clarity across the project.

**For future research**

This research provides an initial understanding of how EHubs are emerging within the Dutch built environment in response to structural congestion in the electricity grid. However, given its qualitative and exploratory nature, based on three early-stage projects, there are several areas that require further academic and applied investigation to deepen, refine, and extend the insights gained

An important direction for future research concerns the long-term performance of EHubs. This study focused primarily on planning and early implementation stages, which means little is known about how these systems perform over time. Longitudinal research could provide insight into the stability of governance models, financial viability, and user engagement as projects transition into full operation. Such work would clarify whether early enabling conditions lead to lasting outcomes or whether additional barriers emerge during later phases.

There is also a need for more quantitative analysis. While this research relied on qualitative case studies and interviews, future studies could use structured surveys or data-driven methods to assess the prevalence and significance of various barriers and enablers across a wider set of initiatives. This would help build a broader evidence base and allow for more systematic comparison between projects. Such efforts may become more feasible as additional EHubs reach more advanced stages of development and operational maturity.

Comparative research across countries could provide additional insights. National contexts such as Denmark, Germany, and the United Kingdom have adopted different approaches to decentralised energy systems. Studying their institutional and legal frameworks could highlight transferable lessons and help identify which governance mechanisms are most suitable for the Dutch context. Moreover, although the political and regulatory environment in China differs significantly from that of the Netherlands, China has made considerable progress in the technical implementation of decentralised energy systems. Examining these developments may offer valuable insights into system integration, digital infrastructure, and operational scaling, even if not all aspects are directly applicable.

Legal and regulatory aspects also require deeper examination. While this research showed how temporary exemptions can help projects move forward, there is a clear need to examine how permanent frameworks can be designed to support collective energy systems. Future work should explore how the revised Dutch Energy Act can accommodate new forms of shared infrastructure, including questions about liability, ownership, and contracting arrangements.

Social and behavioural dimensions have received limited attention to date. While this research suggests avoiding the inclusion of residents in operational responsibilities within EHubs, their support remains essential for legitimacy and long-term success. Future research could explore how factors such as trust in system operators, transparency in governance, data privacy, and perceptions of fairness influence public acceptance of decentralised energy systems.

Financial models form another key topic for further research. Many pilot projects still depend on subsidies or temporary funding arrangements. Future work could explore the feasibility of cooperative ownership, service-based energy models, or other strategies that make use of flexibility markets. A better understanding of these models is critical for enabling replication and scale without continued public funding.

Lastly, the integration of energy systems with mobility and heating remains an under explored area. While this research recognises the importance of sector coupling, further investigation is needed to examine how energy hubs can be effectively designed and managed in coordination with local transport systems and thermal networks.

Collectively, these future research efforts can contribute to more informed approaches to the design, governance, and financial structuring of EHubs. Advancing this knowledge is essential for transitioning from isolated pilot initiatives to scalable and robust energy solutions within area development contexts.

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# A

# How does the Energy Grid operate in the Netherlands?

The energy chain in the Netherlands is a complex and multi-layered system. At the top of the chain is the national Transmission System Operator (TSO), in the Netherlands this is one single party: TenneT, responsible for managing the generation of electricity in power plants. Meanwhile, the Gasunie Transport Service handles the high-pressure gas transport infrastructure. Both TenneT and Gasunie are state-owned entities, operating under the authority of the Dutch Ministry of Finance.

Electricity generation begins in centralized power plants or large-scale renewable energy installations. From these sources, electricity enters the high-voltage grid (typically at 150,000 volts), which is mostly above ground and enables long-distance energy transmission. The power is subsequently routed to regional distribution stations, where it is transformed to medium voltage (approximately 20,000 volts) and enters the distribution grid, which is primarily underground. Next, the electricity reaches local transformer substations, where it is further reduced to low voltage levels (230 volts), making it suitable for delivery to residential, commercial, and light industrial consumers. Electricity is then distributed through underground cables directly to end-users.

In addition to traditional power plants, large wind farms deliver electricity directly to distribution stations, while solar parks feed into transformer substations. The rapid growth of renewable energy generation, particularly from solar and wind sources, has led to increased pressure on the electricity grid. This is especially evident in the high- and medium-voltage networks, which are experiencing net congestion due to the surge in electricity production. Furthermore, households generating electricity through solar photovoltaic (PV) panels, particularly during peak production times, can strain the low-voltage networks as they attempt to feed excess energy back into the grid.

The combination of increased electricity consumption and a growing number of decentralized energy producers feeding into the grid highlights the need for grid upgrades to accommodate the energy transition.

When wanting to connect to the grid two destinctions can be made:

- Large consumers (NL: grootverbruikers) - >3x80 amp(55kW)
- Small consumers (NL: kleingebruikers) - <3x80 amp(55kW)

There is no transport capacity for new connections on the grid. There is still the possibility to get a connection to the grid, because this a legal requirement, however there is no legal obligation to actually deliver energy.

