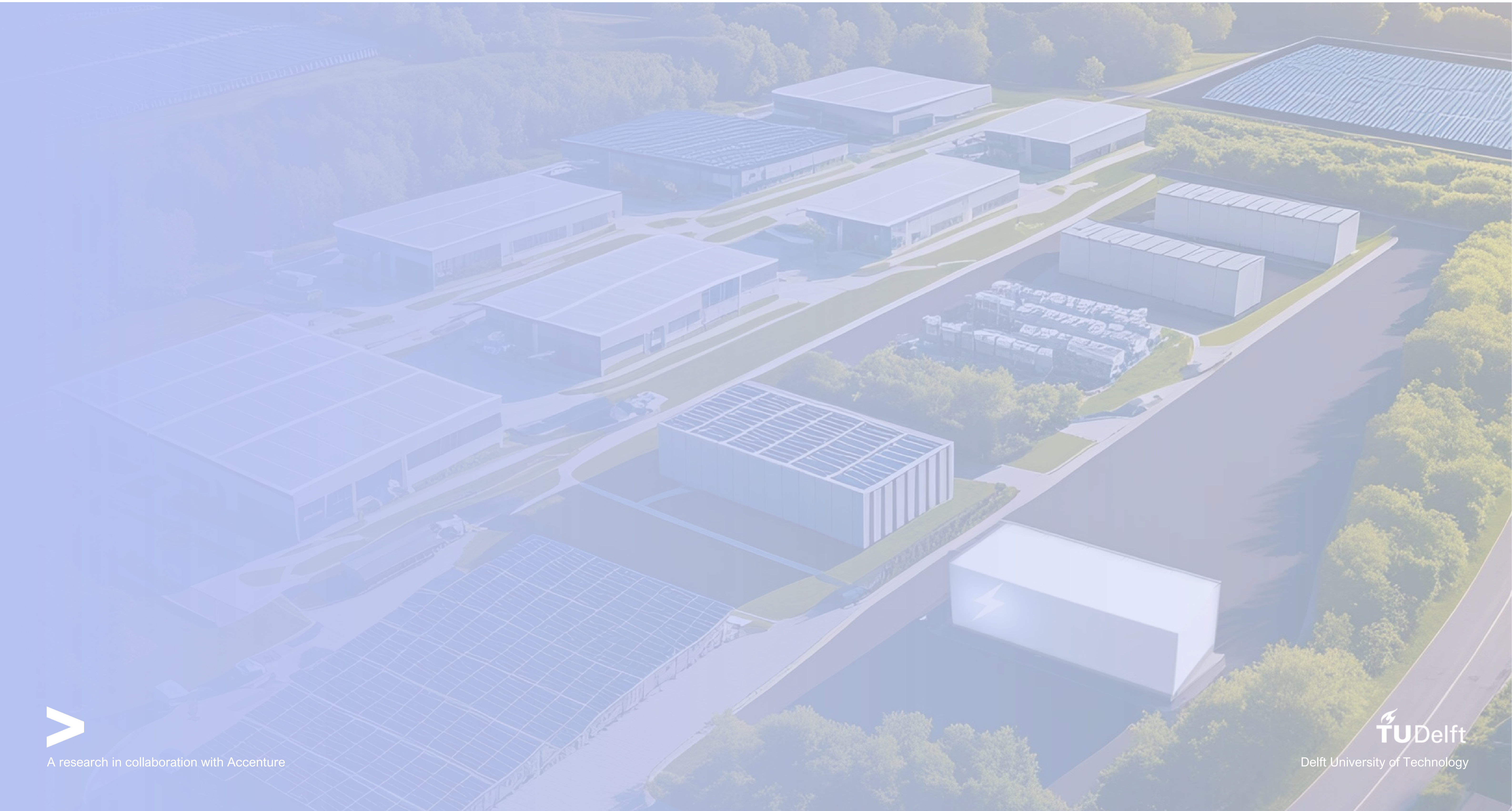
Toward enhanced collaboration for the strategic integration of battery storage within energy hubs in the Netherlands

MSc Thesis Strategic Product Design | Noor Schaafsma | June 2025
Delft University of Technology | Faculty of Industrial Design Engineering



A research in collaboration with Accenture

Delft University of Technology

PREFACE

Dear reader,

My journey began throughout my time at IDE, with a broad interest in sustainability and the question of where I could make the greatest impact. It soon became clear to me that the energy transition holds a central role in shaping a more sustainable future. Throughout my master's, my interest in the energy sector grew, and I stumbled upon something that slows down the transition to clean energy in the Netherlands: grid congestion. I am happy that through this project, I can make an impact by looking at one of the most energy-intensive areas: business terrains.

Through this thesis, I was able to dive deeply into the complexity of the energy sector and how it is changing, and I can confidently say: there's a lot more to it than meets the eye. The energy transition will require major shifts not only in our technical systems but also in the way we organize, collaborate, and think. With this thesis, I hope to contribute a small but meaningful part to that bigger puzzle.

The research was conducted as part of the MSc Strategic Product Design at the Faculty of Industrial Design Engineering at Delft University of Technology. It was carried out in collaboration with Accenture, where I had the opportunity to contribute as an intern within the Strategy & Consulting Utilities team. I am very grateful for the insights, support, and professional dialogue I encountered throughout this process.

This journey was not always easy, and I am grateful to everyone who helped me along the way. I would like to express my heartfelt thanks to them.

First, I would like to thank my graduation committee, Sine and Mahshid. You are both very inspiring and knowledgeable, and I am happy I could learn from you. You gently helped me find the right direction while giving me the freedom to discover problems and solutions on my own. More importantly, you helped me build confidence and believed in me, even at times when I struggled to believe in myself. Your guidance, especially when I felt stuck, was invaluable, and I am very grateful for your support and contributions.

Next, I would like to thank Koen, Henk, and Alexander, my supervisors at Accenture. From the very beginning, you welcomed me into the team, and I've learned an incredible amount in a short period of time. Your expertise in the sector added relevance and practicality to the project, which was very valuable. I really appreciate your engagement in the project, and your energy and enthusiasm are contagious and motivated me. I truly enjoyed working with you, and I'm very thankful for your support and the opportunity to collaborate with you.

To all participants of the study, I'd like to express my thanks. I'm grateful for your knowledge, perspectives and the interesting discussions that sometimes emerged during conversations. In particular, I'd like to thank Angela for providing help and expressing her enthusiasm about the topic, which really motivated me at the time I needed it.

Finally, I'd like to thank my friends, family, peers, my fellow interns at Accenture, and one person in particular, Chris. She is a critical, though supporting figure in my life, and a very good reader. I'd like to thank her for being so engaged and supporting me throughout this process.

This thesis is the product of many working hours, effort, and enthusiasm. I hope this thesis contributes to the growing conversation on energy flexibility, and that it offers practical value to those seeking to accelerate the transition toward a decentralized and resilient energy system.

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ABSTRACT

The Netherlands is in the middle of the transformation of the energy system. As electricity demand and (decentralized) renewable electricity generation grow, the electricity grid is increasingly facing congestion. This threatens the pace of electrification, business growth, and sustainability ambitions. Energy hubs (EHs), local and decentralized energy systems, have emerged as a potential solution, especially if they include battery storage. This helps local balancing and efficiency. However, the development of these EHs, including storage on Dutch business terrains, is lagging behind.

This research shows that the lack of collaboration, due to misalignment of interests of network operators (DSOs) and and EH collectives, is a critical factor that delays the development of EHs. This research explores how design, especially strategic and participatory design, can play a role in addressing these challenges. The goal is to understand how collaboration between DSOs and EH collectives can be designed to facilitate battery storage integration in Dutch business terrains. This is done through a literature review, stakeholder interviews, and participatory co-creative workshops.

The literature review showed that EHs can be considered to consist of four interconnected elements: technology, organization, regulation and finance. Each element influences the others, revealing a web of dependencies that must be managed strategically, as battery operations can also pose a risk for grid congestion. Interviews showed that actors in the system differ in drivers and barriers. Four main tensions were identified:

- Operational control of batteries,
- Capacity allocation,
- Risk allocation,
- Uncertainties in emerging contracts

Co-creative workshops with different stakeholders offered a way to discuss these tensions and align interests. In the workshop, two decision-making scenarios were explored and evaluated: DSO-led flexibility and EH-led flexibility. Results showed that stakeholders generally preferred a hybrid future, where DSOs act as facilitators and the EHs have control over battery use. Participants emphasized the need for EH authority, mutual trust, fairness of compensation and reliability of the systems. The workshop also revealed boundary conditions to achieve these needed values and move toward grid integration of battery-based EHs. Based on these insights, two tools to support EH developers, DSOs, and regulators in navigating the complexity have been developed:

- A morphological chart that shows options of the EH configuration
- A roadmap showing steps for each aspect of the EH toward system integration

This thesis contributes to the energy transition by offering a deeper understanding of the problem, a shared vision for the preferred future, and clear requirements to achieve it.

KEYWORDS: stakeholder collaboration, participatory design, energy hubs, battery storage, grid congestion

TABLE OF CONTENT

ABBREVIATIONS

ACM – Autoriteit Consument en Markt
BESS – Battery Electric Storage System
DER – Distributed Energy Resources
DSO – Distribution System Operator
EH – Energy Hub
EMS – Energy Management System
EV – Electric Vehicle
HV – High Voltage
kW / MW – Kilowatt / Megawatt
kWh / MWh – Kilowatt-hour / Megawatt-hour
LV – Low Voltage
MV – Medium Voltage
PPA – Power Purchase Agreement
PV – Photovoltaic (solar energy systems)
RES – Renewable Energy Sources
ROI – Return on Investment
TSO – Transmission System Operator

1.

INTRODUCTION

Context & Project Goal

In this section the project will be introduced. First the project background and motivation of the topic battery storage within energy hubs (EHs) will be explained, then the research problem and gap will be given, followed by the research goal and approach.

1.1 BACKGROUND

1.1.1 The energy transition

Global temperatures have risen by 1,5 °C above pre-industrial levels, leading to huge problems like biodiversity loss and rising sea levels. The primary driver of this warming is fossil fuel combustion for energy consumption, which accounts for approximately 86% of CO_2 emissions (IPCC, 2023). Therefore, we need to transition to a net-zero emission society by 2050, using clean renewable energy sources (IEA, 2024).

To be able to reach these climate goals industries and residences need to decarbonize, and processes that rely on fossil fuels, like cars, heating systems and industrial processes need to switch to clean energy (Figure 1) (Ministerie van Economische Zaken en Klimaat, 2022a). The Dutch government set the goal for 2030 that 27% of all used energy should be from renewable energy sources (RES) (Rijksoverheid, 2024). By 2050, a much higher share of 60% or more of the total energy consumption is predicted to come from green electricity (Sijm, 2024), with electricity making up 17% of the total energy consumption (EBN, 2023). Currently, already half of the electricity produced in the Netherlands is from renewable sources, which is about 60 billion kWh (CBS, 2024), and this is expected to increase to 65% by 2030 and 90% by 2050 (European Commission, 2020; Sijm, 2024).

The shift to electricity and renewable energy is increasingly important for industries and business, as these consume a lot of energy; half of total gas consumption and a third of total electricity consumption in the Netherlands annually. To give an impression of expected growth in electricity demand: for Cluster 6 industrial sector it is expected to grow by a factor of 2.4 between 2022 and 2030 (Stichting Cluster 6, n.d.).

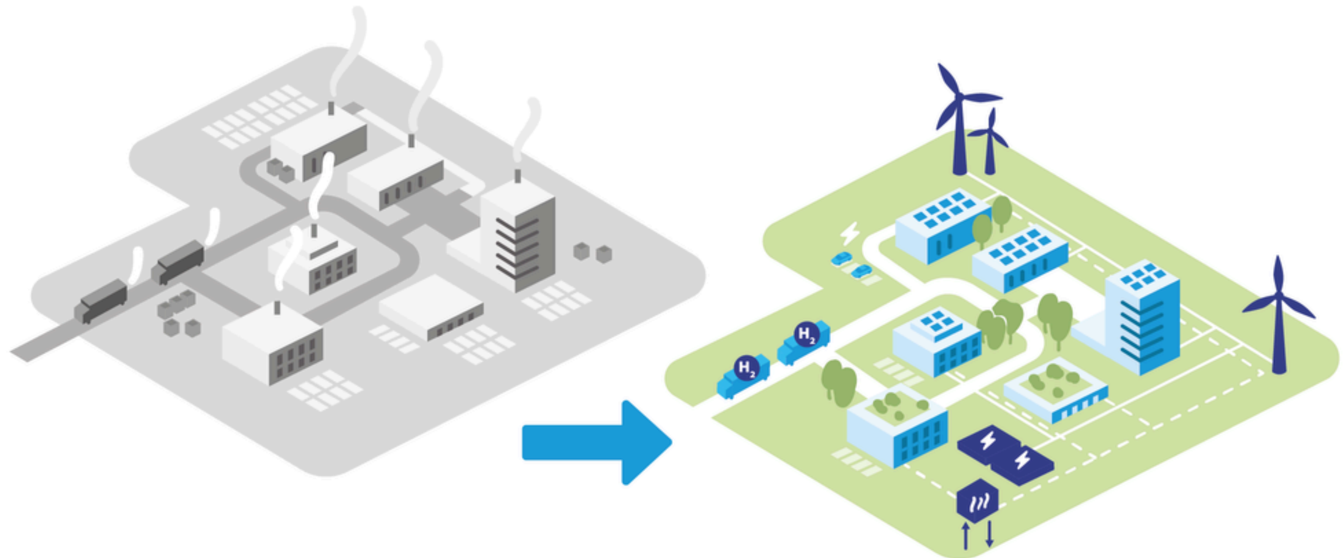


Figure 1: Transition to sustainable business terrains. Source CE Delft (2023d)

1.1.2 Leading to grid congestion

While the electrification and renewables have increased exponentially, the capacity of the power grid lags behind, which can result in inefficiencies and potential disruptions. This is called grid congestion. Congestion can occur when there is too much demand for electricity, typically between 16:00 and 21:00 when most people arrive home, and start cooking or charging their car, as well as when there is too much supply of electricity, typically between 12:00 and 14:00 when much solar energy is generated. The problem lies in the simultaneous peaks, and the mismatch between energy production and consumption highlights the need to rethink our traditional energy system.

Traditionally, electricity generation was predominantly centralized, relying on large-scale gas power plants. The energy system can be divided into three parts: generation, distribution and use (Netbeheer Nederland, 2019). Energy production and consumption are managed by commercial parties within a free market, while the distribution of energy is the responsibility of network operators, as set by law. The Electricity Act of 1998 states that the production, trading, and supply of electricity must be separated from grid operations.

On a national level, TenneT, manages the high voltage electricity networks, and locally, distribution system operators (DSOs) manage the electricity networks on medium and low voltage (Netbeheer Nederland, 2019). Power is transmitted linearly from high-voltage transmission networks through medium- and low-voltage distribution networks toward end-users like households, businesses, and industries, as depicted in Figure 2.

However, the rise of RES is reshaping the system, because these are installed anywhere in the system, across all voltage levels of the grid. For example, residential solar panels feed electricity back into the grid from the low-voltage level, which disrupts the traditional linear energy flow (Netbeheer Nederland, 2019). This shift toward distributed energy resources (DERs) is called decentralization. Energy is now generated and consumed at multiple points throughout the network, as shown in Figure 2. Furthermore, these RES have an intermittent nature, because their output depends on weather conditions that might lead to fluctuations like high production peaks during sunny or windy periods and low peaks or no output when these conditions are absent. These developments make grid operations more complex.

One consequence of congestion is that customers cannot secure a new or larger transport contract with the grid operator. This means new organizations can no longer be established, and existing organizations face limitations on electrification or expansion. The map in Figure 3 shows where requests for access to the grid are denied because of congestion. In 2024, 9396 transport requests for large-scale electricity use were denied (Netbeheer Nederland, 2024b).

Network operators are situated in a predicament. The electricity grid infrastructure needs to double or even triple in capacity over the next decade (Ministerie van Economische Zaken en Klimaat, 2022b). To meet this demand, network operators have already doubled their annual infrastructure investments since 2019, reaching nearly €4 billion per year (Ministerie van Algemene Zaken, 2022b). These investments take time to realize, because network operators are limited by long permitting procedures, material and personnel shortages (Heshusius et al., 2024). According to DNV (2024), approximately a quarter of the planned investments may not be completed by 2030, contributing to a projected 28% shortfall in transport capacity compared to demand.

Expanding the grid is not enough to solve these grid issues. Therefore, the increase of flexible grid capacity will be of high importance in the grid of the future (Ministerie van Algemene Zaken, 2022b). Flexibility is the system's ability to dynamically manage supply and demand balance (Sijm, 2024).

