Tackling Grid Congestion: Governing Energy Hubs in Dutch Business Parks

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Abstract

This research investigates the organizational and governance dynamics of energy hubs (EHs) as a solution to grid congestion in Dutch business parks. The researcher used a qualitative multiple-case study approach, gathering data through desk research and semi-structured interviews with eight stakeholders involved in energy hub projects. The analysis identifies key stakeholder groups and examines their roles, interests, and challenges. The researcher categorizes stakeholder insights into four main themes: needs, functionalities, constraints, and opportunities. Notable opportunities include using Group Transport Agreements (GTOs) to optimize grid capacity, shared battery storage to mitigate congestion, and real-time energy management systems (EMS) to enhance operational efficiency. Recurring barriers to implementing energy hubs include high initial investments, limited access to capital, unclear legislative frameworks, liability concerns, technical complexity, and resistance to change. The findings highlight the need for structured business models, clear regulations, and enhanced stakeholder collaboration to facilitate energy hub development. This research provides practical insights for energy decision-makers and stakeholders engaged in mitigating grid congestion and supporting local sustainability.

Keywords

Energy hubs, grid congestion, decentralized energy systems, stakeholder governance, Dutch business parks, and regulatory barriers.

Introduction

In the Netherlands, renewables comprised 48% of electricity production in 2023, but grid congestion increasingly limits capacity for new connections, hindering business growth and sustainable development (Netherlands, 2024; Statistiek, 2023). Energy hubs(EHs), localized systems for energy generation, storage, and sharing, offer a decentralized solution to ease grid strain and support renewable integration (Eladl et al., 2023). However, their governance and stakeholder dynamics in Dutch business parks remain underexplored. This study investigates these challenges, focusing on organizational and regulatory barriers. The paper proceeds with a literature review, case study, methodology, stakeholder analysis, findings, discussion, conclusion, and future work.

Climate change and environmental degradation are important issues facing society today. In response, the European Union's Green Deal targets climate neutrality by 2050, accelerating the shift to renewable energy (*Transforming Our World*, n.d.). In 2024, greenhouse gas emissions in the Netherlands declined, driven primarily by cleaner electricity generation and transportation, despite an increase in industrial emissions (Bergeijk, 2025; PhilipSchmitz, 2024). However, as renewable energy continues to grow rapidly, new challenges emerge, particularly related to grid congestion and capacity limitations. These new challenges emphasize the need to investigate alternative solutions to effectively manage the increasing demands of the energy transition.

One issue is that renewable energy sources, like solar and wind power, do not produce a steady amount of electricity all day because they depend on the weather (Papaefthymiou & Dragoon, 2016, p. 1). Another challenge is that electricity generation is becoming more decentralized. In the past, power mostly came from large fossil-fuel power plants, which made it easier to control the supply and demand. The Dutch grid was designed for this centralized system, where electricity was produced in a few big locations and then distributed to users. This setup helped keep the grid stable and reliable (*Basisdocument over energie-infrastructuur (oktober 2019)*, 2019). However, as more energy comes from smaller, scattered sources, the grid needs to adapt to this new reality.

The current situation of the Dutch electricity grid demonstrates that limited grid capacity is a problem, and initiators of new projects frequently encounter restrictions on electricity connections. Connecting essential facilities such as new hospitals, residential neighborhoods equipped with heat pumps and electric vehicle chargers, or electric boilers becomes challenging or impossible without adequate grid capacity. Considering these limitations, exploring alternative options to increase grid capacity beyond traditional grid upgrades is crucial to facilitate quicker connection of new consumers.

Upgrading the grid is an expensive and time-consuming process, largely due to complicated regulatory procedures (*Basisdocument over energie-infrastructuur (oktober 2019)*, 2019). Consequently, new connections to the grid often cannot be approved, further limiting growth and innovation. One promising way to ease these issues is through decentralized energy generation. This approach involves producing renewable energy locally, making the system more stable, flexible, and adaptable to changing energy demands. By enabling quicker deployment without lengthy approval processes, decentralized systems help reduce pressure on the grid, and make renewable energy integration more practical and responsive. Nevertheless, decentralized systems often require higher initial investments. Despite this, their ability to reduce congestion, accelerate implementation, and improve the flexibility of renewable energy integration makes them a valuable solution in addressing current grid challenges.

In this case, local energy communities are stepping up to be part of the solution. For these communities, balancing effectiveness, cost, and environmental impact is important. This paper investigates how EHs can help address grid congestion by examining governance structures and stakeholder roles. The study uses a PESTEL framework alongside thematic analysis to assess how political, economic, social, technological, environmental, and legal factors influence EH deployment.

Energy Hub. An energy hub is a local system that integrates multiple energy sources, such as solar panels and batteries, to manage supply and demand efficiently. It enables energy generation, storage, and sharing among businesses, reducing grid congestion and enhancing sustainability (Eladl et al., 2023). Using real-time energy management systems (EMS), EHs optimize renewable energy use and support grid stability (*Optimizing Microgrid Efficiency, Resilience and Cost Savings*, n.d.). In Dutch business parks, limited grid capacity holds back growth by restricting new business connections, expansion plans, and integrating sustainable technologies. EHs provide a practical, local alternative to expensive grid upgrades. Therefore, EH serves multiple purposes at once, it is anticipated that they could promote sustainability, improve reliability, and help keep energy costs manageable within the energy network (Eladeb et al., 2025).

Case study: The Municipality of Best. Best, a town in North Brabant near Eindhoven, has a thriving economy driven by its industrial, logistics, and technology sectors, with infrastructure supporting both businesses and residents. Its flat landscape and adequate spring-summer sunlight make it ideal for solar energy production, with significant potential for rooftop solar panels on industrial, commercial, and residential buildings.

However, the shift towards decentralized solar energy challenges the local electricity grid. The grid must adapt to manage the fluctuating input from renewable sources, especially since solar energy generation is considerably lower in the fall and winter months. During this time, electricity demand tends to rise due to increased heating needs. Historically, heating has relied primarily on natural gas, but there is now a transition towards electric heat pumps, which further elevates electricity consumption in winter. This change necessitates careful planning and adaptation of the energy infrastructure to balance renewable energy production with seasonal energy demands.