We are experiencing grid congestion, especially in: construction power, charging power, thermal energy

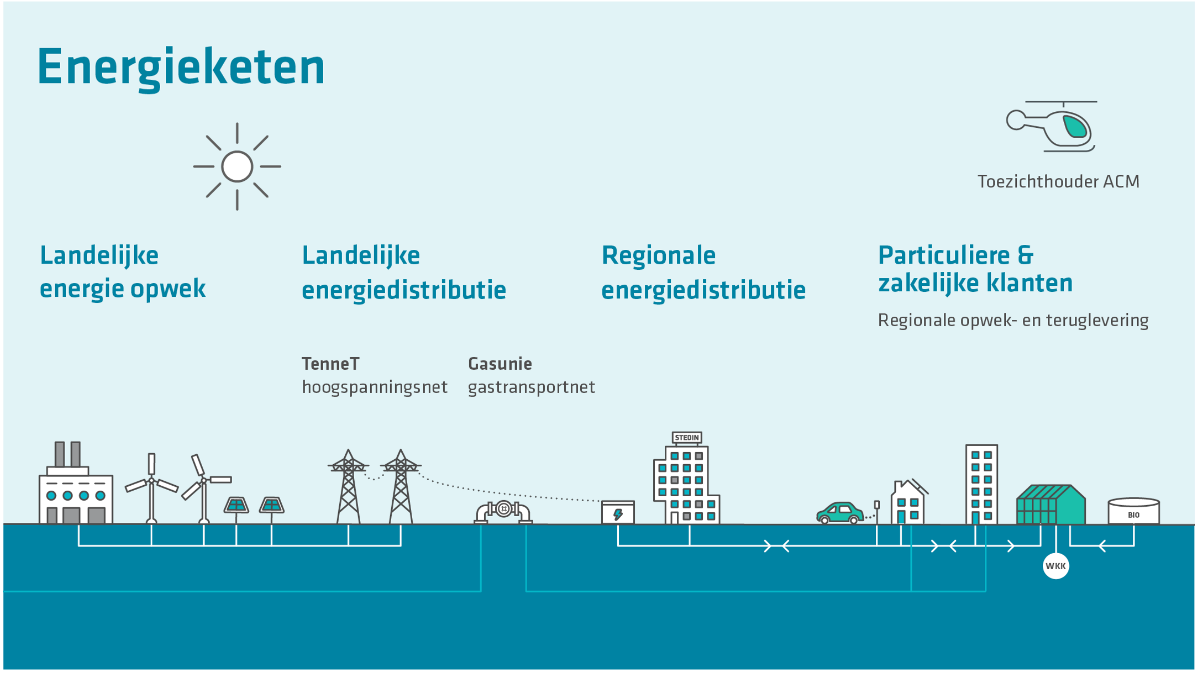


**Figure A.1:** Energychain Nertherlands (Stedin, n.d.)

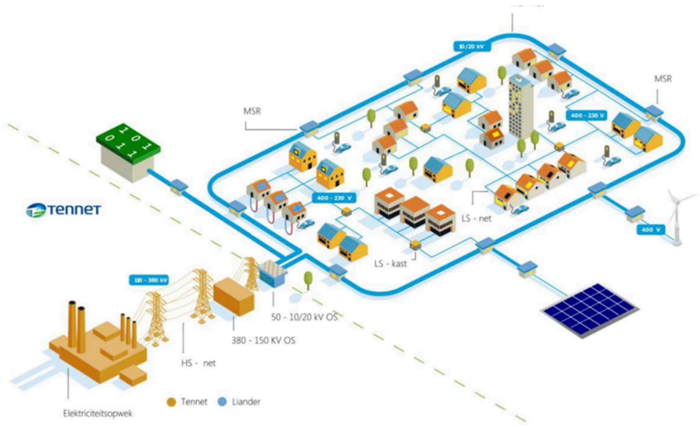


**Figure A.2:** Energychain Netherlands (Liander, 2023)

power, hospitality, non-residential areas, business relocations, and small connections in the second phase of the neighbourhood under discussion. (NEPROM, 2024)

The current process to get a connection to the gris is the following:

1. Report locations to the municipality and grid operator (alert system).
2. Dialogue with the municipality and grid operator about what is possible.
3. Carefully consider existing transport capacity for temporary use and demolition.
4. Secure transport capacity for residential areas.
5. Plan and develop projects with an awareness of the existing grid limitations and capacities, avoiding overburdening the network.

# B

# Origin Grid Congestion

The root cause and history of grid congestion is complex but necessary to understand both the nature of the problem and why it has become such a pressing concern in recent years.. It is illustrated through a timeline shown in Figure 1.1.