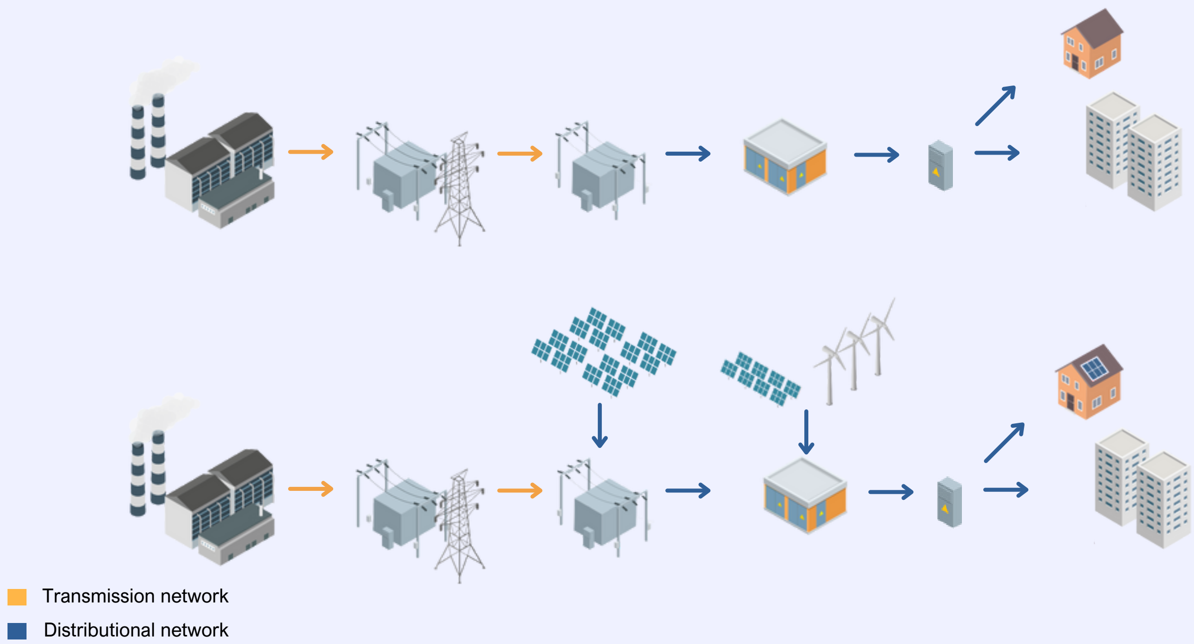


Figure 2: The traditional energy system (top), & decentralization (bottom) (autors image, based on Netbeheer Nederland, (2019))

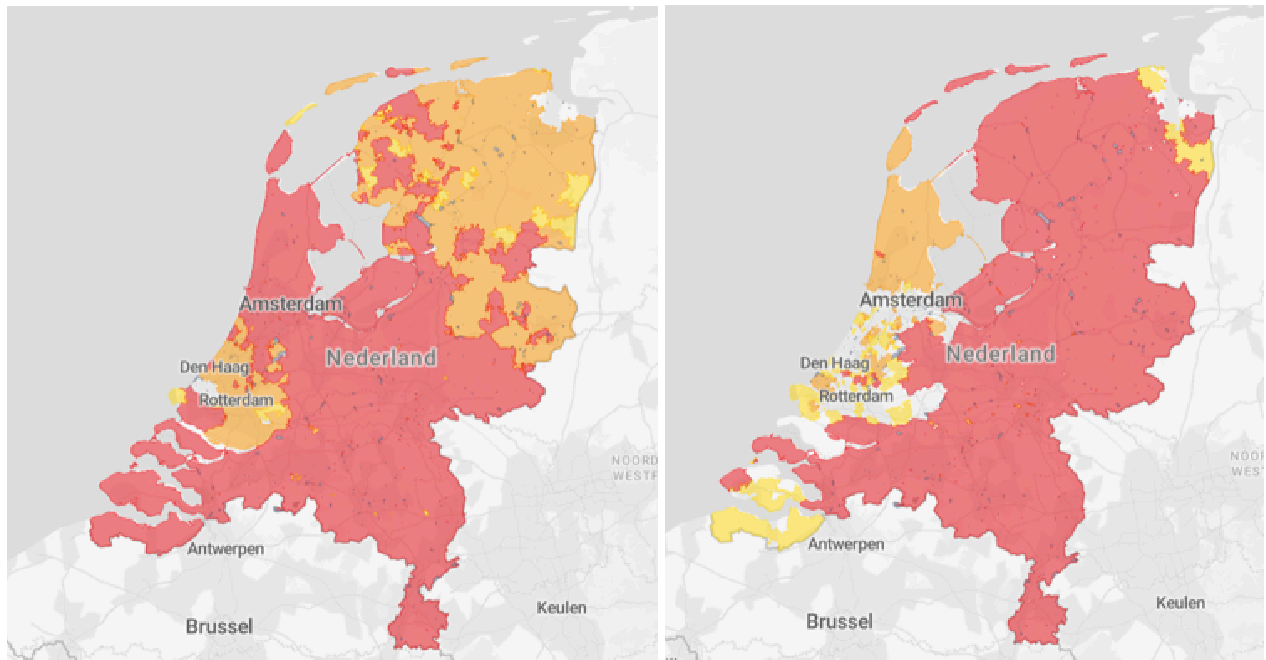


Figure 3: Demand congestion left, supply congestion right. In red areas applications for transport capacity are rejected or postponed by the network operator. (Netbeheer Nederland, no date)

1.1.3 Energy Hubs can provide local balancing

One promising solution to enhancing grid flexibility is the implementation of EHs (EHs). An EH is defined as a decentralized, smart-controlled energy system where energy supply, demand and storage are coordinated to enhance local balance (Ministerie van Algemene Zaken, 2022b). EHs provide local flexibility and enable energy consumers and prosumers to collectively manage their energy demand and supply in a way that minimizes pressure on the electricity grid. As businesses face the risk of stalled expansion or electrification, they can collaborate with neighbours to reduce grid impact. For example, on business terrains, it is common for one or more companies to not fully utilise their contracted transport capacity (GTV) for electricity for a large part of the time. At the same time, there are other companies that need extra capacity at those times to be able to grow and electrify. The DSO processes aggregated energy profiles, and therefore, the individual businesses have more capacity if they align their energy production and consumption to avoid simultaneous peaks, as can be seen in Figure 4. Key stakeholders of the EH include service providers that provide platforms to coordinate energy flows, DSOs responsible for grid contracts, and companies that consume or produce electricity.

EHs consist of a physical and virtual infrastructure. Virtually, the local energy supply and demand are connected and coordinated through an energy management system (EMS). The physical infrastructure can include RES, energy storage, conversion to other energy carriers like heat or hydrogen, and mobility charging facilities (Figure 5) (CE Delft, 2024). To be able to establish an EH with a group of participants, the participants need to be on the same grid level and transformer substations. Generally, most under-development EHs have a virtual interconnection; however, options like a closed distribution system (CDS) and a direct line connection between generation assets and consumers are also possible ways of sharing electricity locally (De Bruin et al., 2023).

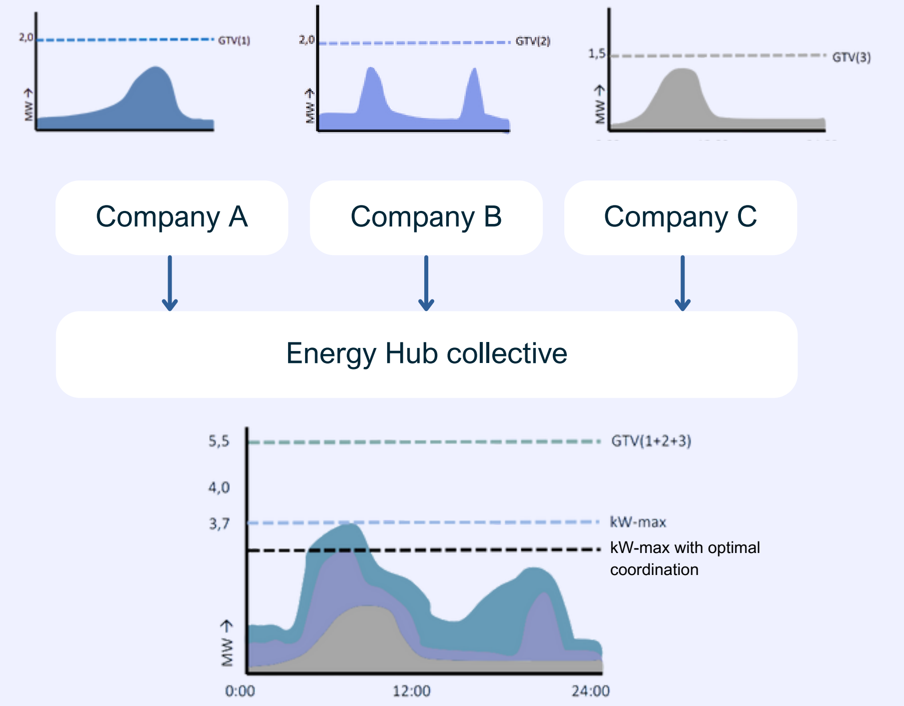


Figure 4: Visual overview of Energy use profile within EH. Source: Authors image, based on Netbeheer Nederland, (2023b).

1.1.4 Rise of battery storage

In this research, the focus lies on battery storage within EHs. There are different types of energy storage that are suitable for different types of flexibility, depending on the length of time and the function storage technologies perform. The choice of size, type, location, and connection of storage systems within EHs depends on the purpose of the EH (Mohammadi et al., 2017). Hydrogen and gas storage are suitable for the longer-term flexibility varying from months to a year, while heat and hydro storage can offer flexibility for the mid-long-term varying from weeks to months. For short-term batteries can offer flexibility, varying from days to seconds (Ministerie van Economische Zaken en Klimaat, 2023a; Truesdale & Ruzzenenti, 2024). Batteries offer several advantages to businesses participating in EHs.

They can:

- help participants of an EH adjust their energy usage profiles without major changes in their operations.
- reduce supply and demand peaks during the day,
- increase consumption of self-generated electricity,
- create potential revenue through energy trading,
- enable conversion to other heat or hydrogen storage

(Ministerie van Economische Zaken en Klimaat, 2023a; CE Delft, 2024).

Battery storage offers potential because installations have grown incrementally globally since 2012 (*DOE Global Energy Storage Database*, n.d.). Also in the Netherlands, in recent years, there has been a growth in battery storage in the utility, commercial and residential segments.

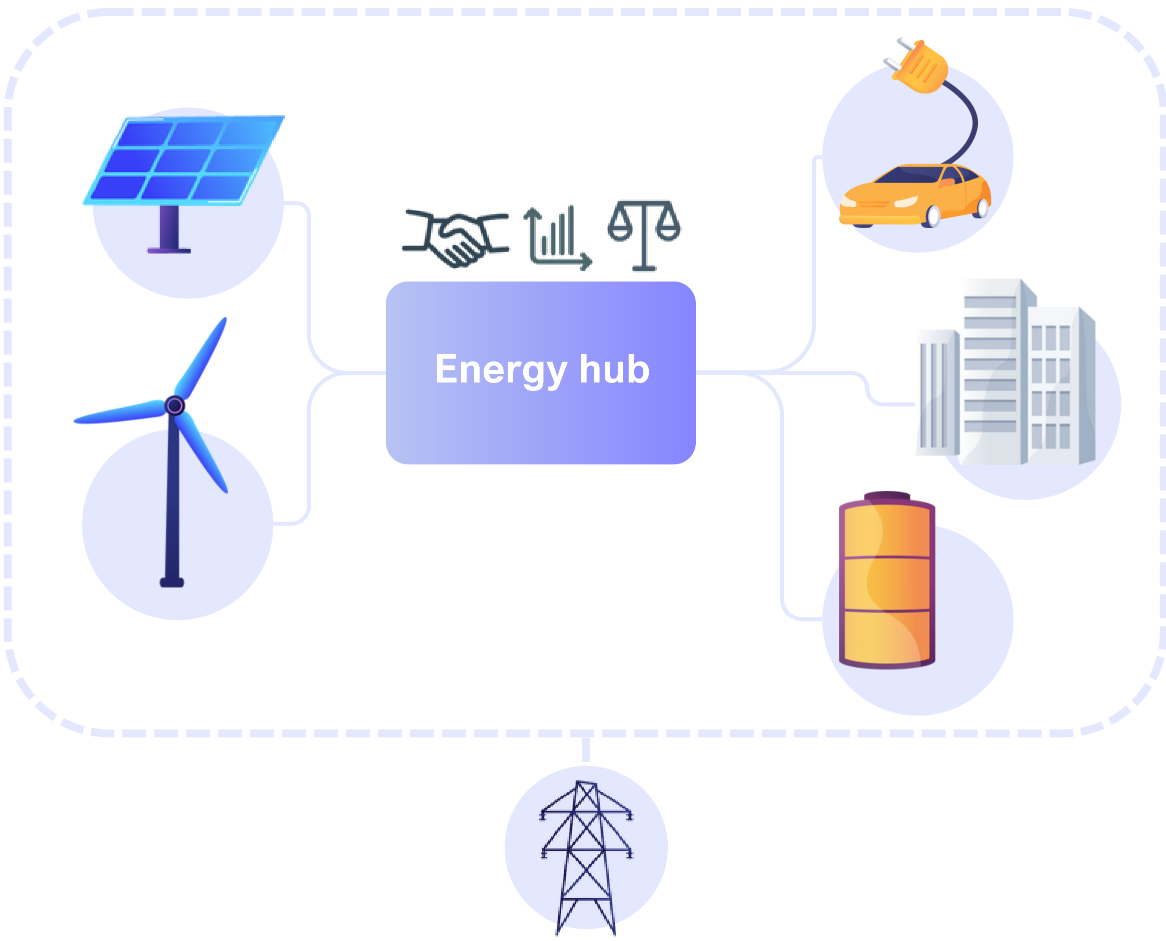


Figure 5: visual overview of the components of an energy hub. Authors image, based on Firan (2021).

In 2023, 24.400 new battery systems were installed, with a total capacity of 410 MWh, as can be seen in Figure 6. Also, the costs of the most common battery storage type, Lithium-Ion battery cells and packs, are decreasing rapidly, as can be seen in Figure 7 (BloombergNEF, 2024).

These developments show the growing relevance and potential of battery storage in local energy systems, especially in energy intensive areas: business terrains.

1.1.5 Potential & future vision

The Netherlands has almost 4,000 businesses and industrial terrains (De Graaf et al., 2024). Of the total energy consumption in the Netherlands in 2019, 30% is from business terrains (CBS, 2019). Furthermore, a third of the total employment is concentrated on these business parks, and they are responsible for generating around 30% of the country's total added economic value (GDP) (De Kort et al., 2023). These business parks are of high value for the Dutch economy and employment, and therefore need to be able to expand. Research shows that there is a potential of 3,7-7,3 GW of flexible capacity through EHs on business terrains (RVO, 2025b).

A study from De Graaf et al. (2024) identified 349 business parks as promising locations for the development of EHs (Figure 8).
These sites are particularly attractive because they are in areas with expected net congestion (>3 years), often near high-voltage to medium-voltage (HS/MS) substations, and have high electricity demand. Within these hubs, battery storage is considered an essential building block to manage peak loads, enable self-consumption, and balance renewable generation. The identified business parks thus offer strong potential for implementing battery storage as part of the overall EH design. The study shows that electricity peaks after electrification on these middle to large business terrains (annual electricity consumption > 12 GWh) increase from 6 MW to 10MW on average. The average value of an EH is a peak reduction of 2,7 MW, and a CO_2 emission reduction of 1,7-4,7 ktons (De Graaf et al., 2023).

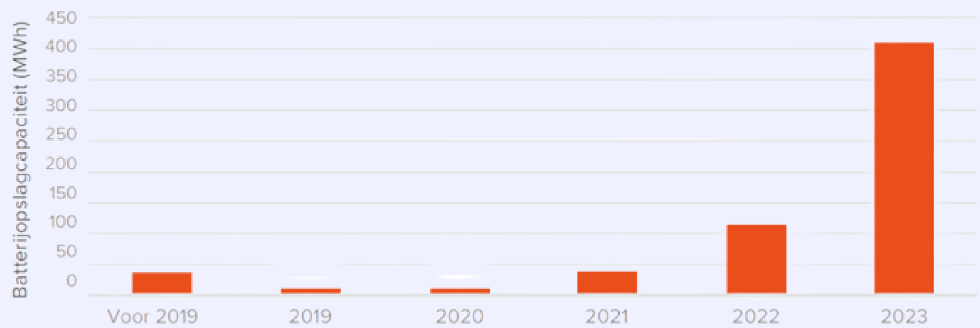


Figure 6: The total of new installed battery systems in the Netherlands. Source: DNE Research (n.d.)

Volume-weighted average lithium-ion battery pack and cell price split

Figure 7: Volume-weighted average lithium-ion battery pack and cell price split, 2013-2024. Source: BloombergNEF (2024)

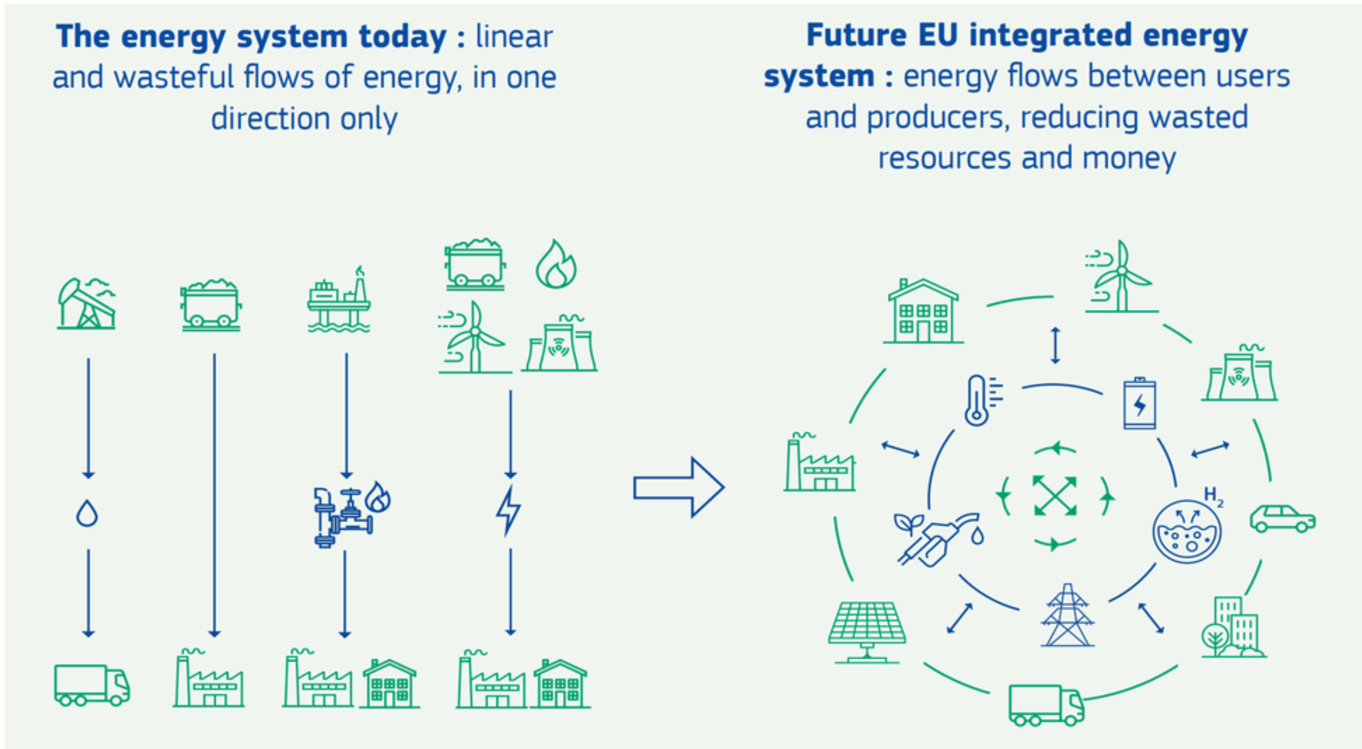


Figure 9: European energy strategy. Source: European Commission (2020)

Looking ahead, battery storage within EHs can be an important aspect of the Dutch energy transition.