Problem statement. Grid congestion increasingly hinders the growing demand for renewable energy and business expansion in the Netherlands, blocking local stakeholders from seizing opportunities related to sustainable development. This study considers EHs a potential solution to grid congestion, as they support renewable integration and local business operations. Despite the presence of existing studies on EHs, they often overlook the specific roles, interests, and challenges encountered by these key stakeholders within the context of regulatory frameworks. Furthermore, much of the literature approaches the topic from the technical or economic dimensions or from a broad international perspective, which may not adequately address the unique policies and regulations relevant to the Dutch context. To fill this gap, this study analyzes how governance structures and stakeholder collaboration shape the development and implementation of EHs in Dutch business parks.

Research Goal: This research examines how EHs are managed and organized in Dutch business parks, with a focus on the role of renewable energy in supporting grid stability. It originated in the municipality of Best, where grid congestion raised specific concerns. To gain broader insight, the study also includes additional cases from the surrounding region, drawing on experiences from various stakeholders involved in EH projects.

RQ. What economic, technical, and operational challenges do stakeholders face in deploying energy hubs in Dutch business parks, and how can governance structures address them?

- **SQ1.** How can regulatory and market barriers hinder the EH implementation in Best's business parks be addressed?
- **SQ2.** How does local energy balancing through EHs impact grid congestion?
- **SQ3.** What local challenges hinder successful EH implementation in Dutch business parks?

Background of Energy Hubs

An energy hub is a smart local energy system where companies work together to produce, store, and use sustainable energy (*Innovatieprojecten*, n.d.). Think of electricity, heat, or gas. In a hub, they make agreements on how to share and manage energy, including how it is generated, stored, transported, and used. It is a shared solution for businesses that want to grow or become more sustainable but are limited by the current power grid capacity.

Currently, developers mostly establish EHs at the local level, such as in business parks or neighborhoods, rather than across entire cities or regions. This is because of how the electricity grid is set up. The current focus is on supporting hubs in business parks and industrial areas, where grid congestion is already a big problem, especially on the high and medium voltage lines. Many customers face issues like limited grid access and power transport shortages, meaning they cannot always get the electricity they need. EHs help solve this by making better use of the grid, helping companies smooth out their energy use. They also open the door to adding other energy sources in the future, like heat or hydrogen, making the whole system more sustainable and flexible.

Every EH is unique, differing in design, technology, and organizational setup based on local needs and conditions, so there are several pilot projects to find the best way to support each one. This brings many benefits to customers. They are testing new tools that help share data about how the grid works, where energy is going, and what the limits are. With this information, customers get a clearer view of their EH and how much capacity they have, which helps them plan better and save money.

Literature review

The idea of an energy hub first came up in a project called VOFEN, where it was seen as a system that connects different types of energy, like electricity or natural gas, and makes it possible to store, convert, and deliver energy in useful forms (Andersson, 2007; Mohammadi et al., 2017). These systems were mainly studied from a technical angle, showing potential to reduce emissions and costs, ease congestion on the grid, and improve energy efficiency. Recently, researchers have shifted their focus to include the social and organizational aspects of EHs. According to RVO (*Hoe helpt de routekaart Samenwerken in energiehubs u?*, n.d.), they can be seen as local partnerships where different parties agree to work together on producing, sharing, storing, and using energy in a coordinated way.

In practice, EHs often rely on a mix of energy sources, both renewable, like solar and wind, and conventional, such as electricity and gas. Research by Eladl et al. (2023) shows that electricity and natural gas are the most common inputs in EH studies (Figure 1), followed by solar and wind energy (Eladl et al., 2023).

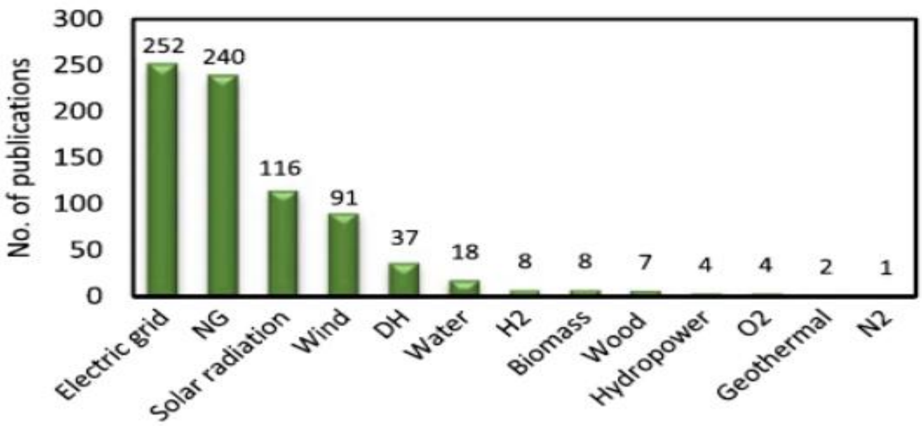

Figure 1. Most common inputs for EHs in previous studies (Eladl et al., 2023)

A mix of energy sources in EH requires conversion before they can be used. This is where converters come in, technologies like transformers, boilers, heat exchangers, electrolysers, fuel cells, and compressors help turn one form of energy into another (Mohammadi et al., 2017). Some converters, like combined heat and power (CHP) systems, are especially valuable because they can produce both heat and electricity from a single source, improving overall efficiency. CHP is frequently mentioned in EH studies for its versatility and performance (Eladl et al., 2023; Mohammadi et al., 2017).

Alongside converters, energy storage is another key component. Storage supports supply-demand balance, particularly with variable sources like solar and wind. Common storage types include batteries, thermal storage, hydrogen, natural gas, and even ice (Eladl et al., 2023). What EHs provide depends on the needs of their users. Most often, they supply electricity and heat, but in some cases, they also deliver cooling, gas, or hydrogen. These hubs can be set up in various locations, from residential neighborhoods to industrial parks and even transport hubs like ports and airports (Geidl et al., 2007).