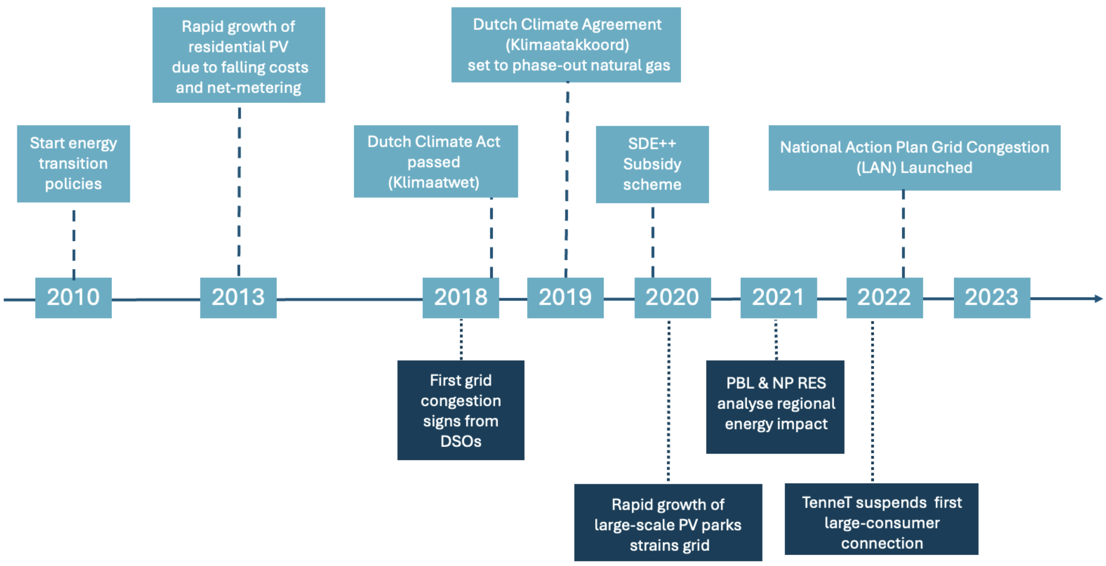


**Figure B.1:** Grid congestion in the Netherlands: Key events and drivers (Author)

In 2019, the Netherlands adopted the Dutch Climate Act, legally committing to long-term emission reduction targets. As part of this transition, the Dutch government set out to phase out natural gas use in the industrial sector, the power generation sector and residential heating. One of the key goals is to have 1.5 million of the countries eight million dwellings heated without natural gas by 2030.

Further ambitions were outlined in the Dutch Climate Agreement (Ministerie van Economische Zaken en Klimaat (2019)), including achieving full electrification of industry by 2035 and becoming climate neutral by 2050. These targets require a profound shift towards renewable energy sources and structural reduction in fossil fuel dependency (Klimaatwet, 2023).

In 2022, Tennet, the Dutch transmission system operator, suspended new connections for large consumers in the provinces of Brabant and Limburg for the first time. This measure was taken in response to sever grid congestion caused by a surge in electricity demand due to pressing strains on the grid. The increasing pressure on the grid in these regions stemmed from a combination of strong economic growth and government policy incentivising the electrification of industry and the reduction of $CO_2$ emissions.

In 2020, the Netherlands experienced a rapid surge in solar power deployment, reaching the highest level of installed PV capacity per capita in the EU (Pato, 2024). This boom was largely caused by a generous subsidy scheme for utility scale PV parks (SDE++) and net-metering for residential solar panels. This further enhanced pressure on the electricity grid.[1]

The low-voltage grid, designed for a simultaneous demand of only 1-1.5 kW per household, is increasingly challenged by rising peak loads. Households have the right to install high-capacity connections (up to 8 or 17 kW) without consent from the DSO. This further complicates capacity forecasting for grid operators (Ministerie van Algemene Zaken, 2025).

[1]In response to growing concerns about the system imbalance and inequality, as net-metering provides limited incentive to align generation with consumption and primarily benefits households with the means to invest in solar panels, the government has announced a phased termination of the net-metering scheme starting in 2025 (Ministerie van Algemene Zaken, 2025)