The benefits of EHs are a sustainable energy supply, while also relieving pressure on the electricity grid (Ministerie van Algmene Zaken, 2022b), and reducing energy costs (CE Delft, 2024).

"Local what can be done, central what must be done." (Ministerie van EZK, 2023b)

Ultimately, EHs will form the bridge between centralized infrastructure to local decentralized systems to reach our sustainability goals and deliver economic and social value to individuals, network operators and society, as is needed according to European commission's energy strategy (Figure 9) (European Commission, 2020).

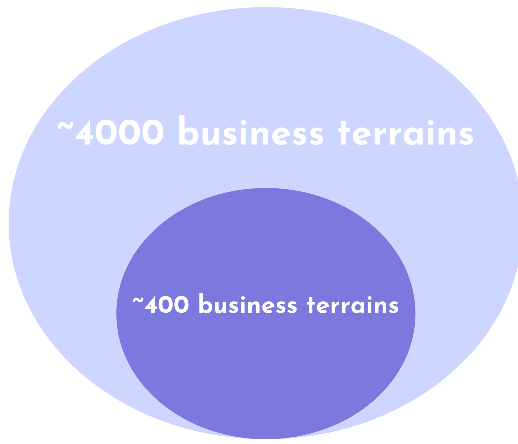


Figure 8: Potential for batteries in EHs in the Netherlands

1.1.6 Research problem & gap

There are limited examples of current EHs in use, but there are approximately 200 EHs being developed today (Sustainable Scale-Up Foundation, n.d). Examples are the EH in Tholen, where 4 companies share a 2MW battery, and the currently under development EH in Boekelermeer, planning on using a 5MWh battery system (Figure 10) (Stedin, 2024; Liander, 2025). In Figure 11 and 12 it can be seen that despite growing interest in EHs, implementation in the Netherlands remains limited and initiatives remain in the first phase of EH development (Ministerie van Algemene Zaken, 2022b; Sustainable Scale-Up Foundation, n.d.).

Challenges to realizing EHs include a lack of standardized contract forms, limited transparency on grid capacity, high upfront investment costs, unclear ownership and revenue models, and weak stakeholder coordination (CE Delft, 2024).
Furthermore, while literature confirms the technical potential of battery storage systems for balancing (local) supply and demand (Hooshmandian et al., 2025; Islam et al., 2024; Koohi-Kamali et al.,2013; Nozari et al., 2022), it often overlooks stakeholder collaboration. Unclear ownership and revenue models and weak stakeholder coordination are a problem (Van den Boom, 2023). In addition, existing regulatory structures fail to sufficiently incentivize the use of battery storage for local congestion relief (Dusonchet et al., 2018). There is limited academic focus on how battery storage can be strategically integrated within the grid (Saldarini et al., 2023; Stecca et al., 2020), as successful deployment of storage requires coordination between DSO and storage operators (Babayomi et al., 2022).

Academics highlight the need for participatory and context-specific approaches to storage governance (Parra et al., 2017; Van den Boom, 2023). Yet, few studies explore how such approaches can support decision-making around collective battery deployment. This reveals an urgent research gap at the intersection of the battery storage in EHs and participatory decision-making.

Research confirms that batteries within EHs will be needed; however, how the energy systems and actor collaboration need to be (re)organized is hardly researched.

Figure 9: Battery storage system energy hub Alkmaar. Source: Liander (2025)

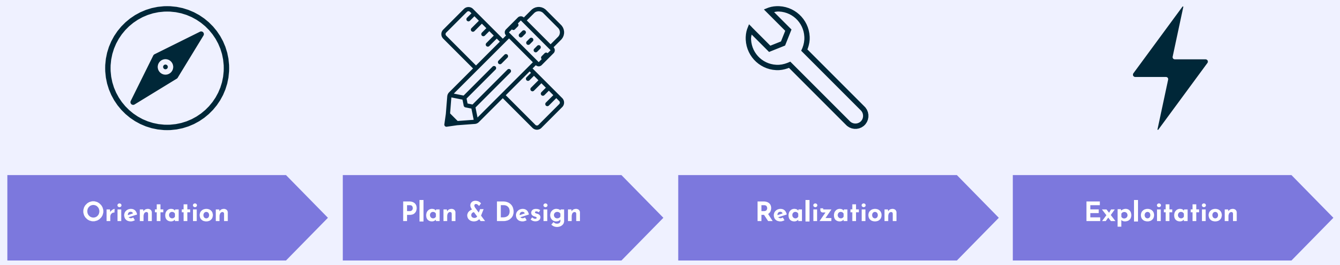


Figure 11: Development process. Author's image based on Kennisplatform Energiehubs (2025)

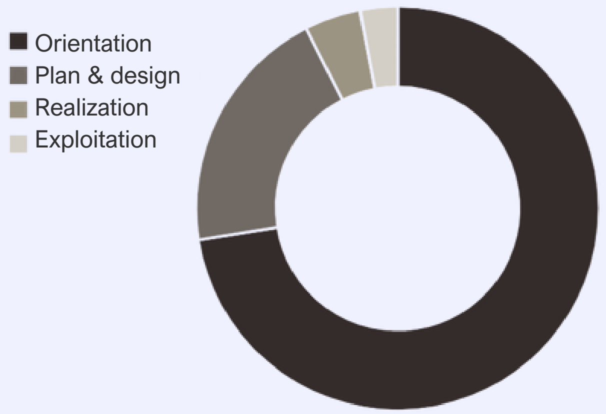


Figure 12: Energy hubs in the Netherlands and their development phase. Source: Sustainable Scale-Up Foundation, (n.d.)

1.2 PROJECT GOAL

This thesis explores how actors can collaboratively organize EHs with battery storage to mitigate grid congestion and enable a sustainable energy system.

The goal is to investigate the barriers and drivers of battery storage integration in EHs for EH participating companies and network operators. Based on these findings, future decision-making strategies will be developed and explored with stakeholders, in order to define what future steps are needed to get toward a collaboration model that benefits all actors.

This leads to the main research question:

How can collaboration between network operators and energy hub collectives be designed to integrate battery storage on Dutch business parks and help reduce grid congestion?

Within this research question, several sub-questions emerge:

1. What is the foundation of an energy hub, and what role does battery storage play within it?
2. What are the experienced drivers and barriers in integrating battery storage within energy hubs?
3. How can a participatory design process facilitate collaborative decision-making about battery storage within energy hubs?
4. What tools can be designed to help the participatory process in order to catalyze the integration of battery-based energy hubs to reduce congestion in the Netherlands?

In Table 1, the method and goal of each question are explained.

Table 1: Structure of methods and goals per SQ

Sub-question	Method	Goal
1. What is the foundation of an energy hub, and what role does battery storage play within it?	Literature review, initial interviews, and attendance to events (Appendix VII)	Establish contextual understanding of the system, frame battery (potential) functionality and risks within EHs, and analyze the involved actors.
2. What are the experienced drivers and barriers in integrating battery storage within energy hubs?	Derives from coding interviews and identifying the barriers, drivers and potential tensions	Define the main barriers and drivers that different actors experience about battery storage integration in EHs, and find the relation between these drivers and barriers
3. How can a participatory design process facilitate collaborative decision-making about battery storage within energy hubs?	The data (transcript and workshop materials) from the co-creation workshop are analyzed and synthesized	Make abstract tensions tangible (via contrasting scenarios), build alignment between actors, identify steps and preconditions for moving toward battery-based EHs
4. What tools can be designed to help the participatory process in order to catalyze the integration of battery-based energy hubs to reduce congestion in the Netherlands?	Addressed through the co-creation workshop, and combining knowledge about the topic.	Derive infromation from all generated insights to design and deliver tools that can help the development of EHs including battery storage.

1.2.1 Scope

This research focuses on the integration of battery storage in EHs in Dutch business terrains and industrial clusters. This project's scope is defined by geographical focus and domain.

Geographical focus: The Netherlands
The research is set within the Dutch electricity system, where grid congestion is among the most pressing challenges in Europe (Netbeheer Nederland, 2023a). The Netherlands is an interesting environment for studying battery adoption within EHs because of the current network constraints.

Domain: energy hubs on business parks & industrial clusters
EHs exist in many shapes and sizes, ranging from neighborhoods to large industrial areas (Mohammadi et al., 2018; Hirsch et al., 2018). De Graaf et al. (2024) distinguishes four different types of EHs: the built environment, mobility, business parks and cluster 6 companies (large-scale energy consumers). For this thesis, the focus lies on business parks and industrial clusters. The study targets batteries deployed at EHs in business parks and industrial sites, because these locations are currently contributors to grid congestion. These areas consume a large amount of electricity, and these companies need to electrify or use renewables as energy sources to ensure compliance with sustainability goals (De Kort et al., 2023). Furthermore, these terrains are important for energy transition because renewable generation can be directly connected to energy use. However, conclusions from this research might be of relevance to community energy storage in neighborhoods as well.

1.3 PROJECT APPROACH

A design-driven approach is suitable for the iterative exploration of future collaboration for battery deployment in EHs. More specifically, strategic design is suitable. The definition of strategic design is "the use of design principles and practices to guide the co-formulation and co-implementation of an innovation strategy toward outcomes that benefit people and organizations" (Calabretta, Gemser, Karpen, 2016). The EH innovation has the potential to support the energy transition and relieve congestion; however, the co-development of the institutional conditions is needed. Strategic thinking involves the exploration of multiple future pathways; therefore, it fits this project. Furthermore, strategic thinking requires a deep interpretation of research findings to define the underlying problem (Voros, 2003). Therefore, problem exploration is a critical first step in designing and co-developing future scenarios that can guide effective decision-making around battery integration in EHs.

This thesis therefore adopts the double diamond approach (Design Council, n.d.). This approach consists of four phases: discover, define, develop, and deliver. The double diamond framework is known for both divergent thinking, exploring an issue more widely, and convergent thinking, exploring an issue more deeply. This approach is suitable because it allows for deep understanding and exploration before jumping to conclusions. The first diamond focuses on contextual **research** and problem framing, while the second emphasizes **design** ideation. This method ensures the right problem is found first, for which the design can be applied later. In Figure 13, the project's approach is visually projected.

Discover
In the discovery phase, the goal is to explore the context and foundation EHs and batteries in the Netherlands. It consists of doing desk research and speaking with people that are connected to the issue. In this stage the goal is to diverge and investigate all connected elements that influence collaboration and the system as a whole, from a larger perspective.

Define
In the second phase, the define phase, the converging of findings will happen. The answers of SQ1 and SQ2 will be analyzed to form conclusions, and eventually reframe the problem, which means redefining the problem; finding the underlying problem that needs to be solved. This will be done by analyzing and interpreting the literature and the interviews found in the discovery phase. The reframed problem is the starting point of the second diamond, representing the design phase.

Develop
In the development phase, the designing will start. Different collaboration scenarios will be designed and tested with stakeholders in a co-creation workshop. During this workshop different ideas will be discussed, and a desired future will be sketched. The aim is to answer SQ3.

Deliver
In the final phase, the delivery phase, all of the information gathered will be combined to formulate catalyzing design concepts that will help the (organizational) development of battery storage in EHs. This translates the findings into actionable recommendations and strategic interventions that network operators and policymakers can implement. Here SQ4 will be answered.

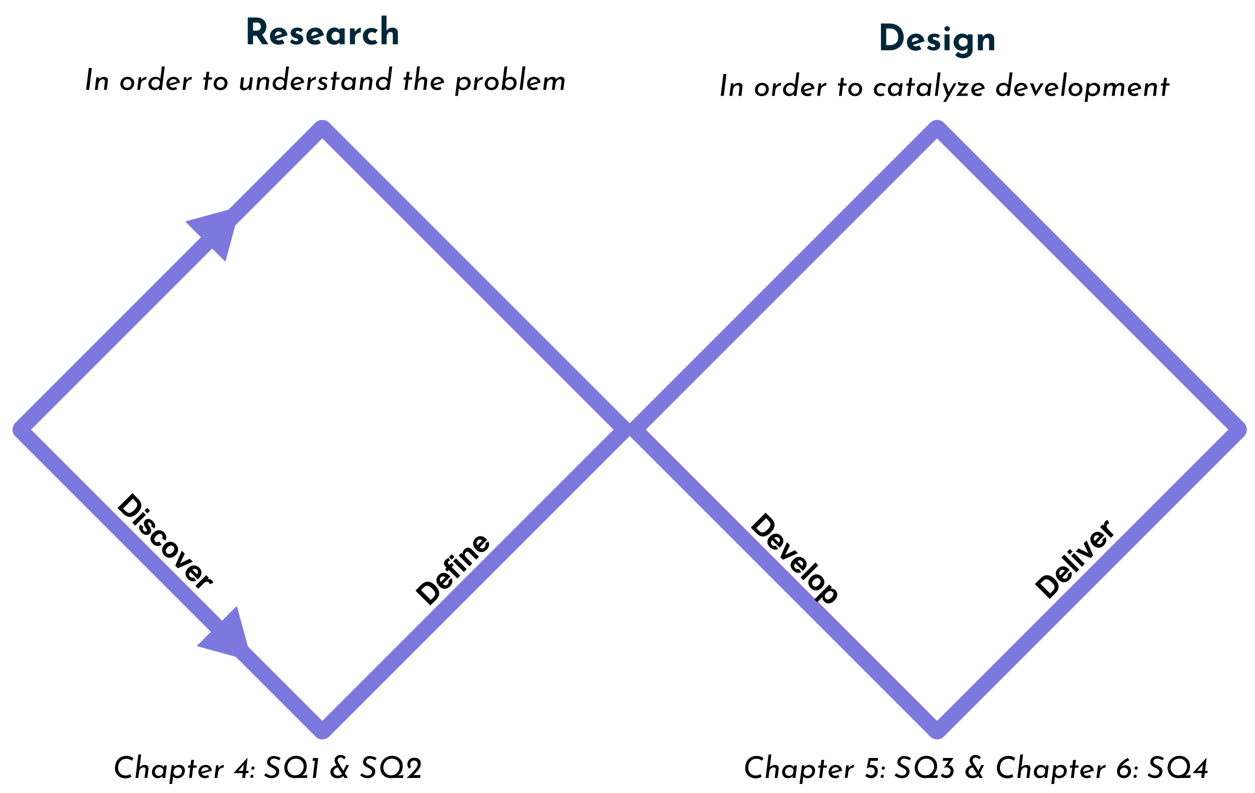


Figure 13: Visualization of the research approach (author's image)

2.

RELEVANT THEORY

Literature review & relevant theory

Before defining the method, a literature review was conducted to establish a theoretical foundation for the study. In section 2.1 the concepts of EHs and battery electric storage systems (BESS) are briefly discussed. The method for this literature review can be found in section 3.1.1. Then in section 2.2 relevant theory about systems thinking, participatory design and speculative scenarios are discussed. These theories are used throughout the process as a lens, tool, and guidance.

2.1 Definition of concepts

2.1.1 Energy hubs

EHs and, similarly, the concept of microgrids, are increasingly important for achieving flexible, reliable, efficient, and smart electrical systems (Mohammadi et al., 2017). There is no universal definition of an EH. The concept emerged in 2006 at first, and was then defined as “EH is a unit that provides the functions of input, output, conversion and storage of multiple energy carriers” (Mohammadi et al., 2017; Bagherzadeh et al. 2024). EHs can be hybrid, which means that production, conversion, storage and conversion of different energy carriers can take place. In this case, the focus lies on just electrical storage; therefore, single energy vector (electricity) energy communities and EHs are researched. The EH concept is highlighted in Figure 14 (Mohammadi et al., 2017).

These EHs and microgrids must optimally manage energy flows from and to multiple assets or elements, like renewable sources and consumers. For that purpose, EHs are enhanced with digital communication and information technologies. The aim of these technologies is processing and analyzing large amounts of information to optimize flexibility, making EHs be called ‘smart’ (Rohde & Hielscher, 2021; Mohammadi et al., 2017).

Hirsch et al. (2018) states that whether microgrids will remain niche depends on regulatory and legal challenges and whether the value or economic benefits delivered to owners outweigh any cost premiums. Norouzi et al (2022) highlights the barriers for smart microgrids are that there are no standardized regulations for grid connection, network operators are not eager to connect microgrids, and the microgrids themself fall under strong regulation, which creates uncertainty for investment.