EHs are generally grouped into four categories based on where they're used: residential, commercial, agricultural, and industrial (Eladl et al., 2023; Motallebi Azar et al., 2020). This study focuses on hubs located in business parks, which fall under the industrial category. Since industry is the world's biggest energy consumer, it has a major role to play in cutting greenhouse gas emissions and improving energy efficiency (Motallebi Azar et al., 2020). Industrial EHs are particularly valuable because energy use in these settings is often more predictable than in homes or offices, which can make planning and implementing such systems easier (Lachut et al., 2014). However, the shift towards renewable energy and smart grid in industry can be challenging and costly, and the high upfront investment often slows down the adoption of smart and clean energy solutions (Motallebi Azar et al., 2020).

Beyond the technical and physical side of EHs, their success also depends heavily on how well different stakeholders work together. In this research, the focus is on how these collaborations and governance structures function within business parks. While there is limited academic work on this specific topic, the study will draw insights from existing research in related areas. Vereshchagina et al. (2015) highlight the importance of stakeholders' engagement in the development of smart grid technologies and renewable energy across the European Union (Vereshchagina et al., 2015). They point out that if some parties are reluctant to participate, it can slow down progress significantly. The authors suggest that governments should play a proactive role in raising awareness about the benefits of these technologies. However, their focus is more on broader system-level aspects than on the specific project-level interactions and challenges in countries like the Netherlands.

Rodin & Moser (2021) examined the obstacles to industrial energy cooperation and organized them into five main categories: economic barriers, social and managerial barriers, framework barriers, technical and engineering barriers, and information provision barriers (Rodin & Moser, 2021). Their study identified a total of 100 distinct barriers spread across these categories, each linked to various phases of implementation. For instance, some governance and organizational challenges include a lack of trust between companies and park managers or service providers. Some regulations may hinder the adoption of specific technologies, as well as frameworks that restrict effective collaboration in the gas and electricity sectors. These examples highlight the complex landscape of challenges that stakeholders face in achieving successful energy cooperation.

In summary, existing research provides valuable insights into energy governance and cooperation but fails to focus specifically on business parks in the Netherlands or to comprehensively analyze stakeholder dynamics and barriers. This new research aims to bridge that gap and offer actionable solutions for developing EHs within the country's regulatory framework.

Research Methodology

This study follows a research design (see Figure 2) where we worked through the three steps, Explore, Implement, and Validate to explore how EHs are governed and put into practice in business parks. We employed the industry-as-laboratory approach, which is a widely used research method in systems engineering (Falk & Muller, 2019).

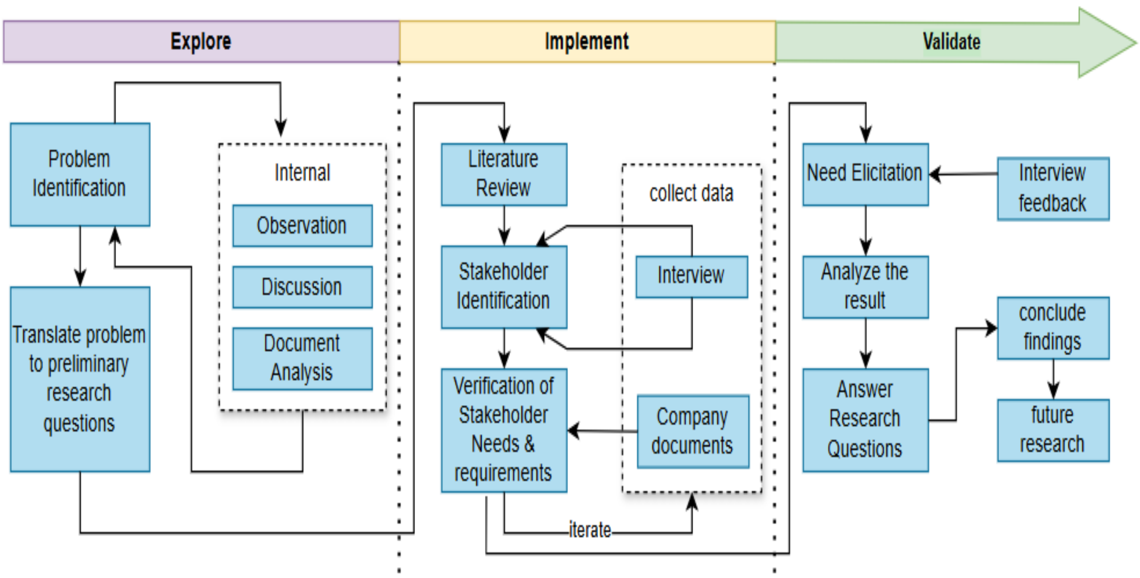

Figure 2. Research Design

No	Stakeholder's Role
1	Local energy cooperative, active in a workgroup on strategy and energy storage
2	Chair (solar park)
3	Project manager energy transition / owner
4	Program manager
5	Project manager / senior consultant
6	Director of digital system
7	Chair Best Duurzaam, active in Energy corporation Best Energie
8	Board member

Step 1 - Explore. In the exploration phase, the aim was to identify the problem within the desired area. We followed an iterative process, continuously incorporating feedback and revisions from the supervisor until we approved a specific method. The problem identification was based on observation, informal discussions, and document review. Through this process, we were able to find preliminary research questions.

Step 2 - Implement. This phase began with a literature review of academic papers, policy documents, and industry reports on EHs, grid congestion, and stakeholder dynamics. The study examined multiple EH projects in Dutch business parks, selected for their variation in size, stage of development (from early planning to full operation), and implementation strategies. This ensured a comprehensive understanding of EH governance across different contexts.

Semi-structured interviews. We selected semi-structured interviews for their capacity to support exploration and discovery (Muller, 2013). The researcher conducted all interviews online with participants from businesses, distribution system operators (DSOs), municipalities, and hub managers directly involved in the projects. Each session lasted between 30 and 60 minutes. We tailored the questions to each group and explored governance models, regulatory challenges, technical issues, and stakeholder roles (Table 1). After each interview, we summarized the insights and documented them in a spreadsheet, which included 68 statements across all cases. The researcher then coded the statements thematically to identify recurring patterns. We grouped the findings into four categories: needs, functionalities, constraints, and opportunities. Linking these categories to relevant PESTEL factors added contextual depth to the analysis. This process helped us align stakeholder insights with our analytical framework and allowed us to interpret the results consistently.