# C

# Description Barriers & Enablers

| Themes | Type | Label | Description |
| --- | --- | --- | --- |
| Technical | Barrier | Forecasting_uncertainty | Uncertainty in load forecasting due to phased construction over a 10-year period creates challenges for accurate system sizing and planning. |
| | Barrier | Inflexible_large_consumers | Large-scale energy users, such as supermarkets and student housing, are difficult to control or shift, reducing system flexibility. |
| | Barrier | No_grid_data_acces | DSOs currently provide insufficient public access to real-time grid data, hindering effective planning and decision-making. |
| | Barrier | Grid_capacity_limit | Grid connection limits (e.g., 5.2 MW for the area) create operational risks and require complex real-time balancing. |
| | Enabler | Centralised_solution | Centralised thermal energy demand (heating and cooling) provides predictable, high-load profiles and a clear system design focus. When combined with thermal storage, it enables effective peak load reduction. |
| | Enabler | Predictable_profiles | Predictability of household energy profiles in high-density apartment blocks supports reliable system modelling. |
| | Enabler | EMS | Automated monitoring and real-time control systems help manage net capacity and avoid overload. |
| | Enabler | Regulatory_support | New regulations allow for new integrated technical design solutions |
| Organisational | Barrier | Complex_stakeholder_coordination | High number of stakholders and phased dilivery complicate coordination and commitment |
| | Barrier | Late_involvement_technocal_advisor | Energy decisions often remain vague due to institutional silos and late-stage involvement of technical experts. |
| | Barrier | Stakeholder_dependency | High dependency on central stakeholders like the municipality and key utility partners increases risk if actors withdraw. |
| | Barrier | Slow_Development | Leghty development time. |
| | Enabler | Stakeholder_collaboration | Collaborative alignment between responsible stakeholders ensures that shared objectives can be effectively achieved |
| | Enabler | Cooperation | A pre-existing area organisation facilitated the joint procurement of mobility and heating infrastructure, and provided a coordinated governance structure that enabled the application of a Group Transport Agreement (GTO) for shared grid access |
| | Enabler | Joined_procurement | Municipality and developers jointly procured central heating/cooling operator, fostering commitment, cooperation and scale. |
| | Enabler | Win_win_framing | Early on, clear win-win framing of collaboration by a technical advisor increased stakeholder willingness to engage. |
| | Enabler | Technical_advisor | A technical advisor with project management skills acted as a boundary-spanning actor, aligning technical decisions with broader project goals and ensuring implementation progress |
| | Enabler | DSO_recignition_nonresidential | Recognition by the DSO of the necessity to include non-residential loads, such as supermarketa, in large-scale area developments led to the development of a new contractform (GTO) |
| | Enabler | Willingness_DSO | The DSO took an exceptional role in enabling the pilot, showing institutional willingness to support innovation beyond standard procedures. |
| Legal | Barrier | Legal_liability_risk_DSO | Lack of legal clarity on liability in shared grid configurations creates risk aversion among DSOs |
| | Barrier | Legal_liability_risk_Developer | Contractual liability for exceeding grid capacity poses significant risk to the cooperation, particularly in a development with unpredictable and multi-actor peak demand. |
| | Barrier | Lack_of_legal_instrument | Lack of existing legal instruments for EHubs made implementation difficult before ACM policy change. |
| | Enabler | Cooperation | Creation of a legal cooperative as a grid contract holder enabled shared responsibility among stakeholders. |
| | Enabler | Obligation_connecting_dwellings | The legal obligation for DSOs to connect residential dwellings ensures a baseline of infrastructural commitment, which creates opportunities for innovative configurations to be realised within a guaranteed connection framework. |
| | Enabler | Pre_contracted_load | Pre-contracted connection in advance of building. No waiting-list problem. |
| | Enabler | Pilot | Support from the municipality to explore exceptions and innovative governance instruments enabled experimentation. |
| Financial | Barrier | High_upfront_investment | High upfront investments to ensure critical loads, while grid connection rights are not yet secured at permit stage. |
| | Barrier | Stakeholder_dependency | High investment requirements and interdependency between developers increase financial and coordination risk, especially in large-scale centralised energy systems. |
| | Barrier | Stakeholder_dependency | Dependence on shared infrastructure creates financial exposure and coordination risks for developers. |
| | Enabler | Pre_contracted_load | Contracted capacity was secured early through a group transport agreement (GTO), mitigating long-term investment risk. |
| | Enabler | Commitment_stakholders | Developer consortioum was willing to invest upfront in storage assets. Project leaf paid for the battery system upfront to ensure garanteed supply. This commitment made the EHub viable. |
| | Enabler | Flexibility | To be affordable for its consumers, the energy system must be flexible, allowing the choose to purchase energy at the lowest cost. |

**Figure C.1:** Description Barrier & Enablers Merwede (Author)

| Themes | Type | Label | Description |
|---|---|---|---|
| Technical | Barrier | Lack_of_standardization | Lack of standardisation across residential systems led to inconsistent installations and technical complications in maintenance and troubleshooting. |
| | Barrier | Small_scale_implimentation | Small-scale implementation resulted in high complexity due to the number of components, connections, and potential failure points. |
| | Barrier | Decentralize_solutions | Initial design restrictions prevented the installation of a central battery, requiring decentralised and less efficient storage solutions. |
| | Enabler | EMS_integration | Battery systems were integrated with local EMS to prioritise solar self-consumption and mitigate local grid congestion. |
| | Enabler | EMS_refinemens | The project enabled practical testing and refinement of EMS software and system design, contributing to organisational learning and innovation capacity. |
| Organisational | Barrier | Unclear_Roles | Diffuse project responsibilities led to unclear role divisions, causing inefficiencies in technical support and accountability. |
| | Barrier | User_autonomy_design | High level of user autonomy in housing design and system choices undermined system coherence and created coordination challenges. |
| | Barrier | Time_intensive_support | Managing interactions with 40+ residents for technical support proved time-intensive and unsustainable. |
| | Enabler | Stakeholder_collaboration | The energy cooperative demonstrated strong engagement, intrinsic motivation, and commitment to innovation, ensuring resilience through project challenges. |
| | Enabler | Early_enagement_technical_advisor | Technical advisor being involved from an early stage, and taking on extensive responsibility. |
| | Enabler | Residents_ technical_knowledge | Technical knowledge of residents. |
| | Enabler | Close_collaboration | Close collaboration between the EMS-provider and cooperative facilitated flexible problem-solving and adaptive project management. |
| Legal | Barrier | Future_legal_uncertainty | The end of the experimental grid arrangement risks legal and operational uncertainty for continued functioning under formal DSO oversight. |
| | Barrier | Permitting_constrain | Initial permitting constraints blocked the implementation of a centralised battery system, limiting design efficiency. |
| | Enabler | Cooperation | Establishment of an energy cooperative by residents provided a legal vehicle for collective ownership and governance of energy infrastructure. |
| | Enabler | VPP | The legal and technical possibility for Schoonschip to operate as a Virtual Power Plant (VPP) opens up new opportunities for demand-response services, additional revenue streams, and stronger integration with the wider electricity system |
| Financial | Barrier | Decentralized_solutions | Decentralised infrastructure design increased costs due to duplicated installations and complex maintenance requirements. |
| | Barrier | Limited_scalability | Limited financial scalability of small-scale energy hubs reduces business case viability and discourages replication. |
| | Enabler | Subsidies | Public subsidies enabled the pilot project to proceed, compensating for lack of commercial profitability. |
| | Enabler | Innovation_added_value | The project created long-term value for the EMS provider through experience gains and technological development, despite low direct financial returns. |