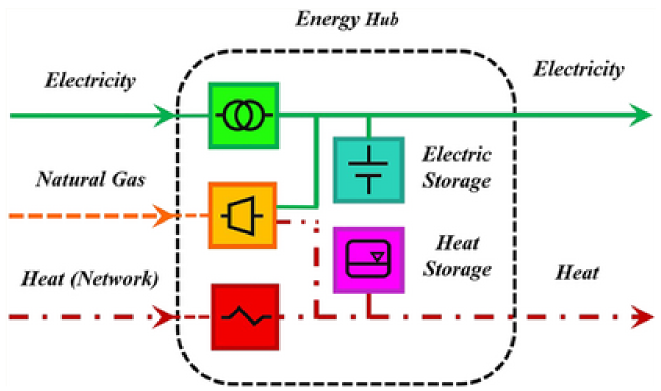


Figure 14: The energy hub concept. Source: Bagherzadeh et al. (2024)

2.1.2 Battery electric storage systems

Batteries are defined as ‘any device that supplies electrical energy obtained by direct conversion of chemical energy, with internal or external storage, and consisting of one or more non-rechargeable or rechargeable battery cells, modules or packs;’ by the EU Battery regulation (RVO, 2024a).

In academic literature Battery Electric Storage Systems (BESS) are a widely researched topic, especially in combination with RES. BESS can improve the reliability and stability of power systems, by offering a means of storing excess energy when supply exceeds demand and discharging energy when needed particularly with the increasing penetration of RES (Saldarini et al., 2023; Islam et al., 2024; Mohler & Sowder, 2017). Also, battery storage within microgrids offers a solution to provide operational resilience (Hooshmandian et al., 2025). The integration of energy storage in an energy system requires advanced energy management systems (EMS) for optimal planning, control, and management (Koohi-Kamali et al., 2013). BESS enables this by providing multiple services: frequency regulation, peak shaving, congestion management, and load shifting (Mohammadi et al., 2017).

2.2 Relevant theory

In this section several relevant theories to understand the broad nature of the problem, and design methods to explore collaborative futures with stakeholders, will be explained.

The adoption of battery storage within EHs into the electricity grid is a challenge shaped by many different factors. It does not just require the battery to be connected, but also social, financial and governance aspects of the connection. Therefore systems (Meadows, 2009) theory can provide help. The energy system can be seen as a complex socio-technical system. Therefore, the research also draws from the multi-level perspective theory by Geels (2002) to understand the situation. Furthermore, the design phase of this research draws from participatory design theory, and speculative scenarios as foresighting technique.

2.2.1 Systems theory

According to Meadows (2009), a system is defined as "an interconnected set of elements that is coherently organized in a way that achieves something". There are three essential components in any system: its elements, the interconnections between these elements, and the function or purpose that the system collectively serves.

The energy system in the Netherlands, as well as EHs can be considered as a complex system, due to the many involved actors, the interplay of technical and institutional constraints, digital and physical infrastructure. The elements include physical infrastructure, actors (e.g., DSOs, businesses, service providers), and regulatory frameworks (e.g., transport contracts). These elements are interconnected through both technical flows (electricity, data) and organizational relationships. Both of the system's purposes are to ensure (local) energy provision, and possibly, as can be seen in the energy system right now, can change over time due to changing circumstances (climate change).

System thinking provides a valuable analytical lens to understand the increasing complexity of energy, and actor networks. It allows us to

- lose our intuition of the system,
- understand the parts,
- see interconnections,
- ask questions about possible future behaviors of the system and be creative about the system redesign (Meadows, 2009).

Furthermore, to be able to change a system, one must find leverage points. "Leverage points: places in a system where a small change could lead to a large shift in behavior" (Meadows, 2009).

Systems thinking requires zooming in and out within the process, as explained in section 1.4. The system can be analyzed according to different levels, the multi-level perspective offers a means for this (Geels, 2002).

The multi-level perspective as a way to understand the system

The multi-level perspective is a framework to analyze and understand transitions in socio-technical systems by examining the interaction between different system levels: landscape (macro), regime (meso), and niche (micro) (Geels, 2002) (Figure 15).

This theory is based on the idea that technology itself has no power, this means that an artefact 'that works' has no meaning without the web it is in. Just in association with social structures, the technologies have a meaning, and they only work in the socio-technical configuration.

In this conceptualization the technological transition consists of a change, and this does not come easily because elements are linked together and the new technologies must break through current regulations, infrastructure, user practices and networks that are aligned with current technology.

Socio-technological regimes represent this in the model. A socio-technical regime is the current set of rules, way of handling, product characteristics, embedded in institutions and infrastructures. These rules are defined by different social groups. Looking from an even higher macro level, a set of deep structured trends, like the energy transition can be seen. This is the landscape. These are broad external factors.

If a regime is confronted with tensions, the linkages loosen up, which creates opportunities for innovations. Understanding the interaction between these levels helps identify the barriers and opportunities for integration of EHs with batteries within the greater regime (Geels, 2002).

Transitions happen when niches align with landscape pressures, and the regime becomes destabilized or open to change. These are called "windows of opportunity".

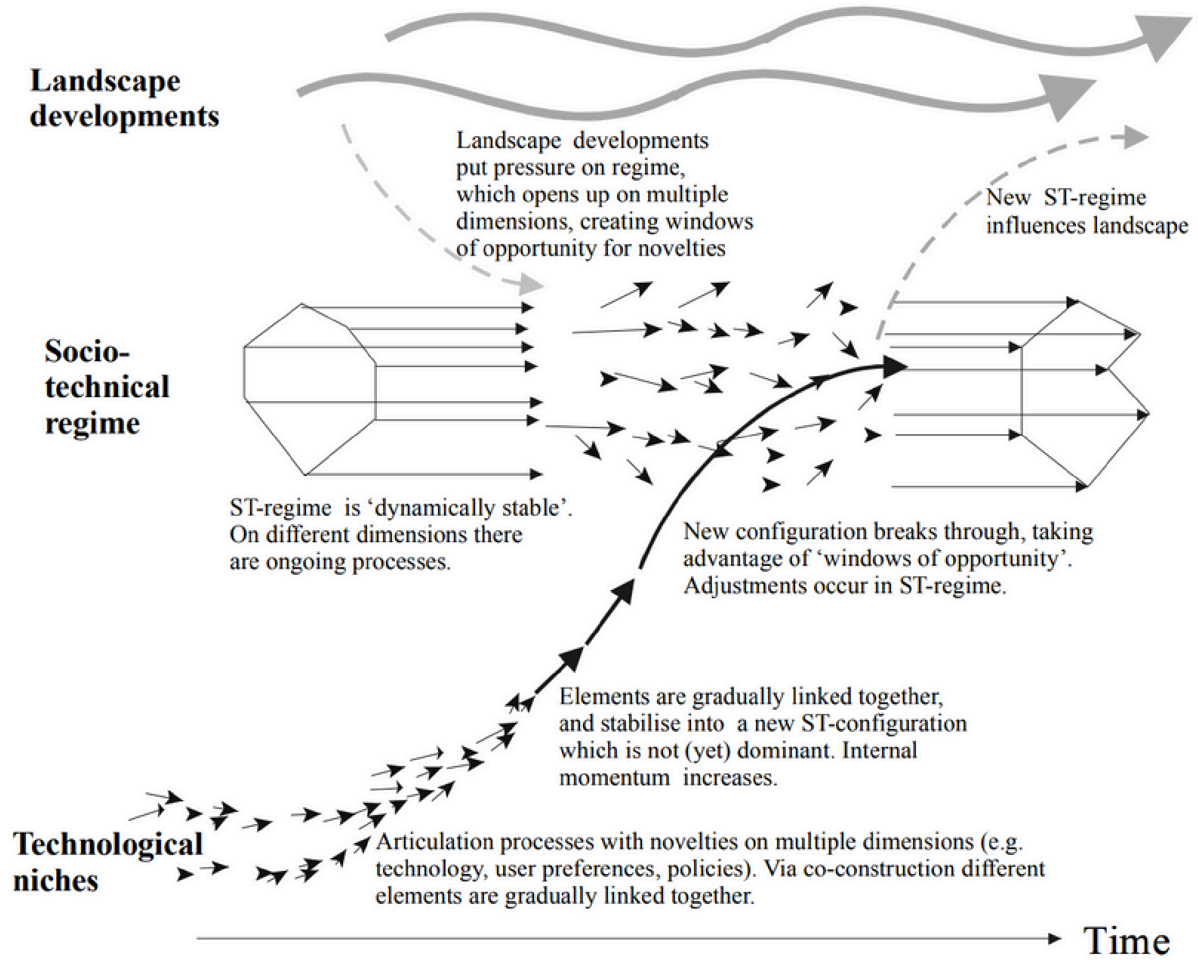


Figure 15: The multi-Level perspective. Source: Geels (2002)

It has become clear that due to the energy transition the Netherlands encounters pressures of rising grid congestion, decentralization and climate goals. These landscape pressures are destabilizing the existing energy regime, as there are limitations to current control and governance structures. Actors in the field indicate that the current model needs to change. This urgency caused by congestion creates windows of opportunity for regime change.

The regime level is at this moment dominated by DSOs, and the structure favours predictability and linear and top-down decision-making. Especially centralized grid planning, unbundling rules and risk-averse governance structures hamper change. The regime is not ready to accommodate decentralized, and flexible energy systems like EHs with battery storage.

EHs are innovations that involve new actor networks and emerging technologies. The development of EHs is limited by institutional misalignment at the regime level. The EH development is still dependent on regime actors to be able to scale up.

The multi-level perspective reveals that EHs with battery storage are niche innovations that respond to landscape pressures, but they remain fragile and fragmented due to regime rigidity. The current regime is partially destabilized but remains centralized and change is happening slowly. New contractual frameworks and DSO roles are evolving slowly. Battery-integrated EHs offer system value, but success will depend on intentional institutional innovation, particularly around contracts, and role redefinition.

Design thinking adresses the gaps of systems thinking

Buchanan (2019) argues that while systems thinking can model complexity, it cannot identify concrete problems and frame actionable recommendations. Design thinking is therefore complementary to bridging this gap. Through design approaches, engaging in real-world problems, emphasizing local context, user experience and experimentation, can create meaningful change in complex environments. This does not necessarily mean redesigning complete systems, but through design a transformation by small wins and a focus on stakeholder values, rather than relying on top-down planning, systems can slowly change (Buchanan, 2019). Calabretta et al. (2016) emphasize, strategic design helps navigate complexity through the co-formulation of innovation pathways; A way that can help find the small wins toward a desired future of the system.

2.2.2 Participatory design

From the previous sections, it becomes clear that the topic of this research situates in a complex system. In such systems, linear or top-down planning approaches often fall short, as they overlook the different values, interests, and interdependencies among actors. To address this complexity, the research adopts a participatory design (PD) approach as a method for facilitating collaboration and co-creation.

Participatory Design (PD) is a human-centred design approach that actively involves stakeholders in the design process and decision-making. It emphasizes democratic collaboration and the collective shaping of more desirable futures (Van Der Velden & Mörtberg, 2015). It originates from the Scandinavian workplace democracy movement, where the opinion emerged that workers need to have a real say in decisions about how technology is designed and used at work (Muller & Kuhn, 1993). PD advocates for users to be integrated into the design process to ensure user democracy, but nowadays it is often more used for the sake of improving products.

There are different methods for exercising PD. Through these methods, the values of users will emerge and can be incorporated into the prototype (Van Der Velden & Mörtberg, 2015). Muller and Kuhn (1993) have made an overview of PD methods and when and with whom to best use them. In the early stage of the design development phase, contextual inquiry, ethnographic methods, **envisioning future solutions**, card games, and co-development are presented as usable methods for small groups of participants. For designers participating in the world of the users, contextual inquiry and envisioning future solutions are usable, and on the other hand, when users participate in design activities, co-development is seen as a valuable method. This research reaches out to future envisioning. The applied method will be explained in section 2.2.3.

The Convivial Toolbox by Sanders & Stappers (2012) is a guide to generative design research, which emphasizes participatory co-creation methods. Co-creation is described as both a mindset, method, and set of tools (Sanders & Stappers, 2012). The Convivial Toolbox by Sanders & Stappers (2012) is a guide to generative design research, which emphasizes participatory co-creation methods. Co-creation is described as both a mindset, method, and set of tools (Sanders & Stappers, 2012). Complex problems can be addressed through these collective forms of creativity and generative design thinking. The book presents tools that enable non-designers to express their needs and values in an early stage of the design process. This book is used as a guide for the participatory workshops in this research to be able to engage DSOs, businesses, and regulators in discussions.

2.2.3 Speculative scenarios

Due to the complex, changing context of EHs scenario building was selected as a core method to explore plausible future models of collaboration. Foresight enhances strategic thinking by generating forward views (“what might happen?”), which help expand the perception of strategic options (Voros, 2005).

Different possible futures can be distinguished into possible, probable and plausible futures. This is shown in the possibility cone in Figure 16 (Voros, 2003; Dunne & Raby, 2013). More important is the preferable future in this figure. The creation of the (‘plausible’) futures, and testing and discussing these are a means to thinking about and designing a ‘preferable’ future. These futures can be presented in the form of scenarios: intentionally simplified, fictional, and provocative narratives that encourage participants to imagine alternative possibilities beyond the constraints of the present (Dunne & Raby, 2013).

It is important to distinguish between speculative scenarios and prescriptive visions of the future. Scenarios that dictate how the future should be, risk becoming overly moralistic and didactic. Furthermore, the future should not be regarded as a fixed destination but rather as a continuous, evolving process shaped by collective choices and interactions. The concept of the preferable future is inherently complex, as it raises the question: Who defines what is preferable, and on what basis? Currently, governments often shape these definitions, but the question remains whether they should have the authority to determine societal aspirations.

This method is suitable because it stimulates discussion, surfaces shared values, and explores collective visions for the future of battery and EH integration. Through speculative design and scenario-based thinking, collective visions for the future can emerge, incorporating. diverse perspectives rather than relying on institutional or corporate interests. While predicting the future remains impossible, speculative approaches allow for the proactive identification of factors that could increase the likelihood of desirable futures (Dunne & Raby, 2013). At the same time, potential risks leading to undesirable outcomes can be recognized early and mitigated accordingly.

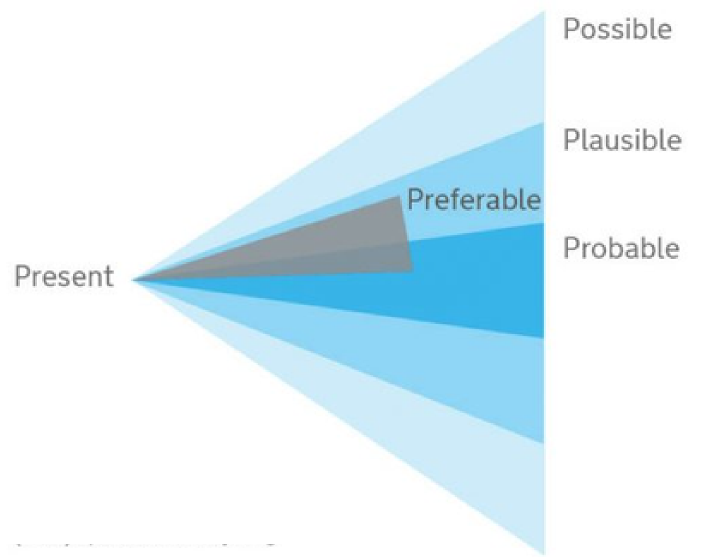


Figure 16: Possibility cone. Source: Dunne & Raby (2013)

3.

METHOD

Data collection & analysis

In this section, the method will be presented. In 3.1 the data collection method is explained, and in 3.2 the data analysis is explained.

This project needs a deep understanding of the challenges that actors experience in integrating battery storage in EHs. A qualitative research approach has been selected because this method is well-suited for grasping actor interactions and experiences and the socio-technical contexts that influence EH development and battery adoption. First through literature studies, elements of the system are explored, then through interviews the experiences of different actors are grasped, and finally co-creation workshops will generate insights into a strategic and preferable future.

3.1 Data collection

3.1.1 Literature review

The initial phase of data collection consisted of conducting a literature review to gather existing knowledge and insights related to battery storage and EHs. The primary objective is to understand how battery storage within EHs works, and what and who are needed, as well as themes, trends, and gaps in the current literature. The literature review is twofold, both academic papers and literature from the Dutch industry and governmental websites have been used.

The review of academic papers was conducted in a structured manner, focusing on sources related to EHs, battery storage integration, and collaborative energy system planning. The review process involved exploratory and targeted searches using Google Scholar as an academic database. Keywords for search terms included energy hubs, smart microgrids, battery storage, community storage, and participatory design. Sources were selected based on relevance and recency, with an emphasis on European and Dutch contexts between 2015 and 2025. In Appendix III, a table with a comprehensive view of all selected papers, including summary and methods, can be found.

The review of Dutch industry reports was conducted through searching for papers and reports containing information about battery storage and EHs, primarily from governmental bodies, industry associations, and network operators. Also, through snowballing, relevant reports and websites were found. This is aimed at gaining an understanding of the current progress of battery storage and EHs within the Dutch context.

3.1.2 Interviews

Interviews were conducted to get a deeper understanding of the experiences of actors of EHs and battery integration. First exploratory interviews were conducted with experts to gain preliminary insights, validation of the understanding of battery integration, and refinement of the research focus. Then in-depth interviews were held to be able to give more specific information. These interviews are aimed at gathering detailed information from different points of view about the barriers and drivers of battery storage integration in EHs. These interviews are semi-structured to allow for in-depth exploration of specific topics while providing flexibility to follow up on interesting points raised by the participants. The interview script with predefined topics can be found in Appendix V. The interviews lasted about 45 minutes and were held in the participant's native language, Dutch, to allow them to express themselves freely. All interviews were recorded and transcribed to ensure accurate capture of relevant information for analysis. The transcripts were then translated into English for detailed analysis.

The participants gave their consent for these recordings and data analysis. The participant consent form can be found in Appendix VIII.