Table 1. Interviewed participants' role

Step 3 - Validate. Findings validated through triangulation, comparing interview data with literature and project documents. Moreover, we got feedback directly from interviewees through follow-up meetings. This approach provided a robust understanding of EH governance, addressing the research question: *What economic, technical, and operational challenges do stakeholders face in deploying energy hubs in Dutch business parks, and how can governance structures address them?*

Analysis and Findings

This section examines the key stakeholders involved in EHs across business parks in the Netherlands, analyzes their needs and concerns, and presents the findings derived from a qualitative stakeholder analysis.

Stakeholder analysis. EHs involve a diverse range of stakeholders. Building on earlier studies (Heuninckx et al., 2022; Rodin & Moser, 2021; Sepponen & Heimonen, 2016), this research adapts stakeholder categories to fit the Dutch business park context. Key groups include end users (businesses), government bodies (Ministry of Economic Affairs and Climate, provinces, municipalities, ACM (The Authority for Consumers and)), service providers (TenneT, Stedin, Liander, Enexis), intermediaries (such as hub managers), and financial actors like banks and investors. Figure 3 visualizes these roles.

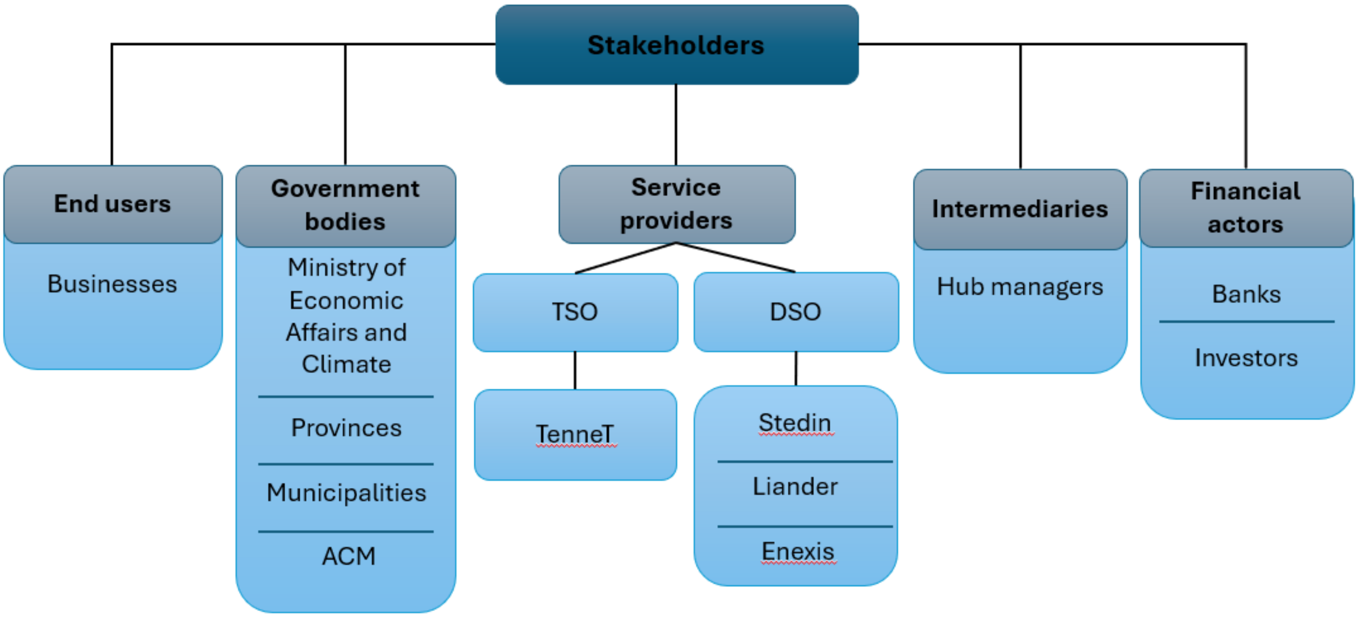

Figure 3. EH stakeholders

This section focuses on the four stakeholder groups most directly involved in the EH projects: businesses, DSOs, municipalities, and energy co-ordinators or hub managers (Table 2). The analysis will examine their roles, interests, and the challenges they face. It uses interviews and spreadsheet data to quantify stakeholder mentions, highlight dominant issues, and link findings to specific cases.

Although the wider energy system includes other important actors like TenneT as a Transmission System Operator (TSO), ACM, the national government, provinces, and financial institutions, this analysis concentrated on those who are most closely connected to the specific EH cases studied. This study intentionally focused on stakeholders directly involved in the projects and conducted interviews mainly with them, as engaging broader systemic actors was less practical.

Stakeholders	Responsibilities	Interests	Challenges
Businesses	Share data Invest in assets Adopt energy practices	Sustainability Grid capacity Growth	Financial uncertainty Data sharing reluctance Expertise gaps
DSO	Inform about current capacity & grid infrastructure Maintain the safety & reliability of the network Follow & enforce relevant regulations Manage contract agreements	Alleviate grid congestion Enhance overall system performance Improving flexibility in energy use and supply	Increased demand for the electricity network Responsibility & risk management
Municipalities	Manage approval processes Subsidies Facilitate collaboration between stakeholders Lobby for changes in laws & regulations	Business growth Mitigate grid congestion Work toward sustainability targets	Clarify responsibilities and level of involvement Decide when and how to engage in the project Concern about losing control to private sector interests
Hub Managers/ Energy Connectors	Encourage cooperation Keep stakeholders working toward shared goals Apply diverse expertise to link the involved parties	Support the shift to sustainable energy Successfully carry out project strategies	Build strong partnerships & engagement Navigate unfamiliar challenges

Table 2. Summary of stakeholder roles, interests, and challenges in EH projects

Figure 4 illustrates the relationships among the various stakeholders involved in an EH. The orange boxes represent key institutional actors who shape the legal, financial, and regulatory framework. The green boxes depict operational stakeholders, who are directly involved in the coordination, implementation, and day-to-day functioning of EHs.