**Figure C.2:** Description Barrier & Enablers Schoonschip (Author)

| Themes | Type | Label | Description |
|---|---|---|---|
| Technical | Barrier | Forecasting_uncertainty | Uncertainty in load forecasting due to phased construction over a 10-year period creates challenges for accurate system sizing and planning. |
| | Barrier | Inflexible_large_consumers | Large-scale energy users, such as supermarkets and student housing, are difficult to control or shift, reducing system flexibility. |
| | Barrier | No_grid_data_acces | DSOs currently provide insufficient public access to real-time grid data, hindering effective planning and decision-making. |
| | Barrier | Grid_capacity_limit | Grid connection limits (e.g., 5.2 MW for the area) create operational risks and require complex real-time balancing. |
| | Enabler | Centralised_solution | Centralised thermal energy demand (heating and cooling) provides predictable, high-load profiles and a clear system design focus. When combined with thermal storage, it enables effective peak load reduction. |
| | Enabler | Predictable_profiles | Predictability of household energy profiles in high-density apartment blocks supports reliable system modelling. |
| | Enabler | EMS | Automated monitoring and real-time control systems help manage net capacity and avoid overload. |
| | Enabler | Regulatory_support | New regulations allow for new integrated technical design solutions |
| Organisational | Barrier | Complex_stakeholder_coordination | High number of stakholders and phased dilivery complicate coordination and commitment |
| | Barrier | Late_involvement_technocal_advisor | Energy decisions often remain vague due to institutional silos and late-stage involvement of technical experts. |
| | Barrier | Stakeholder_dependency | High dependency on central stakeholders like the municipality and key utility partners increases risk if actors withdraw. |
| | Barrier | Slow_Development | Leghty development time. |
| | Enabler | Stakeholder_collaboration | Collaborative alignment between responsible stakeholders ensures that shared objectives can be effectively achieved |
| | Enabler | Cooperation | A pre-existing area organisation facilitated the joint procurement of mobility and heating infrastructure, and provided a coordinated governance structure that enabled the application of a Group Transport Agreement (GTO) for shared grid access |
| | Enabler | Joined_procurement | Municipality and developers jointly procured central heating/cooling operator, fostering commitment, cooperation and scale. |
| | Enabler | Win_win_framing | Early on, clear win-win framing of collaboration by a technical advisor increased stakeholder willingness to engage. |
| | Enabler | Technical_advisor | A technical advisor with project management skills acted as a boundary-spanning actor, aligning technical decisions with broader project goals and ensuring implementation progress |
| | Enabler | DSO_recignition_nonresidential | Recognition by the DSO of the necessity to include non-residential loads, such as supermarketa, in large-scale area developments led to the development of a new contractform (GTO) |
| | Enabler | Willingness_DSO | The DSO took an exceptional role in enabling the pilot, showing institutional willingness to support innovation beyond standard procedures. |
| Legal | Barrier | Legal_liability_risk_DSO | Lack of legal clarity on liability in shared grid configurations creates risk aversion among DSOs |
| | Barrier | Legal_liability_risk_Developer | Contractual liability for exceeding grid capacity poses significant risk to the cooperation, particularly in a development with unpredictable and multi-actor peak demand. |
| | Barrier | Lack_of_legal_instrument | Lack of existing legal instruments for EHubs made implementation difficult before ACM policy change. |
| | Enabler | Cooperation | Creation of a legal cooperative as a grid contract holder enabled shared responsibility among stakeholders. |
| | Enabler | Obligation_connecting_dwellings | The legal obligation for DSOs to connect residential dwellings ensures a baseline of infrastructural commitment, which creates opportunities for innovative configurations to be realised within a guaranteed connection framework. |
| | Enabler | Pre_contracted_load | Pre-contracted connection in advance of building. No waiting-list problem. |
| | Enabler | Pilot | Support from the municipality to explore exceptions and innovative governance instruments enabled experimentation. |
| Financial | Barrier | High_upfront_investment | High upfront investments to ensure critical loads, while grid connection rights are not yet secured at permit stage. |
| | Barrier | Stakeholder_dependency | High investment requirements and interdependency between developers increase financial and coordination risk, especially in large-scale centralised energy systems. |
| | Barrier | Stakeholder_dependency | Dependence on shared infrastructure creates financial exposure and coordination risks for developers. |
| | Enabler | Pre_contracted_load | Contracted capacity was secured early through a group transport agreement (GTO), mitigating long-term investment risk. |
| | Enabler | Commitment_stakholders | Developer consortioum was willing to invest upfront in storage assets. Project leaf paid for the battery system upfront to ensure garanteed supply. This commitment made the EHub viable. |
| | Enabler | Flexibility | To be affordable for its consumers, the energy system must be flexible, allowing the choose to purchase energy at the lowest cost. |