3.1.3 Co-creation workshop

A co-creation workshop is conducted to enable discussion among stakeholders, ultimately to find the middle in conflicting priorities, and refine different scenarios for the decision-making process of battery integration within EHs. The workshop followed a generative design approach (Sanders & Stappers, 2012), as speculative future scenarios were used as boundary objects to provoke reflection, negotiation, and shared sense-making. Participants evaluated two contrasting decision-making scenarios for battery coordination (DSO-led vs. EH-led). A more detailed overview of the workshop is given in chapter 5.3, and the script can be found in Appendix IX.
In total, 3 workshops were held with different participants, in Appendix X the list of participants can be seen. The workshops lasted about 90 minutes. The workshop consisted of three parts.

First, the problem is shown through storytelling. The next step included showing the two different scenarios and explaining them step-by-step. Stakeholders will assess these scenarios using structured feedback mechanisms such as sticky notes or digital collaboration tools (Miro). Finally, in the consensus-building part, participants will engage in a discussion to align values, business models, regulatory frameworks, and grid requirements.

Data collection included audio recordings, photographs of participant-generated materials (or screenshots for online sessions), and documentation of observations. The participant consent form can be found in Appendix X

3.1.4 Participant selection

Participants for the interviews and the participatory workshop were selected based on several criteria. The selection process involved searching LinkedIn, websites of organizations, networking at events, and Accenture's network. The aim was to find employees with specific titles within relevant companies and utilize a snowball sampling method. The criteria for selecting participants included their involvement in battery projects, their role within DSOs, their influence on policymaking, and their expertise in the industry. This selection process aims to gain insights from various perspectives within the field. The list of interviewed participants can be found in Appendix VI. This approach ensured a diverse and knowledgeable group of participants, including battery project developers, DSO representatives, policymakers, and industry experts.

3.2 Data analysis

3.2.1 Interview analysis

Desk research and exploratory interview data were organized into relevant topics aligned with the sub questions.
Interview data was coded through a bottom-up approach, extracting barriers and drivers. Data was analyzed through a thematic content analysis (Braun, 2006). This allows for in depth exploration of qualitative data, uncovering nuanced insights into the challenges of battery integration in a dynamic context. The process consisted of 4 Steps.

1. Transcribing and translating to English, with the help of AI tools.
2. Initial codes were generated in the software Atlas.ti, by focusing on drivers, barriers, and tensions.
3. Then codes will be clustered into code groups.
4. And then these code groups were clustered into themes, representing the barriers, drivers and the found tensions.

The results are reported in chapter 4.2.

3.2.2 Workshop synthesis

The data collected during the co-creation workshop were analyzed using thematic analysis. This method was selected to allow a flexible exploration of qualitative data that emerged from the dialogue and scenario reflection. This analysis was done by listening to audio fragments and looking at the notes of participants through the feedback tools. During this process important (recurring) findings were noted.

First, the feedback on both scenarios was processed this way. This created insight into what participants liked and disliked about each scenario, and how this differed among the participants. Then through clustering of the findings, more general themes were identified. These showed shared values that help overcome earlier defined tensions, but it also showed specific needs, steps and actions highlighted by participants.

4.

RESEARCH

Understanding the barriers & opportunities for battery deployment in EHs

This chapter presents the results of the research phase. This corresponds to the first diamond of the double diamond design process. First, in 4.1, the foundation of EHs, battery storage and the involved actors will be explored. As this starting point of the first diamond is characterized by divergence, different perspectives of the EHs are analyzed to gain a broad understanding.
In the second part of this chapter, the focus shifts toward convergence. Here, the drivers and barriers experienced by actors in integrating battery storage in EHs are presented. These insights lead to a clear problem definition that identifies the challenges that hinder battery storage integration. This problem (re)definition forms the starting point of the design phase.

4.1 The foundation of energy hubs

In this paragraph, sub-research question 1 will be answered:

1. What is the foundation of an energy hub, and what role does battery storage play within it?

The sub-chapters are structured according to several angles of an EH and battery storage: technological, organizational, regulatory, and financial aspects. This is the division of relevant aspects for an EH according to 'the blueprint of an EH' created by MOOI Eigen, a consortium for EH developers (Figure 17) (Eigen, 2025). This way, each element of the EH can be researched in a structured manner, while in the end offering a holistic view. Understanding these foundations is essential to identify what enables or hinders the integration of battery storage within EHs on Dutch business parks for actors.

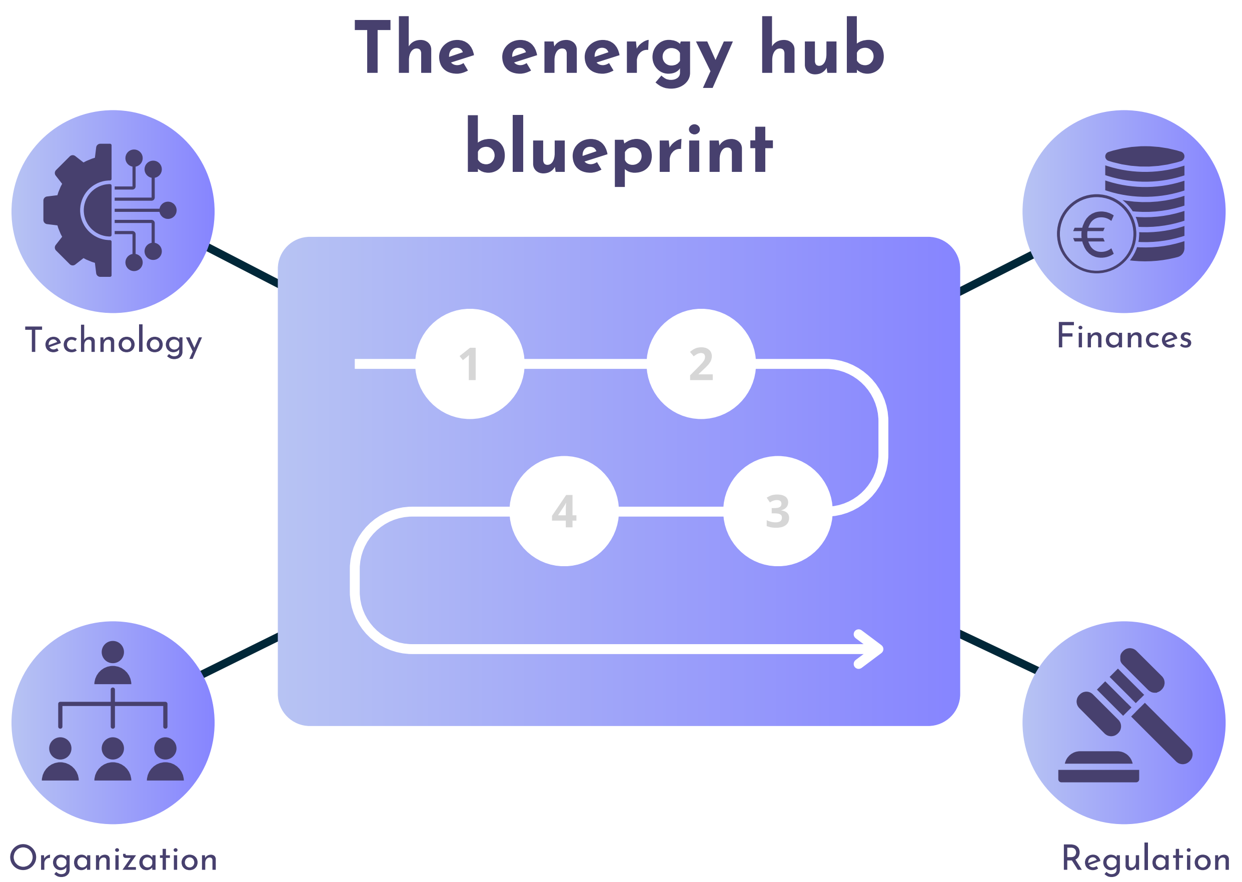


Figure 17: The energy hub blueprint Source: Eigen (2025)

4.1.1 Technology

Effect of batteries on grid congestion

Recent studies by CE Delft (2023a, 2023b) have examined the effect of utility-scale energy storage systems in relation to grid congestion. Batteries can add to congestion as well as alleviate it. This can be seen in Figure 19 for generation-side (feed-in) congestion and in Figure 20 for demand-side (off-take) congestion. This shows that the timing of battery activity is crucial because misaligned operations can worsen congestion. The two types of interactions are explained below:

- Demand-side congestion

In congested areas where companies cannot get sufficient capacity from the grid, batteries can store energy when there's room (Figure 19b, c) and discharge to supply energy to consumers within the EH, reducing peak demand on the grid. This helps to flatten peaks when needed and maintain business continuity. Especially in combination with similar consumption profiles, collective battery use improves utilization of scarce grid capacity by shifting the loads (CE Delft, 2023b; CE Delft, 2024). Current typical battery technologies provide 2 to 4 hours of storage capacity, which means they are effective for solving congestion with a short duration. Structural, long-lasting peaks need different approaches.

- Generation-side congestion

Batteries can also temporarily store excess renewable energy (e.g. solar PVs or wind) when it cannot be fed into the grid due to capacity limits (Figure 20c). This prevents curtailment and increases local use of renewable energy. However, research by CE Delft (2023b) indicates that curtailment is often a more cost-effective solution, especially since batteries in this context are only used 1% of the year (these are the peak hours), and their energy capacity is often insufficient to store the full volume of electricity generated during peak production. Batteries are currently not a structural solution to generation-side congestion, but within EHs they can support optimized local use of renewable energy.

It is concluded that batteries within EHs are most valuable in areas experiencing demand-side congestion. In these contexts, they can reduce peak loads and shift electricity consumption, enabling coordinated local energy use and optimal utilization of scarce grid capacity. Batteries are especially effective in addressing short-duration peaks in demand.

Battery location & requirements

Battery Energy Storage Systems (BESS) can either be installed behind the meter (serving a single company) or as a shared battery at the EH level. The effectiveness of a shared battery depends on visibility and controllability through EMS. This requires placing the battery before the meter and enabling separate measurements. In Figure 18, the placement of a shared battery system can be seen (CE Delft, 2023c). For a typical 2 MW battery system, often consisting of multiple modules, the setup usually includes container-sized battery units. Also, there are a number of safety requirements that need to be met for the battery systems, as outlined in the PGS guidelines for battery systems (CE Delft, 2023c).

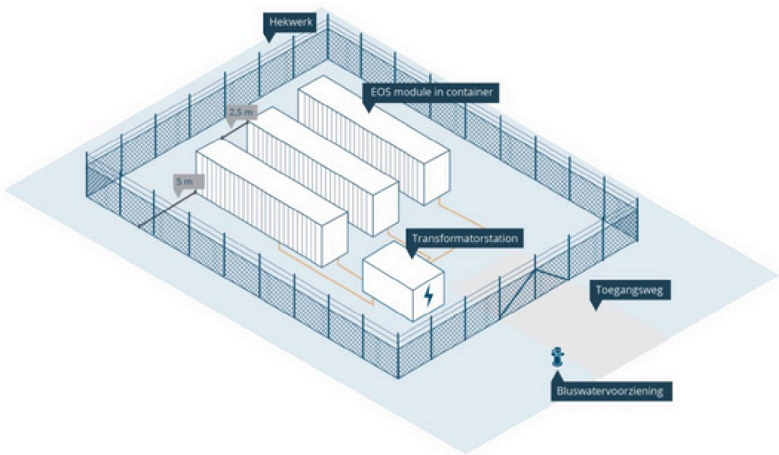


Figure 18: Potential positioning of BESS. Source: CE Delft (2023c)

Concept definition effect of batteries on grid congestion

Off-take grid interaction

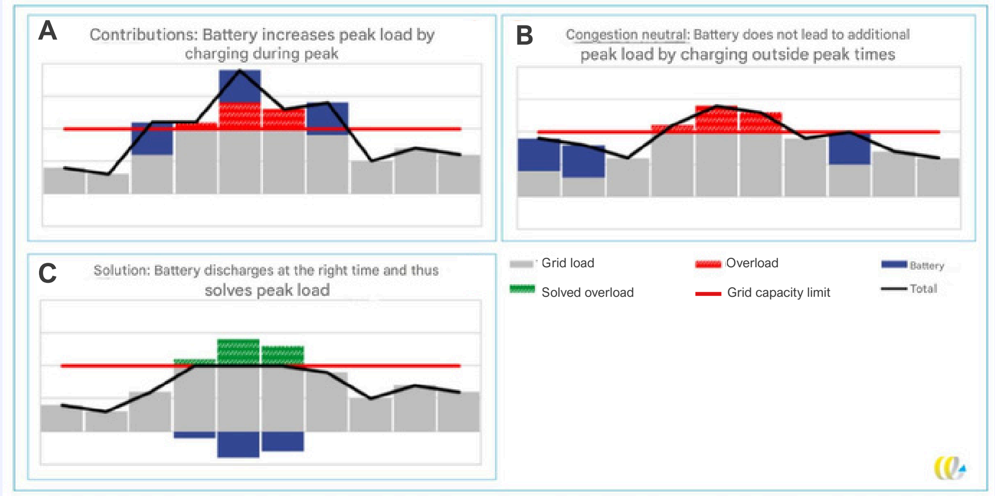


Figure 19: off-take grid interactions. Source: CE Delft (2023a)

Feed-in grid interaction

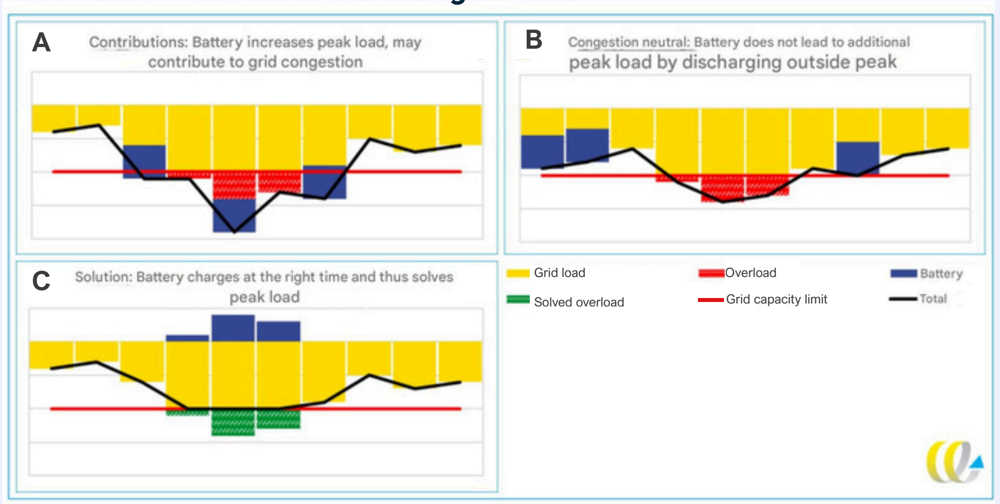


Figure 20: Feed-in grid interactions. Source: CE Delft (2023b)

Coordination & control within an energy hub

The EMS of an EH coordinates the local energy supply and demand and the steering of flexible assets, like batteries (CE Delft, 2024). Through bidirectional data flows, smart meters, and IoT-enabled sensors, the EMS monitors system conditions, forecasts demand, and executes operational adjustments of the battery and other assets (Babayomi et al., 2022). Through emerging technologies like AI and digital twins, these forecasts can be enhanced. Within current EHs, an EH platform (EHP) is used to monitor and optimize the kW and kWh between different applications (Eigen, 2025). The platform is ensured by an open interface (API) which enables an external party to communicate with the application as well (Topsector Energie, n.d.).

The EAN meter (electricity or kWh meter) is owned by a certified metering company and ensures accurate, 24/7 insight into total energy consumption. To monitor individual assets within the system, sub-meters are required (Topsector Energie, n.d.).

EHs can function as a virtual power plant (VPP) within the grid: an aggregator of spatially distributed energy resources and assets (Babayomi et al., 2022).

4.1.2 Organization

Setting up and operating an EH involves organization, but there is no fixed way of organizing an EH. First, a legal entity has to be set up, representing the participating companies in the EH (Kennisplatform Energiehubs, 2025). This entity is the point of contact for all the actors involved and can handle permits and insurance, act as a point of contact for the grid operator and apply for funding and subsidies. In the Netherlands, there are different legal possibilities for such an entity, for example, a cooperation, Ltd “BV” or a foundation (in Dutch: Stichting). Therefore, in this thesis, this entity will be called the EH collective. Different organizations can initiate to form an EH together, like solar parks, industries or other businesses that experience a problem in their energy supply. The organizational structure of an EH is depicted in Figure 21 (Van Rhee, 2023).

Next to this, other actors have an influence on EH development. Through exploratory conversations and literature, a comprehensive actor map (Figure 22) has been developed to visualize key participants. The actors are categorized based on their involvement in EH development. More important are the interrelations between actors within this ecosystem.

The arrows show that an actor has relationships of influence, control, or decision-making power over another actor. This means that some stakeholders may have the authority to make decisions that directly affect others. This map helps to understand what stakeholders are directly involved in, and how they relate to each other. Below, the most important stakeholders and their functions are explained. Appendix IV is a table with all actors and their general role.

EH collective
This is the legal entity of the EH.

EH participating businesses
The EH participating businesses or entrepreneurs each have their own reasons to participate in the EH. These EH participants can be divided into organizations that offer flexibility and the ones that cannot.

Network operators
The tasks of network operators are connecting electricity producers and users to the electricity grid, maintaining the electricity networks, investing in network expansions if needed, and maintaining balance in the grid. In this case the DSO ensures the connection with businesses through contract transport agreements.

Service providers
These technology service suppliers ensure the overall functioning of the EH. They offer and operate the EMS. These are the control systems that enable the optimal operation of the EH.

Other important actors include:

Governments and Regulators (National, Provincial, Municipal)
These actors are responsible for creating and enforcing laws and regulations and managing energy markets. This includes policymakers at both the national and local levels, as well as regulatory bodies like the Dutch Authority for Consumers and Markets (ACM).