At the heart of an EH are several businesses that collaborate through participant contracts. As a group, they also enter into a contract with the DSO, which manages how their shared energy use affects the larger grid. Setting up an EH takes a lot of coordination, and this is where the energy coordinator or hub manager comes in. Their main job is to act as a connector between everyone involved. Local or national governments often facilitate these coordinators.

Municipalities play a hands-on role by issuing permits, organizing stakeholders, and supporting subsidy applications. Financial support can come from banks, investors, and public subsidies, while the national government is responsible for creating the laws and regulations that guide both the EHs and the DSO. When needed, municipalities and coordinators may lobby for regulatory adjustments or pilot project exemptions. The ACM oversees whether projects comply with existing laws and grid codes. Often, the coordinator, municipality, and participating businesses form a leadership committee to manage the project's progress and ensure transparent collaboration across all levels.

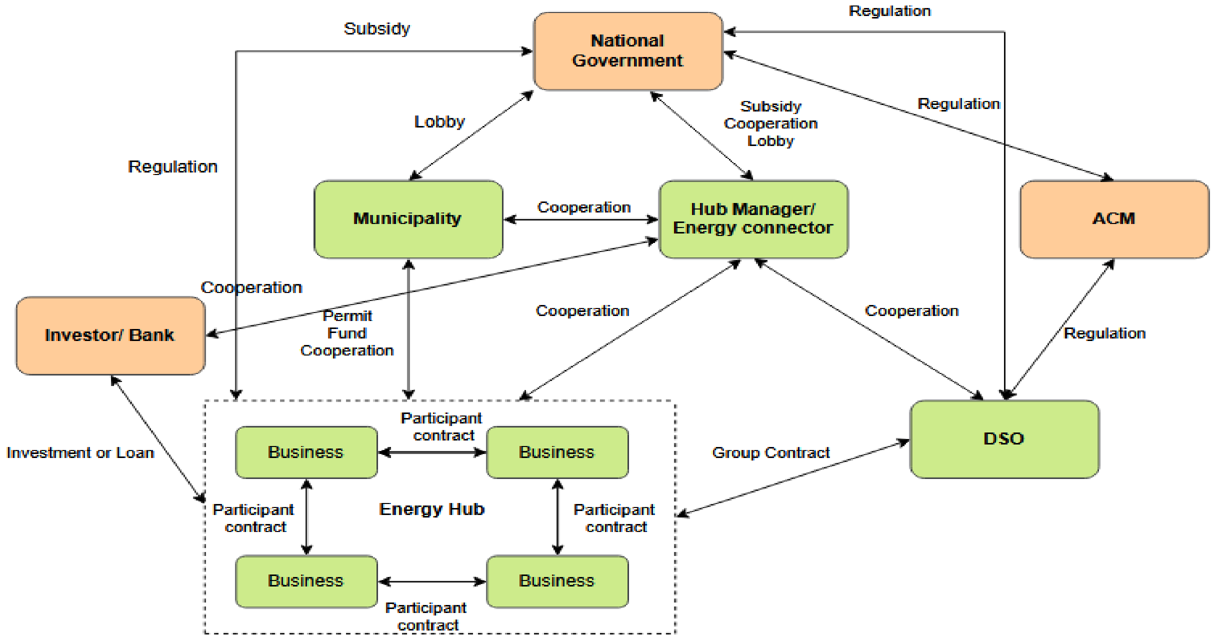

Figure 4. Stakeholder Relationship Diagram

It is worth noting that this chart shows how things work in a single EH, but there is also a lot of collaboration between people working in different hubs. The overall process requires strong teamwork, and the coordinators play a key role in making that happen.

PESTEL Analysis

A PESTEL analysis is a way to analyze and monitor major external factors influencing a system (Johnson et al., 2005). It stands for Political, Economic, Social, Technological, Environmental, and Legal aspects. The following table (Table 3) expands the PESTEL analysis, synthesizing stakeholder insights and findings from EH projects in Dutch business parks.

Political (P). Political factors present both enablers and obstacles. National energy policy plays a crucial role in shaping the legal and operational environment for EHs. However, delayed approvals and a lack of political urgency can hinder timely implementation(Potter, 2016) . Stakeholders emphasized the need for policy advocacy and lobbying to enable regulatory changes, especially regarding shared energy use and ownership models. Moreover, dependency on national political decisions creates uncertainty, particularly for long-term investments, operational planning, and access to grid infrastructure.

Economic (E). Economic constraints are often a major barrier. High upfront investments in battery storage, EMS, and grid infrastructure pose risks to developers and businesses. Many stakeholders cited difficulty in accessing capital and pointed to unclear or delayed financial returns as critical deterrents. Resource limitations and potential economic losses from current grid congestion further exacerbate these concerns, making financial viability a key issue in EH adoption.

Social (S). Social acceptance and engagement emerged as essential for successful EH deployment. Limited public awareness and participation could slow down implementation, especially in community-driven or shared ownership models. Energy demand patterns from businesses also influence how and when EHs operate, emphasizing the importance of understanding local consumption behavior and fostering a participatory approach to system design and management.

P	National energy policy Delaying approvals for energy sharing & hub operations Lobby for regulatory changes Resource dependence	**T**	Battery storage Need for Energy management system Physical space limits infrastructure Lack of experts Complexity
E	High initial investments & economic losses from grid congestion Resource constraints Inadequate access to capital Unclear financial returns	**E**	Footprint Energy type limitation Seasonal demand patterns
S	Public acceptability Public participation Energy demand	**L**	Lack of legal frameworks Lack of ownership Lack of Standardization DSO monopoly

Table 3. PESTEL analysis

Technological (T). Technological challenges include both hardware and system integration issues. Battery storage and EMS are seen as critical functionalities, but their high costs, space requirements, and operational complexity present significant challenges. Beyond their technical utility, batteries are also tools for optimizing energy usage patterns within the group, allowing a more balanced and coordinated profile of energy demand. However, stakeholders cited the high capital cost and degradation over time as issues that require strategic planning. Additionally, they noted a shortage of technical expertise and a lack of standardized solutions, which complicate system deployment, coordination, and maintenance across multiple business park users.