**Figure C.3:** Description Barrier & Enablers Republica (Author)

# D

# List of Interviews

**Table D.1:** Overview of Interviews Conducted

| Date & Time | Position of Interviewee |
|---|---|
| March 15, 2025 – 10:00 AM | Technical Advisor Ehub |
| March 20, 2025 – 2:30 PM2 | Lawyer |
| March 25, 2025 – 9:00 AM | Technical Advisor SS |
| March 25, 2025 – 9:00 AM | Technical Advisor RP |
| April 5, 2025 – 11:00 AM | Technical Advisor MW |
| April 6, 2025 – 11:00 AM | Energy Transition Advisor |
| April 16, 2025 – 14:00 AM | TU Delft Phd cadidate |
| April 17, 2024 – 15:30 AM | Grid operator MW |
| April 19, 2025 – 8:30 AM | MKGG |

# E

# List of Attended Events

**Table E.1:** Overview of Attended Events

| Date | Organiser | Event |
|---|---|---|
| November 18th, 2024 | NEPROM | Bijeenkomst Netcongestie |
| February 2nd, 2025 | SSF/ABN AMBRO | Bijeenkomst Energiehubs in Nieuwbouwwijken |
| April 29th, 2025 | Hogeschool Utrecht | Energiehubs |
| May 19th, 2025 | Provincie Zuid-Holland/SSF | Community of Practice (COP) - Energiehubs 4 |

# F

# Interview Questions

During the course of this research, the focus of the study shifted after the interviews had been conducted. It became apparent that the original research questions did not fully align with the emerging insights and needs of the topic. Fortunately, the interviews still provided rich and relevant data, which allowed for thematic coding to be applied despite the revised set of themes. This flexibility ensured that the research remained meaningful and responsive to the complexity of the subject matter.

# Interview Questions - Master Thesis Lucrees Talsma

**Part 1: Introduction**

*Explain research goal, consent form*

1. Can you briefly introduce yourself?
2. What was your role in [Case Project]?
3. How did you become involved?
4. Can you describe the energy hub formation for me:
    a. Input
    b. System
    c. Output
    d. Phase of lifecycle
    e. How is the project financed?

**Part 2: MANA Network**

A. Actor Identification & Roles (MANA: Actors, Objectives)

- "Who were the key stakeholders in this project? Who had the most influence? And the most knowledge?"
- "What were each group's primary goals? Were there conflicting objectives?"
- "How were decisions made?
- "Were you part of a legal entity within the energy hub?"

B. Resources & Dependencies (MANA: Resources, Dependencies)

- "Which stakeholders controlled critical resources (funding, expertise, land)?"
- "Were there tensions over resource allocation? How were they resolved?"

C. Relationship Mapping (MANA: Relationships, SNA Concepts)

- "How would you describe the trust level between stakeholders?"
- "Were there formal/informal communication channels?"

**Part 3: Collaboratieve governance**

A. Starting Conditions (Ansell & Gash: Preconditions)

- "Was there prior collaboration or conflict among stakeholders?"
- "How were power imbalances addressed?"

B. Institutional Design (Ansell & Gash: Ground Rules)

- "What formal rules or agreements guided collaboration?"
- "How were diverse perspectives included (e.g., residents vs. corporations

C. Facilitative Leadership (Ansell & Gash: Leadership)

- "Was there a neutral mediator or lead organization? How effective were they?"

D. Collaborative Process (Ansell & Gash: Dialogue, Trust)

- "Can you describe a moment where trust was built (or broken)?"
- "How were conflicts resolved?"
-

Part 4: Succesfactors and Barriers?

- "What most enabled the project's success?"
- "What were the biggest hurdles? How could they be avoided?"

Part 5: Reflection and Future

- If you could redesign the governance model, what would you change?
- What advice would you give to similar projects?

* Would you/your company still participate in the energy hub if net congestion was not an influence in the future

*Thank for participation and inform on the review of the transcript and the review period*

# G
# Consent Form

## Introductie onderzoek

U wordt uitgenodigd om deel te nemen aan een onderzoek genaamd: "Energyhubs als oplossing voor gebiedsontwikkeling: Woningbouw mogelijk maken ondanks netcongestie in Nederland."

Dit onderzoek wordt uitgevoerd door Lucrees Talsma van de TU Delft in samenwerking met Fakton Energy.

Het doel van dit onderzoek is om inzicht te krijgen in samenwerkingsnetwerken binnen Energy Hubs en te analyseren hoe verschillende stakeholders samenwerken bij de implementatie van deze systemen in gebiedsontwikkelingen met woningen. Hoewel Energy Hubs in Nederland een veelbelovend concept zijn, bevinden ze zich momenteel voornamelijk in de pilotfase en zijn ze nog niet grootschalig toepasbaar binnen residentiële en gemengde stedelijke ontwikkelingsprojecten.

Dit onderzoek richt zich daarom op de barrières en succesfactoren die de opschaling van Energy Hubs belemmeren of bevorderen. Door de ervaringen van beleidsmakers, netbeheerders, ontwikkelaars en andere betrokken partijen te onderzoeken, biedt deze studie nieuwe inzichten in de governance- en samenwerkingsmodellen die nodig zijn om Energy Hubs op grotere schaal te kunnen gaan implementeren.

De resultaten van dit onderzoek zullen bijdragen aan het identificeren van kritische knelpunten, best practices en beleidsaanbevelingen die de haalbaarheid van Energy Hubs in gebiedsontwikkelingen kunnen vergroten.