- The National Government (Ministry of Economic Affairs and Climate - EZK) formulates legislation and regulations and can contribute to the financing of projects or the stimulation of the right preconditions at the national level.
- Provinces and municipalities play an important role in permits, subsidies and coordination between stakeholders. Municipalities are often the most directly involved in, finance process costs in the initial phase and provide support in obtaining subsidies. They want to improve the local circumstances and contribute to sustainability.
- The ACM sets the rule frameworks for network operators in tariffs and contract formats. Within this framework, network operators are free to fill in their own formats.

Project developers, advisors
Developers and financiers are involved in the realization of EHs through standardization and the provision of services. Often in the case of EHs, a director is appointed who will facilitate the EH.

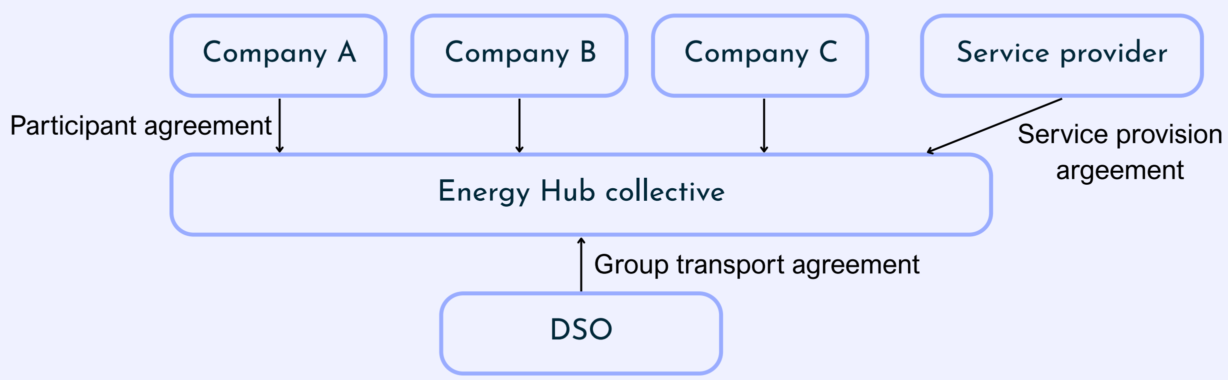


Figure 21: EH organization (author’s image based on Van Rhee (2023))

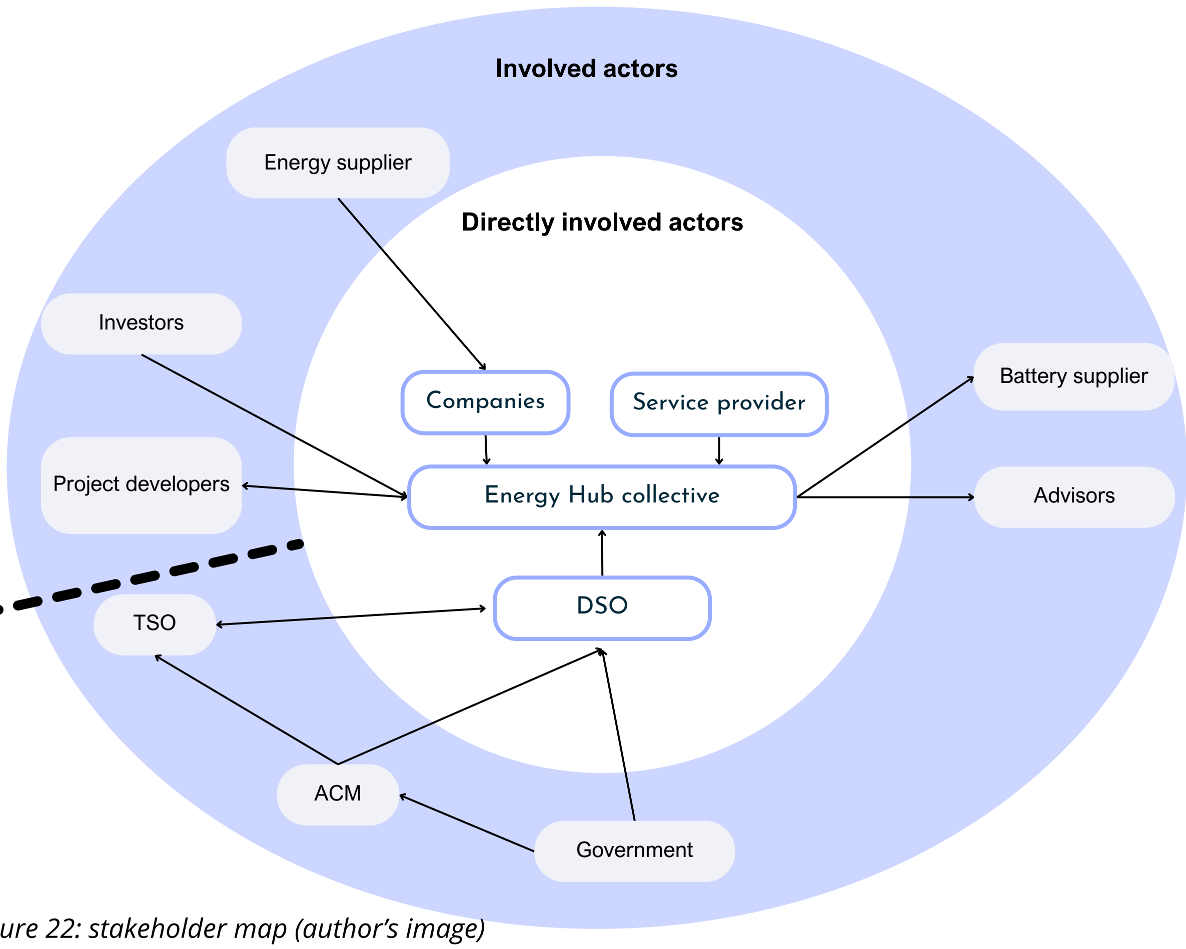


Figure 22: stakeholder map (author’s image)

4.1.3 Regulation

For the development of an EH operational, and financial agreements have to be made among different actors. Besides making agreements among participants, the EH collective needs to establish contractual agreements with the DSO about the transport capacity and grid tariffs. These agreements are laid down in a 'transportovereenkomst'; a transport agreement.

For EHs ,there are several possible contracts currently known: the Group Transport Agreement (group-TO), Collective Capacity Limiting Contract (C-CBC) and alternative transport rights (ATR) (RVO, 2023; Netbeheer Nederland, 2023b). The directives for these kinds of contracts are still under development, as the ACM presented their proposal to the group-TO recently in April 2025 (ACM, 2025). Each type of contract is explained below, and in Table 2, an overview of each contract type can be seen with a description and associated grid access and tariffs.

Table 2: Different types of group contracts. Source: Netbeheer Nederland (2023b)

Contract type	Firm Group Transport Agreement	Collective Capacity Limiting Contract (C-CBC)	Collective Alternative Transport Agreement
Description	Collective contract that replaces the individual transport agreement	Collective contract that exists alongside the individual ATO.	This concerns a collective contract, without the right to transport, unless indicated
Grid access	100% of contracted capacity	Partial access (e.g. 85%): collective commits to a collective capacity limit	No guaranteed access, only when grid has spare capacity
Grid tariff	Full (standard) tariff	Standard tariff, but compensation for curtailed capacity	Great discount on tariffs (eg. near 100% capacity charges)

Group-Transport agreement

A Group Transport Agreement (Group-TO) allows connected customers to collectively optimize and manage their contracted electricity transport capacity. Under Group-TO, the group receives a firm transport capacity, meaning that the contracted group is guaranteed by the network operator to always be able to withdraw or feed back electricity up to the agreed amount. This collective agreement replaces the individual transport contracts between each company and the network operator. A visualization can be found in Figure 23. The group, as a legal entity or cooperation, holds the right to the collective transport capacity and is responsible for complying with the contractual obligations. It is their task to monitor and mutually coordinate and divide network capacity (Netbeheer Nederland, 2023b).

Collective Capacity-Limiting Contract

The Collective Capacity-Limiting Contract (C-CBC) is a contract where a group of connected companies agree to limit their electricity take-off or feed-in during peak times. The network operator sets a collective maximum capacity, which is lower than the sum of individual contracted capacities and in return, these companies receive financial compensation. This compensation is calculated based on the companies missed generation or consumption. The transport capacity limit can either be fixed or dynamic. With a fixed limit, the EH must reduce its transport capacity during specific, pre-agreed periods, like in winter evenings or summer afternoons. Alternatively, with a dynamic limit, the grid operator activates the capacity restriction only when congestion is expected in the area.

A Certified Service Provider (CSP) is required to coordinate this flexible energy usage, and communication happens through the trading platform GOPACS, where these parties receive incentives from network operators (Netbeheer Nederland, 2023b; GOPACS, 2025). The CBC also exists for individuals as well as for collectives. For a C-CBC, all individual parties maintain having an individual ATO (individual transport agreement) CBC as well, but the group collectively agrees to stay within the new limit (RVO, 2024). Under the C-CBC, the group is responsible for internally distributing the available capacity among its members.

Alternative transport rights

Furthermore, there is the option of an alternative transport agreement: The Collective Alternative Transport Agreement (Groeps-ATR). This involves the allocation of non-guaranteed transport capacity and non-firm capacity. It is a service provided by the network operator to a group of connected parties, where the operator allows partial (time-based) access to transport capacity. This agreement is a collective contract, but unlike other agreements, it does not guarantee a right to transport capacity. Under this arrangement, the collective group has control over the distribution of the remaining available capacity (Netbeheer Nederland, 2023b). This model enables greater flexibility in managing transport capacity while addressing grid congestion issues, but it also poses much uncertainty for companies about when they can make use of the electricity grid. Whether a non-firm contract is attractive to a battery operator will be a trade-off between the number of hours of restriction versus the discount on transport rates. This is highly dependent on the profile of the grid load at a location.

Unbundling rules

The Electricity Act of 1998 states that the production, trading, and supply of electricity must be separated from grid operations (Netbeheer Nederland, 2019). This means that network operators cannot own producing or consuming assets within the electricity grid.

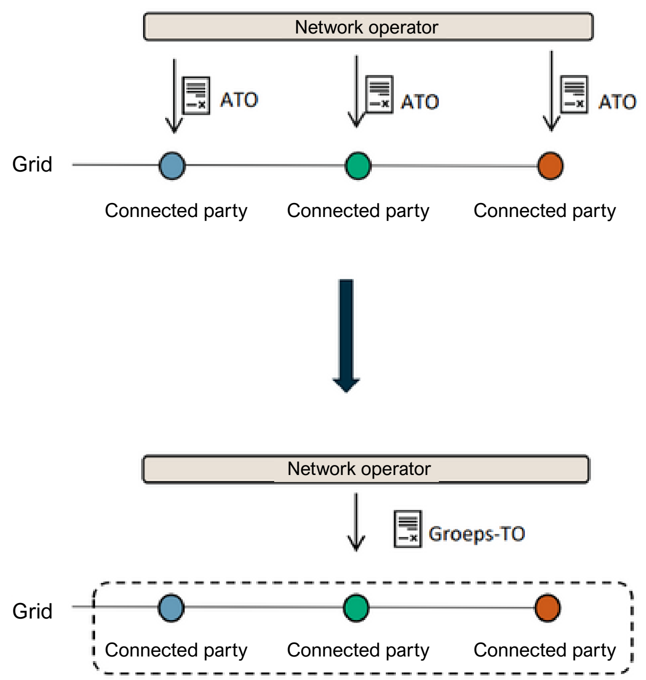


Figure 23: visualization of Group-TO. Translated from Netbeheer Nederland, (2023b)

4.1.4 Finance

The financial aspect of the EHs is very important, as an EH includes investment costs for design and planning, creating fair cost-benefit models for shared infrastructure, and developing a strong value proposition for the operating entity. Additionally, the business models must address the risk and uncertainty faced by investors and insurers. Strategic decisions on configuration, ownership and outsourcing, whether to invest directly or engage third parties, are essential for scalable implementation. Integrating battery storage into EHs presents significant financial considerations that can determine the long-term viability of the EH.

Operating on an economically viable basis is a prerequisite for EHs to exist in the long term. Kooshknow et al. (2022) highlight that finding a viable business model for energy storage is a challenge for the widespread implementation of storage technologies. The upfront capital costs and potential revenue streams shape the business case for batteries. More specifically, research shows that investment costs and network tariffs are important determinants of the viability of the business case (CE Delft 2023c). Understanding these financial implications is essential to ensure sthe ustainable and cost-effective integration of battery systems in EHs. Below, the most important aspects that determine the viability of a battery storage project are presented. These are investment costs, trading, and tariffs.

Investment costs

EH participants need to ensure return of investment of the EH and battery storage project (CE Delft, 2024) and battery storage systems require a high upfront investment, and the still evolving revenue streams from flexibility services are barriers to battery storage deployment (Truesdale & Ruzzenenti, 2024; Stecca et al., 2020), however battery storage is becoming more cost-effective. In the Netherlands, several financial incentives support battery storage projects. First of all, the Energy Investment Allowance (EIA) ensures businesses can deduct 40% of their investment costs in energy-efficient technologies (e.g., batteries) from their taxable profit, making battery investments more attractive (RVO, 2025a).

Furthermore, the SDE++ scheme (Stimulation of Sustainable Energy Production and Climate Transition) provides subsidies to companies and non-profit organizations that generate renewable energy or reduce CO2 emissions on a large scale. Batteries can be used under this scheme to store renewable energy and help manage grid stability, thereby contributing to the reduction of CO2 emissions (RVO, 2024).

Trading

The viability of battery storage depends on strategic deployment across different electricity markets (CE Delft, 2023a). Many studies are focused on optimization methods for BESS to reduce costs (Zarate-Perez et al., 2022).

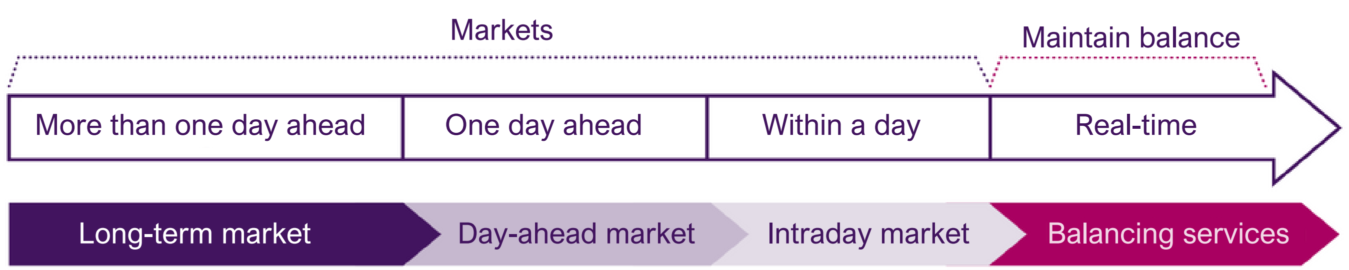


Figure 24: Energy trading and balance maintenance overview with timescales. Source: Ministerie Economische Zaken en Klimaat (2023a)

There are different kinds of electricity markets: the wholesale long term, day ahead and intraday market, and the real time balancing markets (consisting of imbalance, FCR, aFRR, mFRR) (Figure 24). Each of these markets serves different purposes. Long-term and day-ahead markets facilitate planned energy procurement, intraday markets allow adjustments closer to real-time, and balancing markets provide rapid-response services to stabilize the grid by correcting imbalances that cause frequency deviations. Furthermore, though currently less prominent, the congestion market can complement the battery business models. EHs with batteries can relieve grid congestion by aligning their operations with market-driven flexibility mechanisms. This happens through the platform GOPACS.

Research shows that trading on imbalance markets (aFRR) are the most profitable (Van den Boom, 2023; CE Delft 2023a). Batteries can respond fast to fluctuations in supply and demand. By strategically charging and discharging based on market signals, batteries can generate revenue.
Several sources (Babayomi et al. 2022; van den Boom, 2023) emphasize that battery systems that operate just for profit through electricity markets can worsen or cause local grid congestion, as is shown in Figures 19 and 20. However, Van den Boom (2023) explains that without trading on these electricity markets the investment opportunity for battery storage is unattractive.

Furthermore, these markets are volatile and unpredictable, therefore the revenue streams of batteries are still evolving (Truesdale & Ruzzenenti, 2024; Stecca et al., 2020). On the other hand, recent research from McKinsey stated the revenue potential of energy storage technologies is often underestimated. It is argued that traditional evaluation models should be adjusted to better assess the profitability of energy storage projects and their contributions to sustainability goals (Van Der Marel et al., 2025).

Network tariffs

The business case of a battery depends largely on grid tariffs (CE Delft, 2023c,a)
Studies from CE Delft (2023a, 2023b, 2023c) show that the economic viability of battery projects is less promising because of high network tariffs, which account for almost half of the total costs of these collective batteries.

Currently, network costs are allocated to end users based on consumption. However, for grouped users that enter a collective transport right (GTV) leads to lower total allocations than the sum of individual rights, resulting in cost savings under the current tariff system and creating a financial incentive to form groups (Netbeheer Nederland, 2023b). However, further analysis is needed to ensure cost-reflective billing at the network level where group members are connected.

In Figure 25, an overview of the costs and generated revenue for 2MW, 8MWh battery is shown. This is based on findings from CE Delft (2023c), and additional calculation of revenue for the congestion market done by the author (Appendix XIII).