Environmental (E). Environmental concerns relate to both the physical footprint of infrastructure and its impact on the surrounding ecosystem. Stakeholders noted limitations in the types of energy sources (primarily solar due to wind restrictions), as well as mismatches between generation and demand (e.g., low weekend consumption). Seasonal variability and space availability also influence the feasibility and effectiveness of EHs, especially in urbanized or industrial zones.

Legal (L). Legal and regulatory uncertainty presents a major structural barrier. The absence of a dedicated legal framework for EHs, especially around shared ownership, data governance, and liability, creates hesitation among potential participants, uncertainty, and delays in project approvals. DSO monopolies and restrictions on energy storage ownership further complicate the legal landscape. These inconsistencies limit innovation, particularly for pilot projects requiring experimental setups. Standardization and clarity in legal responsibilities are essential to reduce risks and facilitate participation.

Systemigram Use in PESTEL Analysis for EHs

Systemigram is an effective tool to synthesize diverse stakeholder perspectives through the lens of PESTEL factors, providing a comprehensive view of EH systems (Squires et al., 2010). Figure 5 visualizes the interconnected system shaping EHs in industrial parks.

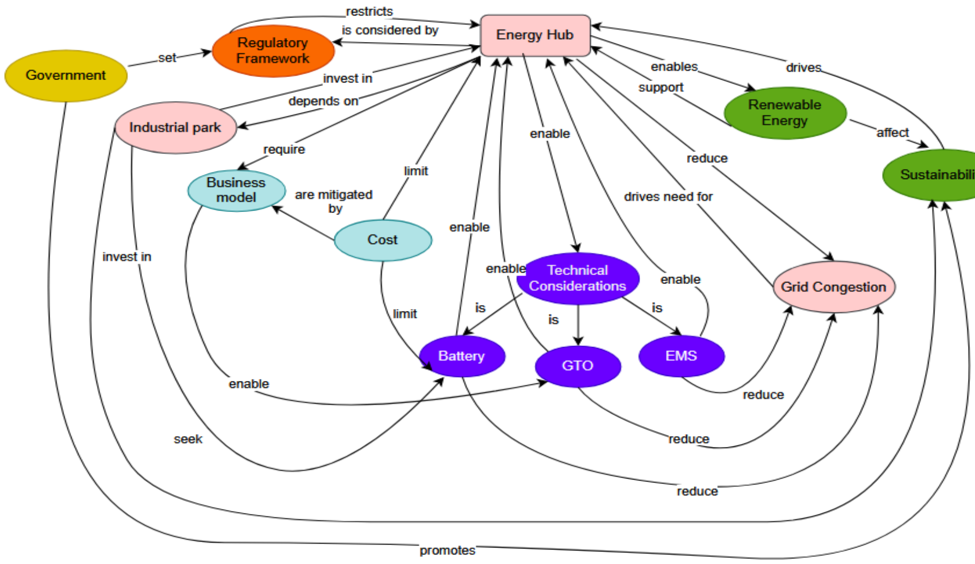

Figure 5. Systemigram of EHs in industrial parks

EHs reduce grid congestion by enabling technologies like batteries, GTOs, and EMS, but face limitations from cost and regulatory frameworks. Governments influence the system by setting rules, while business models and cost-sharing strategies are essential for investment. EHs support renewable energy integration, which further reduces congestion and drives sustainability. The systemigram reveals feedback loops and dependencies, showing how coordinated action across technical, economic, and policy domains can unlock EH potential and strengthen the energy transition.

Stakeholder Insights and Key Findings

This section synthesizes the findings from stakeholder interviews conducted across multiple EH projects. The study coded the stakeholder interview data and categorized them into needs, functionalities, constraints, and opportunities (see Table 4). A separate spreadsheet containing this data accompanies the research.

Stakeholder Needs. Stakeholders identified different needs. Among the most frequently mentioned features was battery storage, which is valued for supporting peak shaving, enabling load shifting, and serving as backup during grid stress. One participant stated, *"Batteries provide critical storage capacity, enabling businesses to operate within a limited connection to the grid collectively"*.

Stakeholders also emphasized long-term financial planning and a structured business plan, cited five times, as essential for project viability. As one participant explained, "*A long-term business plan is necessary to justify investment and ensure the financial sustainability of battery storage solutions*." In addition, stakeholders stressed the importance of a clear business plan to define responsibilities and manage risks within group-based contracts. One interviewee noted, "*A clear business plan must be in place for organizations entering or leaving an EH to maintain financial and operational stability*." Additionally, interviewees emphasized the need for EMS and telemetry tools to enable real-time monitoring. They also mentioned group transport agreements and joint connections three times as essential for efficient capacity sharing. Stakeholders identified public awareness, though only once, as an important factor in encouraging community participation.

Functionalities and Technological Capabilities. Interviews revealed several forms of collaboration in the Netherlands to tackle grid congestion. Some stakeholders viewed battery storage as a preventive measure to manage current transport capacity shortages before full congestion develops. As one interviewee explained, "*As long as we are only facing transport shortages, batteries can act as a buffer, keeping a solution ready behind the scenes*." Another key solution discussed is the GTO, which allows companies to jointly use grid capacity under one contract rather than maintain separate agreements. "*By coordinating peaks and troughs, the group can use capacity more efficiently*," one stakeholder noted. GTOs are currently being piloted in 10 business parks and rely on an EMS to divide capacity among members.