Het interview zal **ongeveer 45 minuten** in beslag nemen.
De onderwerpen omvatten stakeholderbetrokkenheid, besluitvormingsprocessen en succesfactoren voor samenwerking.

De data zal gebruikt worden voor academisch inzicht in dit onderwerp. Het zal na afloop worden gepubliceerd op de TU Delft Repository site. U wordt gevraagd om wat **semigestructureerd vragen** op dit onderwerp te beantwoorden.

Zoals bij elke onlineactiviteit is het risico van een databreuk aanwezig. Wij doen ons best om uw antwoorden vertrouwelijk te houden.

We minimaliseren de risico's door de volgende maatregelen toe te passen:

- **Opname en transcriberen**: Het interview wordt audio-opgenomen via Microsoft Teams. De opname wordt getranscribeerd en vervolgens gepseudonimiseerd.
- **Herleidbaarheid Minimaliseren**: Uw persoonlijke gegevens (naam, bedrijf, functie) worden verwijderd of vervangen door generieke termen (bijv. "beleidsmaker" i.p.v. "projectleider bij gemeente X") om uw anonimiteit te waarborgen.
- **Opslag en beveiliging:**
  Originele opnames en transcripties worden veilig opgeslagen op de TU Delft OneDrive, met toegang beperkt tot de onderzoeker en de begeleider. Informed consent formulieren worden apart bewaard op de TU OneDrive om herleidbaarheid te voorkomen.
- **Verwijdering van data**: Audio-opnamen worden vernietigd na transcriptie en verificatie door de deelnemer. Persoonlijk identificeerbare gegevens worden vernietigd een maand na publicatie van de masterthesis.

Uw deelname aan dit onderzoek is volledig vrijwillig, en u kunt zich elk moment terugtrekken zonder reden op te geven. U bent vrij om vragen niet te beantwoorden, en om uw gegevens te laten corrigeren of verwijderen tot aan de verdediging van de masterthesis. Daarna kunnen anonieme gegevens niet meer worden teruggetrokken.

Indien u vragen heeft over het onderzoek of uw rechten als deelnemer, kunt u contact opnemen met:

Uitvoerend onderzoekster: Lucrees Talsma

Begeleidend onderzoeker: Prof. Willem Korthals Altes

| PLEASE TICK THE APPROPRIATE BOXES | Yes | No |
|---|---|---|
| **A: GENERAL AGREEMENT – RESEARCH GOALS, PARTICPANT TASKS AND VOLUNTARY PARTICIPATION** | | |
| 1. Ik heb de informatie over het onderzoek gedateerd [*11/03/2025*] gelezen en begrepen, of deze is aan mij voorgelezen. Ik heb de mogelijkheid gehad om vragen te stellen over het onderzoek en mijn vragen zijn naar tevredenheid beantwoord. | ☐ | ☐ |
| | | |
| 2. Ik doe vrijwillig mee aan dit onderzoek, en ik begrijp dat ik kan weigeren vragen te beantwoorden en mij op elk moment kan terugtrekken uit de studie, zonder een reden op te hoeven geven. | ☐ | ☐ |
| | | |
| 3. Ik begrijp dat mijn deelname aan het onderzoek de volgende punten betekent:<br>- **Type gegevensverzameling**: De informatie wordt verzameld door middel van semigestructureerde interviews, die worden audio-opgenomen via Microsoft Teams.<br>- **Opname en transcriptie**: Alle interviews worden volledig getranscribeerd in tekst en gepseudonimiseerd, waarbij namen, bedrijfsnamen en andere herleidbare informatie worden verwijderd of vervangen door generieke termen.<br>- **Vernietiging van opnames:** Na transcriptie en goedkeuring door de deelnemer worden de audio-opnames permanent verwijderd om de privacy van deelnemers te waarborgen.<br>- **Bevraging en verwerking:** De interviews worden afgenomen door de onderzoeker, en de deelnemer beantwoordt de vragen mondeling. Ook kunnen er tijden het interview aantekeningen worden gemaakt door de onderzoeker.<br>- **Minimalisering van persoonsgegevens:** Alleen strikt noodzakelijke persoonsgegevens worden verwerkt, en alle data wordt zo vroeg mogelijk gepseudonismiseerd om herleidbaarheid te voorkomen. | ☐ | ☐ |
| | | |
| 4. Ik begrijp dat de studie eindigt na de verdediging van de masterthesis in juni 2025.<br>*- De verzamelde gegevens zullen worden bewaard tot een maand na de verdediging, waarna alle persoonlijke gegevens worden vernietigd.* | | |
| | | |
| **B: POTENTIAL RISKS OF PARTICIPATING (INCLUDING DATA PROTECTION)** | | |
| 6. Ik begrijp dat mijn deelname de volgende risico's met zich meebrengt:<br>- Professionele gevoeligheid: Deelnemers delen mogelijk inzichten over samenwerkingen en besluitvorming binnen Energy Hub-projecten, wat gevoelig kan liggen binnen hun organisatie of sector.<br>- Cognitieve belasting: Deelnemers kunnen ervaren dat zij complexe of diepgaande vragen moeten beantwoorden over samenwerkingsprocessen, wat mentale inspanning kan vergen. | ☐ | ☐ |