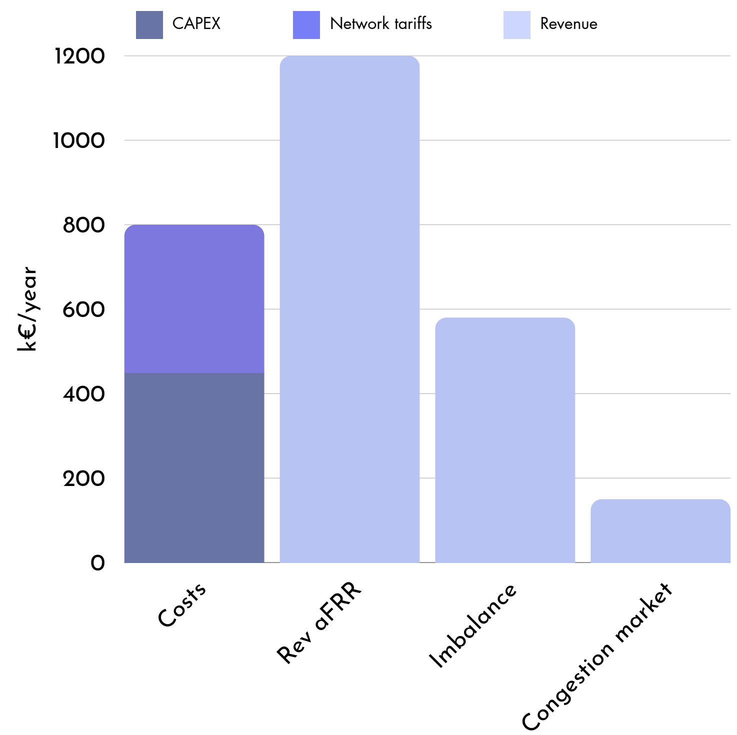


Figure 25: Graph of calculated costs & revenue for a 2MW battery (author's image) (based on CE Delft (2023c))

4.1.5 Conclusion

In this section, a conclusion from 4.1 will be given, answering sub-question 1:

What is the foundation of an energy hub, and what role does battery storage play within it?

While the foundation of an EH can be sketched in terms of technological, organizational, regulatory and financial aspects, there is no fixed configuration for an EH. While the EH blueprint provides a useful framework for analyzing the core components of an EH, it is important to recognize that these elements are interdependent and context-specific.

From section 4.1.1 it can be concluded that batteries within EHs can either worsen or relieve grid congestion, depending on their timing and use; they are especially effective for short-term demand-side congestion, where they help shift loads and improve local coordination of energy use.

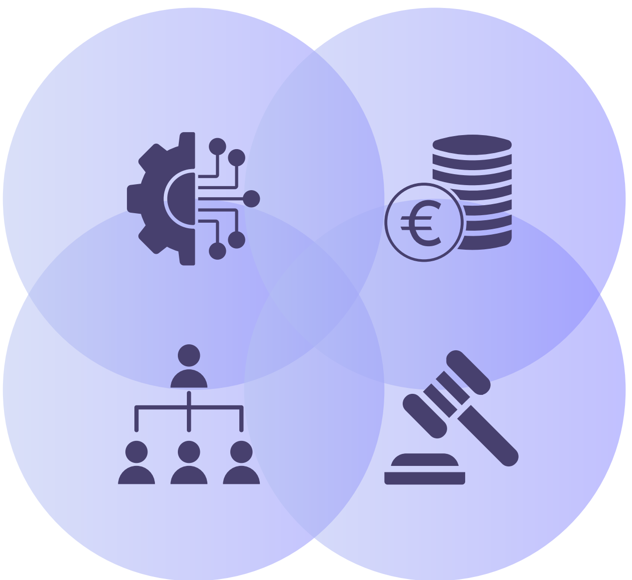
In 4.1.2 it is shown that there is a wide range of actors involved, which highlights the need for structured collaboration to maximize EHs contribution to grid flexibility, sustainability, and resilience.

In paragraph 4.1.3 it becomes clear that the regulatory foundation of EHs is not definite and clear yet. The information also shows there are different possibilities for transport agreements, in each type of contract there is a benefit and downside for one actor.

In 4.1.4 it is discussed that there are different factors influencing the viability of EHs with battery storage. These are high upfront investment costs, evolving revenue models, and the structure of network tariffs. The viability determines whether or not the investment will be made. Uncertainty of returns of the battery system remains a barrier, but participation in markets can strengthen the business case, while on the other hand introducing risks for the grid.

It can be concluded that the elements of an EH mutually influence one another. Technological decisions shape financial outcomes, contractual choices affect operational control, and these, in turn, are both shaped by and shape the organizational context. As systems thinking emphasizes (Meadows, 2009), such interdependencies give rise to complex, emergent behavior, including unintended effects such as increased congestion. This systemic complexity makes it challenging to steer the system toward the desired outcome of using batteries to alleviate congestion.

Because all elements are interconnected, achieving effective implementation requires collaborative and carefully aligned decision-making across all actors involved.
The following section explores the specific drivers and barriers experienced by these actors, as well as the tensions that may emerge from their interactions.



4.2 Drivers & barriers to battery storage in energy hubs

In this paragraph the results of the interviews will be presented. Sub-question 2 will be answered:

What are the experienced drivers and barriers to EH battery integration from different stakeholder's perspectives?

The thematic content analysis showed insights into what the current perceptions and experiences of different stakeholders on battery storage in EHs is. As explained in section 3.2.1, a bottom-up, thematic content analysis is used to analyze the drivers and barriers. In total about 200 codes were generated and then clustered into groups, and then clustered into themes, from which drivers and barriers could be identified. These are explained in 4.2.1 and 4.2.2. Furthermore, after iteration on and re-clustering of the results, tensions between the network operator and EH collective that slow down EH development were found. These are explained in 4.2.3. The chapter ends with a conclusion in 4.3 that leads to the starting point of chapter 5, the design phase.

4.2.1 Drivers

The following drivers were found from the interviews. These are listed in Table 3, based on importance from a grid and EH perspective. Per driver, the main stakeholders experiencing this driver or barrier are listed.

D1 Efficient use of the grid
For many businesses, participation in an EH is not just attractive, it is their only option due to grid congestion. P14 highlights "There is no other option. In the future, there is no choice". EHs offer a way to skip long connection queues by optimizing shared capacity. DSOs also benefit from a more efficient use of existing infrastructure, reducing the urgency for costly expansions. DSO participant P12 mentioned "EHs get off the ground faster, because we have an interest in that happening".

D2 Align energy profiles within EHs
Participants explained that batteries within EHs would be beneficial for aligning their energy consumption and production profiles and deliver peak shaving to remain within grid limits. P9 explains "And then you only need a battery to absorb certain peaks that you cannot smooth out with agreements".

D3 Sustainability
Participants indicated that one driver of battery storage is the ability of businesses to reach sustainability goals. P13 explains "But a battery also has other advantages. Imagine that you can use sustainable energy much more because of that". Battery storage enables locally produced renewable energy and supports broader sustainability goals. Local generation (e.g., solar PV) can be matched with local demand, which helps decarbonize processes and reduce dependence on fossil fuels.

D4 Financial Savings and Revenue Potential
Shared infrastructure within an EH can lead to lower costs through joint procurement and energy optimization. Batteries also offer revenue opportunities via energy market participation (e.g., imbalance and congestion markets). P5 explains "I think there are roughly two or three reasons to purchase a battery…. Number three is the battery that is really used for energy trading, for example for balancing services…. That way you earn it back a bit faster".

D5 Backup Power
Batteries provide a buffer in case of outages, adding resilience for participating businesses, particularly those with critical processes. P1 mentioned "And we can place the batteries there or possibly as a backup"**.**

Table 3: Table of drivers for battery-based EHs for stakeholders

#	Driver	Explanation	Driver for
D1	Efficient grid use	For many businesses, participation in an EH is not just attractive, it is often their only option get a (larger) connection due to congestion.	Businesses, DSO
D2	Align energy profiles within EH	Batteries within EHs are beneficial for aligning their energy consumption and production profiles and reduce demand peaks to remain within grid limits.	Businesses
D3	Sustainability	Battery storage enables optimization of locally produced renewable energy and supports broader sustainability goals.	Businesses, government
D4	Financial savings & revenue potential	Lower costs through joint collaborative procurement and optimization, and offering revenue opportunities through electricity market participation,	Businesses
D5	Backup power	Batteries provide a buffer in case of outages, adding resilience for participating businesses, particularly those with critical processes.	Businesses

4.2.2 Barriers

Interviewees also highlighted several barriers. These are listed in Table 4, based on importance from the EH perspective, along with the stakeholders experiencing these barriers. Below, each barrier is explained.

B1 Complexity initial EH formation
One barrier that was highlighted, regarding EH formation in general, is that not all companies are equally engaged or willing to collaborate, especially when the benefits or required flexibility differ. P14 highlights that each company thinks from "What's in it for me?". If they do not have the problem, why would they join the EH? This can slow down or derail EH development.

B2 Space and Safety Constraints
Several participants indicated from experience that it is hard to find the physical space for a battery on business terrain, especially since the safety standards are high. P6 indicated "I found it surprisingly complicated to find a piece of free land for a few batteries". It seemed to be hard to find a safe spot that could be enclosed. Furthermore, the municipality must give permits for battery installation, which is a time-consuming process as well. P8 indicated that safety rules are currently unclear "There have to be clear rules: what is allowed, what is not, how far away from buildings should they be, how they should be connected.".

B3 Cost & investment risk due to uncertainty earning back investment
Financial risks were a theme that emerged in every interview. The high investment in battery storage seems to be a barrier that is noted by battery supplier P16 "Let me just say that the single biggest factor right now is the price of the asset." Many participants highlight that the battery business case is dependent on trading on electricity markets, and the balance market in particular. P16 highlights that the biggest uncertainty estimating the payback period of the battery is the electricity (market) prices. P2 highlights that the future is unpredictable

"But at the same time, that also makes it very erratic and unpredictable that you are dependent on such a market mechanism. Who says that this imbalance will still yield as much in two years as it does today?"

B4 Risk of more congestion

In case of a congested area, the DSOs remain cautious about connecting batteries to already congested grids. While batteries can help relieve congestion, if mismanaged, they can also worsen it. P5 explains "For example, if batteries start to demand extra energy during peak hours or suddenly start to supply some energy during certain off-peak hours, that can put the grid under high pressure". This cautious stance further complicates the approval and integration process of batteries in general, but also in EHs.

Table 4: Table of barriers for battery-based EHs for stakeholders

#	Barriers	Explanation	Barrier for
B1	Initial EH formation	Not all companies are equally engaged or willing to collaborate, especially when the benefits or required flexibility differ.	Businesses
B2	Space & safety	There are strict and unclear safety rules, along with long permitting procedures of placing a battery.	Businesses, Municipality
B3	Uncertainty earnings	The viability of the energy hub and battery system is crucial for investment. the uncertain battery's payback period results in perceived risks.	Businesses, investors
B4	Congestion risk	In case of a congested area, the DSOs remain cautious about connecting batteries to the grid due to the risk of more congestion.	DSO

4.2.3 Tensions

In the interviews, several tensions between actors emerged. The interests of DSO and EH collectives differ, and in some cases even clash. This slows down decision-making and the EH and battery development. The tensions are about operational control, capacity allocation, unclear risk allocation & liability and uncertainties about emerging contracts and tariffs. These are explained in more detail below and visualized in Table 5.

T1 Operational control of the battery

An expressed concern from DSOs is the unpredictability of battery operations and its impact on the grid. Batteries can switch rapidly between charging and discharging, creating sudden load peaks that are difficult for DSOs to anticipate or manage. According to P6 this is a big challenge: "Yes, we notice that the biggest challenge is the unpredictability of batteries." and by P13 "If a battery has a large capacity, it can put a lot of power on the grid at once. That is very impactful". DSOs cannot control storage assets themselves as they are hindered by the Electricity Act of 1998. This is highlighted by expert P2 "according to the energy law, the grid operator was not supposed to just do everything and that has proven to be the difficult part". This lack of predictability complicates capacity planning, especially as DSOs still base decisions on worst-case scenarios, as is noted by P6 "We are now always assuming the worst loads. That is actually a shame, because you cannot do efficient things with that".

T2 Capacity allocation

Second, EH developers require clarity about the available capacity to facilitate planning and investment, while on the other hand, DSOs are cautious due to potential congestion issues. The sum of all individual capacities is not the same as the technically feasible capacity; the sum of individual capacities is not equal to the technically feasible group capacity. A reduction, which is typically between 10% and 30%, is applied based on factors such as company profiles, grid age, congestion location, and DSO policy. If the discount is too large, collectives may be disadvantaged; too small, and DSOs face overload risks.
This is also highlighted by P7 "At the moment the grid is already full, so grid operators are not eager to connect batteries because they have a big impact on their grid." The EH collective desires guaranteed capacity, while DSOs are not able to give this guarantee. This is why DSOs would like to give alternative contracts, like CBC or non-firm, to be able to have certainty to some extent. Also, it is often not possible anymore for DSOs to provide a firm connection, as P3 states "It is either no contracts or capacity limiting contracts."

T3 Unclear risk allocation and liability boundaries

The uncertainty surrounding responsibility for capacity limit compliance also brings to light a deeper tension around risk allocation and liability. As stated earlier, the business case is important for the EH collective. Therefore, they need insurance about whether or not they will be curtailed or shut off. If the DSO adopts a passive role, merely providing group capacity limits without any monitoring or enforcement, the full operational and financial risk is up to the EH collective. Also, in case of system deficiencies, it remains unclear who is responsible. Without clearly defined responsibilities and risk-sharing mechanisms, both parties may act cautiously, leading to delays in decision-making or even shutting down the project.

T4 Uncertainties about emerging contracts and tariffs

There are regulatory uncertainties regarding emerging contracts and tariffs that form a barrier to decision-making. P14 explains: "And the contractual cooperation with the grid operators is not yet properly arranged." Although different contract forms (e.g. non-firm) offer potential flexibility and cost benefits, these could significantly change EH project economics by affecting energy costs and potential revenue streams, and the lack of clarity and stability in tariff structures and rules for grid access creates uncertainty, and therefore hesitation among EH stakeholders. This is highlighted by P10 "There is a lot of uncertainty in all kinds of parameters, including those grid costs, which determine a very important part of the business case. And because you don't know how they will develop, it is difficult for operators to make a good business model.", and also P16 highlights the need for clear rules "DSOs simply have to offer certainty in clear rules, predictable rates and therefore frameworks in which people come up with the idea of using a battery more quickly where it is of added value for all parties".

4.2.4 Conclusion

In section 4.2, the answer to sub-question 2, is found:

What are the drivers and barriers experienced by actors with integrating battery storage within energy hubs?

Drivers include efficient grid use, aligning energy profiles within an EH, sustainability, cost savings and revenue, and backup power. Barriers include initial EH formation, space and safety constraints, uncertainty over business case, and congestion risk. These barriers and drivers are experienced differently by different actors. Especially, between EH collective and DSO, several tensions are a barrier to EH development. They create hesitation, misalignment, and ultimately stagnation in EH development specifically regarding battery integration. This misalignment points out the need to explore new forms of decision-making and operational coordination of the EHs. In the next section, the problem will be reframed.

Table 5: Table of tensions visualized

DSO	Tension	EH
Unpredictability of battery operations and its impact on the grid	T1. Operational control	Operate battery for trading on electricity markets
Not able to give this guarantee, due to grid constraints (congestion)	T2. Capacity allocation	The EH collective desires guaranteed capacity early information about available capacity
Not responsible if technical failures or contractual breaches occur	T3. Risk distribution	Wants assurance of no curtailment & as less risks as possible
DSO cannot give details about contracts and tariffs yet, as they are not 'ready' and equipped yet	T4. Contractual uncertainty	Needs certainty about contract and tariffs to be able to plan the EH configuration

4.3 Reframed problem

The previous sections highlight the complexity of battery storage EH integration. Actors have differing drivers to participate in an EH, and this hampers decision-making about the elements of the EH. To fully grasp this problem and the complexity a metaphor is described.

A metaphor: The Unfinished Puzzle with Missing Instructions

EH collectives and DSOs are holding different pieces of a puzzle but the picture on the box is missing (Figure 25).

Each thinks: "*Once the picture is clear, we can fit our piece in, but who is responsible for making the picture?*"

But the picture will not become clear until they try fitting pieces together: trial, error, negotiation. The more they wait, the harder the puzzle becomes: electricity demand grows, costs rise, and misalignments deepen.

Clarifying it requires not just placing their pieces but drawing the image together. The full picture of regulation and infrastructure won't emerge until actors engage in building it piece by piece. It is partly about who lays the first piece, but also about what needs to be decided together.

The reframed problem

If the tensions between DSOs and EHs are not discussed, it is not possible to realize EHs with batteries in order to help prevent grid congestion. These tensions can be solved only if collaborative decision-making processes are designed. These processes should lead to a clearer picture of the puzzle on the box.

In the next chapter, it is described how participatory design can help create the processes that help in overcoming these tensions.

Figure 25: Metaphor visualized

5.

DESIGN

Co-creating future scenarios

In this chapter, findings that answer sub-question 3 will be discussed: *How can a participatory design process facilitate collaborative decision-making about battery storage within energy hubs?*

After summarizing the conclusions from the research phase in chapter four, the design goal can be (re)formulated. Therefore, the chapter starts with the design goal, explained in 5.1.
Co-creation sessions are a way to explore how collaborative decisions, as formulated by the four tensions, can be made for battery integration in EHs. Two scenarios present two ‘extremes’, one with the DSO in charge and one with the EH collectives (market) in charge. These are explained in 5.2.
In 5.3, the workshop design is explained.
Then, in 5.4, the outcomes in terms of general observations and the co-created preferred scenario will be presented. These outcomes are not only interesting but also serve as input for the final deliverables presented in chapter 6.

5.1 Design goal

Based on the analysis in the previous chapter, several core tensions were identified: operational control of the battery (T1), EH capacity allocation (T2), risk distribution (T3), and contractual uncertainty (T4). These tensions create uncertainties for both parties, resulting in them remaining in their protective stances which hampers implementation and development. This tradeoff requires collaboratively assessing operational criteria and incentives for the EH to ensure a fair distribution of grid capacity, and fair compensation.