No	Insight type	Category	Description	Times mentioned
1	Need	Technical	Battery storage	7
2		Economic/Legal	Structured business models and Group contract	5
3		Technical	Energy management systems and monitoring tools	4
4		Tech/Legal	GTO (Group Transport Agreement)	3
5		Social	Public awareness and community participation	1
6	Functionalities	Technical	Battery storage to prevent congestion	1
7		Technical	Group transport agreements (GTOs)	1
8		Technical	Energy community	1
9		Technical	Community of EHs	1
10	Constraints	Legal	Lack of legal frameworks and monopoly on DSO ownership	5
11		Technical	Inefficiencies in grid design, space limitations, and solar reliance	4
12		Economic	High upfront costs for battery storage and uncertain lifespan	3
13		Tech/Economic	Transport capacity	2
14		Political	Changing rules causing uncertainty & delay	1

Table 4. Key Findings Categorized by Needs, Functionalities, and Constraints

In parallel, regional initiatives are piloting EHs, with five business groups launching projects, two of which are already operational. These EHs focus on industrial users and prioritize shared capacity over energy trading, as one participant stated, "*Companies pay based on usage; energy trading is planned for a future phase*." Stakeholders emphasized that the design of EHs must be customized to local conditions, noting that "*what an energy hub looks like depends on local sources and demand*." In addition to individual EHs, stakeholders discussed the value of building networks or communities of hubs that share knowledge, strategies, and potentially even infrastructure. They also pointed out that traditional grid contracts inefficiently reserve capacity even when unused, blocking new connections. In contrast, "*Joint connections let companies balance peaks across the day and night, making better use of the grid*," explained one stakeholder.

Constraints and Implementation Barriers. Stakeholders reported fifteen constraints. Regulatory issues include the prohibition of DSO-owned storage and a lack of legal frameworks for EHs, creating delays and uncertainty. Technically, grid infrastructure is not optimized for EHs, with limited space and reliance on solar energy presenting further challenges. Financial risks, especially high upfront costs for batteries and uncertain returns, discourage investment. As one stakeholder stated, "*Battery storage is expensive, and its lifespan is uncertain*." Moreover, stakeholders noted not only "*Shortage of transport capacity, preventing new businesses and residential developments from connecting to the grid*" but also that it caused "*€40 billion in lost economic opportunities annually*."

Opportunities and Future Directions. Despite the identified barriers, stakeholders also outlined several opportunities for the successful implementation of EHs.

1. Group Transport Agreement (GTO). This agreement lets large business neighbors on the same part of the electricity grid share their transport capacity. The grid operator still takes care of the grid's safety and maintenance, but the businesses manage how they divide the shared capacity. As an important part of EHs, with GTO, companies do not need separate transport contracts, instead, they share one contract as a group (Groepstransportovereenkomst (GTO) | Enexis Netbeheer, n.d.). By working together and coordinating their energy use and generation, they can handle the available grid capacity more efficiently and save money. If your company joins a GTO with other businesses, together, you decide how to divide the available capacity and write down your agreements in a joint contract. To join a GTO, you can either become part of an existing group or start one with other companies.

2. Clear Business plan. The multi-actor nature of EHs introduces challenges in coordination. Structured business models must emphasize return-on-investment through load shifting, time-based tariffs, and participation in dynamic pricing markets. Instead of fixed grid fees, adopting a dynamic pricing model, where electricity prices vary based on demand throughout the day, can incentivize flexible consumption and reduce peak loads. This model encourages consumers to shift energy use to cheaper, off-peak times, relieving grid stress and enhancing EH economic viability.

Furthermore, EHs can generate revenue through energy trading platforms, enabling participants to sell surplus energy or flexibility services. For example, businesses could sell stored solar energy from weekends during peak hours on weekdays. Technological investment in automated billing, pricing optimization, and peer-to-peer transaction platforms is essential to make this model functional and scalable.

In addition, the issue of contract design emerged repeatedly: What happens if one member exits? Who assumes liability? A standardized participation contract and blueprint agreement are necessary. It should include exit/replacement clauses, risk-sharing models, tariff mechanisms for shared infrastructure, and clearly assigned roles. A municipal coordinator or hub manager should be empowered to facilitate trust and manage governance structures. Municipalities and DSOs can co-develop co-financing models for EHs, where governments guarantee part of the investment. Additionally, leasing models can reduce entry barriers for businesses.

3. Battery Behind-the-Meter Plan: A promising solution involves deploying batteries behind the meter within business premises. These local storage systems are owned or leased by businesses, giving them direct control over how and when to use stored energy. Behind-the-meter batteries can absorb surplus solar production during low-demand periods (like weekends) and release it during peak hours or when prices are highest. Businesses can reduce their grid reliance and operational costs while participating in local flexibility markets.

Dynamic pricing and energy trading between households and businesses to create new economic opportunities, and the potential for high-capacity EV charging infrastructure through interconnected EHs are other opportunities. These opportunities, while not yet mainstream, signal possible directions for evolving the role of EHs in addressing grid congestion and enabling energy transitions at the local level.

Discussion

SQ1: How can the regulatory and market barriers hinder the EH implementation in Best's business parks be addressed?

Regulatory and market barriers are among the most frequently cited constraints by stakeholders in this study. Interviewees pointed to the absence of legal frameworks for group contracts and the prohibition on third-party energy coordination. These observations align with Rodin and Moser (2021), who describe framework and regulatory barriers as key impediments to industrial energy cooperation. Stakeholders referred to pilot projects as opportunities to test alternative governance models, consistent with observed approaches in existing initiatives (Innovatieprojecten, n.d.).

Interviewees also raised concerns about financial uncertainty, especially around liability and ownership. The idea of introducing insurance schemes to manage shared risks mirrors challenges discussed by Heuninckx et al. (2022), who found that perceived financial risk and lack of clarity discourage active participation in energy communities. These mechanisms can support stakeholder trust and project continuity.

SQ2: How does local energy balancing through EHs impact grid congestion?

Interview data confirmed that EHs are tools to reduce grid congestion, especially in areas with high solar PV generation like Best. Stakeholders described mismatches between solar production and demand, which supports insights from Papaefthymiou and Dragoon (2016), who note the need for flexible systems to manage intermittent renewable sources. By shifting or reducing demand in response to network conditions, EHs can act as a buffer between fluctuating renewable generation and grid stability needs. As a result, they help ease local grid congestion and may delay the need for expensive grid upgrades that would otherwise be required to support the increasing integration of renewable energy. Moreover, EHs allow businesses, buildings, or neighborhoods to consume energy within the same area where it is generated. This reduces the need to transport electricity over long distances and eases pressure on the distribution grid, particularly during peak production or demand periods. Additionally, stakeholders frequently emphasized the role of battery storage in enabling local balancing and reducing peak loads. This supports technical literature emphasizing storage as a crucial component in renewable integration (Eladl et al., 2023).