| PLEASE TICK THE APPROPRIATE BOXES | Yes | No |
|---|---|---|
| - Mogelijke invloed op relaties: Het bespreken van uitdagingen of knelpunten in samenwerkingstrajecten kan, afhankelijk van de context, invloed hebben op de professionele verhoudingen tussen stakeholders.<br>Ik begrijp dat deze risico's worden geminimaliseerd door:<br>- **Vrijwillige deelname**: Deelnemers kunnen op elk moment besluiten om te stoppen zonder opgaaf van reden.<br>- **Anonimiteit en vertrouwelijkheid**: Alle interviews worden gepseudonismiseerde, en persoonlijke gegevens worden niet gedeeld met derden. Alleen de onderzoeker en de verantwoordelijke begeleider hebben toegang tot de oorspronkelijke data.<br>- **Beperkte toegang en veilige opslag**: Audio-opnames en transcripties worden beveiligd opgeslagen op de TU Delft OneDrive, met toegang beperkt tot geautoriseerde onderzoekers.<br>- **Controle door de deelnemer:** Na transcriptie ontvangt de deelnemer een gepseudonumiseerde versie van het interview. Deelnemers krijgen 14 dagen om correcties of redactionele wijzigingen aan te vragen. Als er binnen deze periode geen reactie wordt ontvangen, wordt het transcript als goedgekeurd beschouwt.<br>- **Optie om vragen niet te beantwoorden**: Deelnemers mogen vragen overslaan als zij zich ongemakkelijk voelen bij bepaalde onderwerpen. | | |
| | | |
| 7. Ik begrijp dat mijn deelname betekent dat er persoonlijke identificeerbare informatie en onderzoek data worden verzameld, met het risico dat ik hieruit geïdentificeerd kan worden:<br>- **Professionele herkenbaarheid:** Omdat de studie zich richt op Energy Hubs, een relatief nieuw en specialistisch onderwerp, kunnen deelnemers met unieke expertise of specifieke functies mogelijk indirect herkenbaar zijn.<br>- **Sectorspecifieke context:** De combinatie van functietitel, organisatie en projectervaring kan leiden tot herleidbaarheid, zelfs na pseudonimisatie.<br>- **Publieke of professionele reputatie:** Deelnemers kunnen inzichten delen over samenwerkingsuitdagingen of beleidskeuzes binnen hun organisatie, wat gevoelig kan zijn in een professionele context. | ☐ | ☐ |
| | | |
| 8. Ik begrijp dat de volgende stappen worden genomen om het risico van een databreuk te minimaliseren, en dat mijn identiteit op de volgende manieren wordt beschermd in het geval van een databreuk: pseudonimisatie van gegevens, beveiligde opslag bescherming tegen ongeautoriseerde toegang en vernietiging van persoonlijke data. | ☐ | ☐ |
| | | |
| 9. Ik begrijp dat de persoonlijke informatie die over mij verzameld wordt en mij kan identificeren, zoals naam, werk, emailadres en telefoonnummer, niet gedeeld worden buiten het studieteam. | ☐ | ☐ |
| 10. Persoonlijk identificeerbare gegevens worden vernietigd een maand na de verdediging van de master thesis (Naar verwachting begin augustus 2025). | ☐ | ☐ |
| | | |
| **C: RESEARCH PUBLICATION, DISSEMINATION AND APPLICATION** | | |

| PLEASE TICK THE APPROPRIATE BOXES | Yes | No |
|---|---|---|
| 12. Ik begrijp dat na het onderzoek de gepseudonimiseerde informatie gebruikt zal worden voor kennisdeling binnen de academische en professionele gemeenschappen, evenals voor mogelijke secundaire toepassing in vervolgonderzoek | ☐ | ☐ |
| | | |
| 13. Ik geef toestemming om mijn antwoorden, ideeën of andere bijdragen in geaggregeerde vorm te citeren in de resulterende producten van dit onderzoek | ☐ | ☐ |
| **D: (LONGTERM) DATA STORAGE, ACCESS AND REUSE** | | |
| 14. Ik geef toestemming om uitsluitend geaggregeerde resultaten uit het onderzoek te archiveren in de TU Delft Repository, zodat deze kunnen worden gebruikt voor toekomstig onderzoek en onderwijs. Pseudonimiseerde transcripties of ruwe data worden niet openbaar gedeeld.. | ☐ | ☐ |

**Signatures**

11-03-2025

Naam

Handtekening

Datum

Ik, **de wettelijke vertegenwoordiger**, verklaar dat de informatie en het instemmingsformulier aan de potentiële deelnemer correct zijn voorgelezen, en dat hij/zij de kans heeft gekregen om vragen te stellen. Ik verklaar dat de potentiële deelnemer zijn/haar instemming vrijwillig heeft gegeven.

Naam wettelijke vertegenwoordiger Handtekening Datum

Ik, **de onderzoeker**, verklaar dat ik de informatie en het instemmingsformulier correct aan de potentiële deelnemer heb voorgelezen en, naar het beste van mijn vermogen, heb verzekerd dat de deelnemer begrijpt waar hij/zij vrijwillig mee instemt.

Lucrees Talsma

-

Handtekening

Naam

Datum

Contactgegevens van de onderzoeker voor verdere informatie: Lucrees Talsma,