SQ3: What local challenges hinder successful EH implementation in Dutch business parks?

Stakeholders identified monopolistic control by DSOs and limited access to funding as major challenges. These findings are consistent with Rodin and Moser (2021), who cite centralized control and financial barriers as critical implementation issues.

Interviewees also emphasized that some renewable energy solutions remain financially inaccessible due to high local energy demand and the associated infrastructure costs. In areas where electricity demand is high, the grid often requires upgrades, such as stronger cables, transformers, or control systems, which are expensive and discourage investment, particularly from small and medium-sized enterprises. These observations echo Motallebi Azar et al. (2020), who highlight high upfront costs as a major barrier to EH participation. While many are interested in joining or producing clean energy, the financial burden often prevents them from doing so.

A recurring recommendation was the need to standardize procedures and clarify stakeholder roles. This aligns with the guidance from RVO (Hoe helpt de routekaart Samenwerken in energiehubs u?, n.d.), which advocates for structured collaboration frameworks. This would involve setting clear guidelines that define the roles of various stakeholders, outline project management procedures, and address legal considerations. To ensure these practices are consistently applied, collaboration between policymakers and local actors is essential. For hub initiators or businesses, this could involve deploying real-time monitoring technologies, while at the policy level, authorities can facilitate progress by introducing national standards for energy data collection and monitoring.

RQ: What economic, technical, and operational challenges do stakeholders face in deploying EHs in Dutch business parks, and how can governance structures address them?

In light of persistent grid congestion, EHs are emerging as a promising decentralized solution. However, their development faces several regulatory, financial, and organizational challenges that need a solution. From an economic point of view, the findings indicate the burden of high upfront costs for infrastructure and delayed financial benefits as discussed by Mohammadi et al. (2017). Grid congestion also leads to substantial economic losses, underscoring the need for structured business models to justify investments. Policymakers can support the EHs development by establishing a reliable legal infrastructure. Another possible approach to justify using public funds and subsidies is to quantify the external effects of EHs, particularly by assessing societal benefits like alleviated grid congestion and increased sustainability.

On the technical side, concerns about outdated grid designs and limited space for new infrastructure, matching concerns in Basisdocument over energie-infrastructuur (2019). Operationally, managing group contracts was a common challenge. Several stakeholders called for clearer legal frameworks and dynamic pricing mechanisms, ideas supported in policy tools by RVO and ACM. The framework can offer clear direction while minimizing administrative complexity for stakeholders. Greater coordination among different DSOs could support the development of a harmonized and transparent regulatory framework.

Organizationally, involving technical experts early in project development was seen as a success factor. Stakeholders also noted the value of early-stage public support for coordination and legal setup. Loan guarantees and risk-sharing mechanisms, as described by stakeholders, can further lower the barrier for private investment and align with sustainable growth objectives.

Conclusion

The growing integration of renewable energy and the increasing electricity demand have placed considerable strain on the Dutch electricity grid, resulting in grid congestion. This congestion creates obstacles for business development, the electrification of industrial activities, and the connection of new renewable energy projects, ultimately slowing the Netherlands' progress toward a sustainable energy transition. Both the literature and stakeholders interviewed in this study view EHs as a promising approach to easing grid congestion. This study first mapped out the stakeholders involved in EH initiatives, then focused on the four most actively engaged groups: DSOs, municipalities, businesses, and energy coordinators or hub managers, analyzing their roles, interests, and the challenges they face.

The findings revealed that stakeholders often take on multiple roles, highlighting the complex and interconnected nature of EH projects. Each group influences different aspects of the process, and none of the stakeholders dominated decision-making across the studied cases. While interests vary, the research found no strong evidence of direct conflict among the groups. All stakeholders, however, have encountered notable challenges. The analysis of these barriers shows that while EHs offer promising solutions to grid congestion and energy transition goals, their success depends on addressing key governance and organizational hurdles. With targeted action and strengthened cooperation among stakeholders, EHs have the potential to play a key role in building a more sustainable and resilient Dutch energy system.

Future Research

While this study provides qualitative insights into the governance and stakeholder dynamics of EHs in Dutch business parks, several areas remain for future exploration. Expanding the stakeholder base to include financial institutions, regulatory authorities, and residents would offer a more comprehensive view of multi-actor collaboration and its challenges. Comparative studies across different regions or countries could reveal which governance models are most effective under various regulatory and market conditions. Additionally, as both regulatory frameworks and energy technologies continue to evolve, future research could employ longitudinal designs to examine how EH governance adapts over time.

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In the process of developing this thesis, ChatGPT (GPT-4o) was used to suggest linguistic reformulations and improve clarity in English.

Biography

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She holds a Master of Science in Innovation and Technology Management with a specialization in Systems Engineering from the University of Southeastern Norway. With a background in Computer Engineering, Artificial Intelligence, and experience in business development, financial, and technology management, she combines analytical and technical expertise with a strong interest in sustainable energy systems. Fatemeh's professional interests lie at the intersection of sustainability, digital transformation, and energy innovation. She is passionate about applying systems thinking and interdisciplinary approaches to advance the green energy transition in Europe.

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Gerrit Muller, originally from the Netherlands, received his master's degree in physics from the University of Amsterdam in 1979. He worked from 1980 until 1997 at Philips Medical Systems as a system architect, followed by two years at ASML as manager of systems engineering, returning to Philips (Research) in 1999. Since 2003, he has worked as a senior research fellow at the Embedded Systems Institute in Eindhoven, focusing on developing system architecture methods and the education of new system architects, receiving his doctorate in 2004. In January 2008, he became a full professor of systems engineering at the University of South-Eastern Norway in Kongsberg (USN), Norway. He continues to work as a senior research fellow at the Embedded Systems Innovations by TNO in Eindhoven in a part-time position. Since 2020, he has been an INCOSE Fellow and an Excellent Educator at USN.