Why scenarios?
Given the uncertainty and the complexity of EHs and their future, speculative scenarios were chosen as a design method to explore divergent pathways. Following Dunne & Raby (2013) and Voros (2003), scenarios were used to map possible futures based on key uncertainties derived from literature and stakeholder input.

Drawing back to the metaphor, by testing different images of the puzzle (scenarios), stakeholders can indicate what pieces they have, what pieces from others they need and what pieces they still need to develop.

The scenarios are the outcome of the identified tensions between DSO and the EH collective. These will be made visible, discussable, and debatable in a co-creation session. The scenarios are used to initiate dialogue, identify stakeholder positions, and explore what a collaboration model could look like. This allows the project to focus not on a predefined solution, but on structuring the conversation that is currently missing in practice. In the next section, the scenario development is explained in depth.

5.2 Scenarios

5.2.1 Scenario ideation

The intention of creating scenarios for the co-creation session is to explore the future potential and provide answers to questions about future systems integration and what this means for different actors. In this section, it is explained how these scenarios are designed.

Simonse (2024) describes both affinity mapping & matrix mapping as possible ways of describing future scenarios. The technique of affinity mapping organises a large number of facts or ideas into their natural relationships. The technique of matrix mapping seeks and structure the relations in two dimensions by placing the highest uncertainties on each axis. In this research, both methods were applied. However, matrix mapping proved most effective. Two key tensions emerged most prominently from the interviews:
1) The need for DSOs to maintain control over connected assets (as highlighted in tensions 1 and 2)
2) The risks faced by EH collectives which are largely influenced by the viability of their business case (as discussed in tensions 3 and 4).

As a result, the following axes for the matrix were chosen: “Who has control?” And “How is the business case structured?”

In Figure 26, the matrix based on these dimensions is shown. The left side of the matrix resembled the current situation and was therefore neglected. The right side, which represents more speculative or desirable futures, was used to develop the two scenarios that were presented in the co-creation sessions.

To allow participants to experience a vision of the future in the present, these scenarios must take the form of prototypes. Prototypes make future visions tangible, communicate new values, enable user interaction, and support strategic decision-making around the allocation of resources for future design innovations (Simonse, 2024). Similarly, the Design Council (n.d.) emphasizes that aspects of the future and its consequences should be made tangible and testable in order to expand the space for imagination. Ideation of possible ways to show the two contrasting scenarios took place and can be found in Appendix XI.

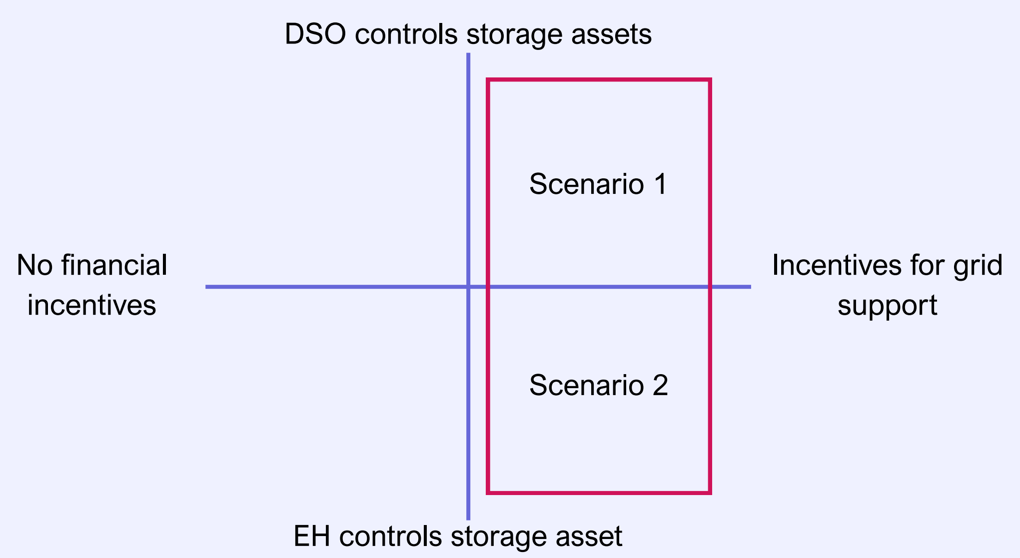


Figure 27: Matrix mapping visualization

Eventually, a mapped step-by-step process of the most important steps in the development process, for each scenario, was chosen as the most suitable. This is the quickest way for participants to get an overview of what the process would look like and what actors would make what types of decisions.

These scenario overviews were developed based on the identified tensions, and different existing EH realization plans that have been developed in the past year by organizations Rijksdienst voor Ondernemend Nederland (RVO), Dutch DSOs and Eigen consortium, as depicted in Figure 11 in the introduction (Eigen, 2025; Firan, 2021; RVO, 2023). These plans state four phases of EH development: orientation, plan & design, realization, and operation & exploitation (Firan, 2021). In the literature from these sources, more specific steps are described. These were mapped in Miro. The touchpoints between the EH collective and the DSOs were highlighted per phase. These are:

Initiation
1. Data from DSO
Information from DSO is needed for the research phase, like the technical capacity of the connections and, net topology.

Plan & Design
2. Application at DSO
After planning & designing the EH configuration, the proposed solution for the EH collective is shared with the DSO. How this is done differs per DSO in the Netherlands. Often, this is done through an application on the website or through the account manager at the DSO. The DSO will process the application and will develop/alter (new) contracts.

3. DSO offers criteria
The DSO reviews the application and determines criteria for the collective GTV limit, curtailment conditions, contract terms, and possibilities for flexible arrangements. Prior to this step, certainty about available capacity is generally limited. There is no certainty about what the possibilities are.

4. Signing the transport contracts
The EH participants and collective will sign their individual ATOs and group TOs.

Realize & exploit
5. Commissioning of the DSO protocol
The in-use EH needs to be tested. A pilot phase will be used to find out how the EMS and communication work in practice.
6. Monitoring and feedback
The DSO needs to know whether the EH collective does not exceed grid capacity limitations.

These touchpoints were adapted according to the scenario descriptions in the matrix and their position along the axis. Based on these plans and insights from interviews, the decision-making process for each scenario is developed. In Appendix XI, the complete scenario-building process can be found. In the next section, the resulting scenarios are presented.

5.2.3 Final scenarios

Two contrasting scenarios were developed to examine how negotiation structures and decision timing can shape the integration of battery storage in EHs into congested grids.

Below, the two scenarios are explained. In Figure 27, the refined scenario prototypes can be seen. These visuals provide detailed battery storage processes in EH development and the functioning of each scenario. This is used to show differences and enable participants to understand how each scenario works in practice, and give feedback on specific points.

Scenario 1 DSO-led flexibility

Here, the DSO takes an active role by coordinating when and how battery systems in the EH operate, but without owning or directly controlling them. The DSO acts as a party that sets technical conditions, capacity limits, and triggers for when flexibility is needed (e.g., during congestion). The EH agrees to these terms through regulated contracts (e.g., non-firm connections).

The process in detail

- The imaginary situation starts with the DSO identifying whether EH locations are feasible, regarding grid constraints, based on expected future congestion, and shares available capacity and potential contracts.
- The collective then plans and designs the EH for different contract types, projecting operational use of flexible assets and estimating potential revenues.
- Once the plan is finalized, the DSO reviews and confirms it, accepting the EH's proposed structure within the bounds of grid reliability.
- Following commissioning, the DSO monitors grid conditions to reduce the risk of congestion. The business case might be less interesting for the EH, as the constraints of the flexible use of the battery are much constrained; however, less risk of curtailment is there.

Significant for scenario 1:

- The DSO provides real-time or planned signals to the EHs EMS to activate flexibility.
- The EH still operates its battery, but within DSO-specified constraints.

Scenario 2 Market-driven EH-led flexibility

In this scenario, the EH collective initiates EH development and takes the lead in operating flexibility assets such as battery storage systems. The collective coordinates internally when to charge or discharge the battery based on their own energy needs, financial benefits (e.g., market participation), or mutual agreements. The distribution system operator (DSO) plays a limited role.

The process in detail

- The EH initiates planning and develops its long-term energy strategy and business case, focused on investment viability and operational optimization.
- The EH plans the operational deployment of flexible assets like batteries, calculates potential revenue from flexibility services, and executes its strategy independently. It is possible this needs to be refined.
- The DSO react by providing general tariff structures and available capacity, but does not co-design the EH configuration.
- If necessary, the EH adjusts its strategy to maintain profitability or respond to curtailment. There is more risk of curtailment in this case; however, there is also more freedom to operate the battery according to market participation.

Significant for scenario 2:

- The EH determines its own strategy for optimization (e.g., peak shaving, self-consumption, energy market participation), which can include a greater business case.
- The DSO has limited insight into or influence over battery operation, which could lead to more curtailment.

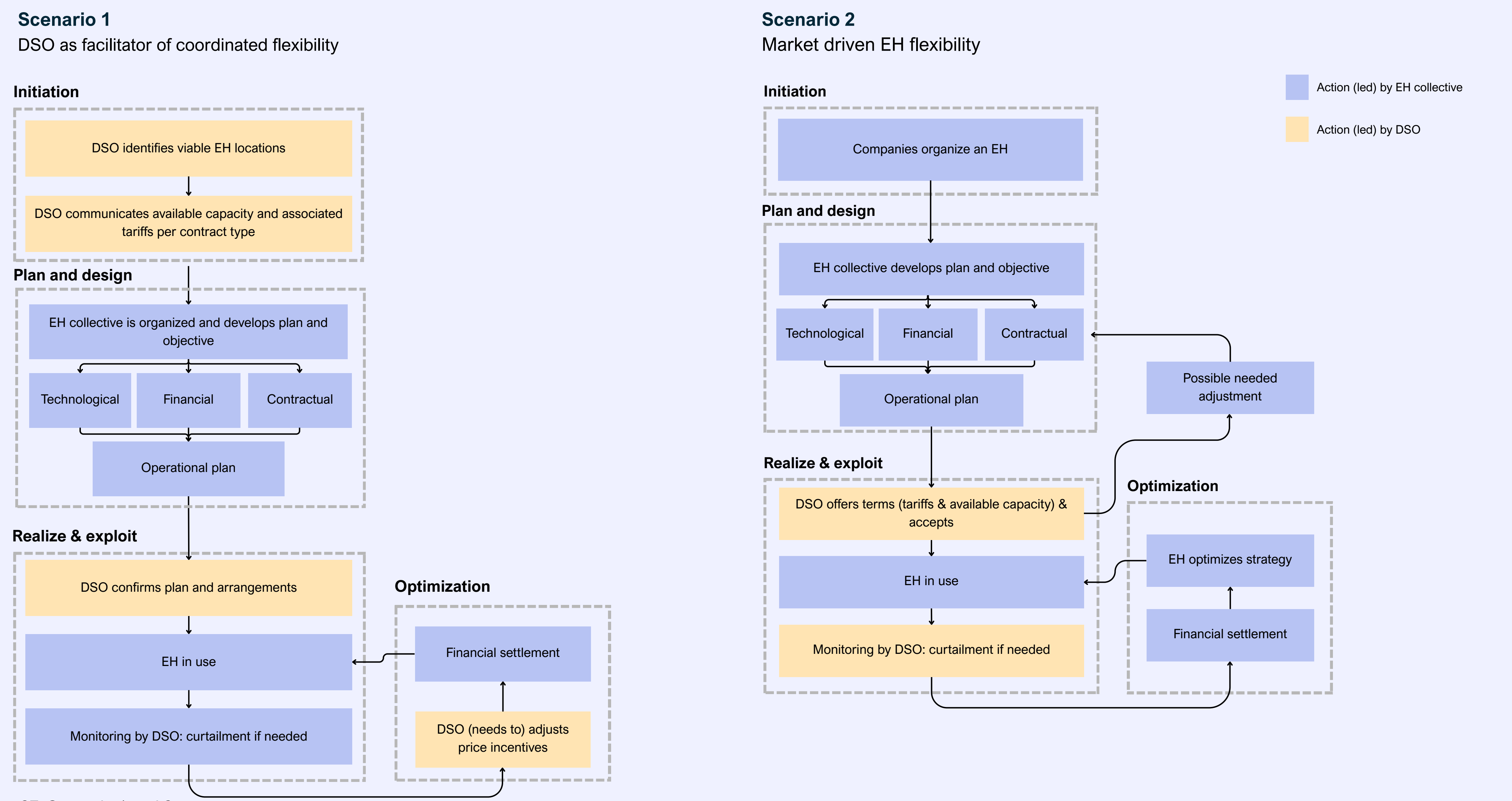


Figure 27: Scenario 1 and 2

5.3 Workshop design

In this section, the outline of the co-creation workshop is shown. The goal of the workshop is to explore these two scenarios for EH decision-making about battery storage with stakeholders. The workshop is a generative design method and enables participants to express tacit and more latent knowledge, like values (Sanders & Stappers, 2012). Through structured discussions and evaluations, stakeholders will assess the feasibility, risks, and benefits of each scenario to ultimately discuss their preferred scenario.

In total, three workshops were conducted. Two of them were online, and one was a physical meeting. In Appendix X, the participants of the sessions can be found.

The full co-creation script is included in Appendix IX, but in this section, the steps of the workshop are explained. Figure 28 visualizes the process.

Step 1
The session began with a short presentation of the context and the problem, this is done by using the SCQ (Situation-Complication-Question) method. Then the goal of the workshop was explained.

Step 2
To make the problem tangible, a fictional but realistic narrative was presented, illustrating the challenges a business park faces when attempting to integrate storage within a congested grid. Reflective questions in between were used to help participants relate and make sure the problem is aligned with real-world situations. Questions were: “Do you recognize this situation?” “What would your organization do in this case?” “What assumptions are missing from this story?”

Step 3
The two scenarios were generally introduced. Then, each scenario was explained in detail and step by step. For one of the workshops, this step happened in break-out rooms. The participants were asked whether they understood the scenario, and whether they were missing parts, by placing post-its. Then the scenario is evaluated. First, general pros and cons were listed, then more in-depth questions were asked about the 1) desirability, 2) viability and 3) feasibility of the scenario.

Step 4
In the final step of the session, participants (in the case of session 1, reconvened in the main group to) reflect collectively on the insights gathered. The facilitator summarized the conclusions from scenario evaluations, and then participants engaged in a group discussion to discuss insights. The focus was on identifying the most valuable aspects of each scenario and discussing the next steps and conditions necessary for implementation. This dialogue also served to foster mutual understanding among participants and helped surface shared priorities, highlighting opportunities for collaborative design and alignment.

Workshop tools & materials
Digital format: Presentation slides, Miro board for the interactive input
Physical workshop format: Presentation slides, printed scenario sheets, post-its, and whiteboards for clustering insights.

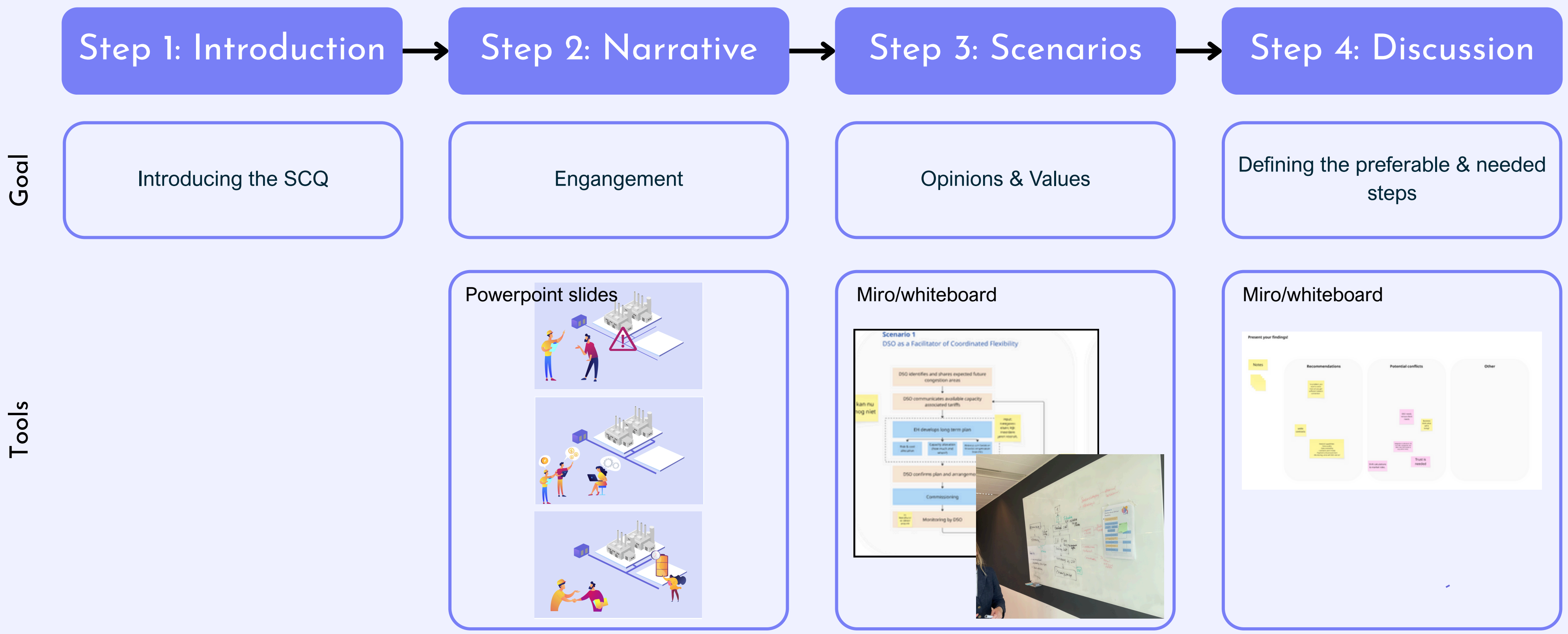


Figure 28: The workshop’s flow

5.4 Results

The workshops provided valuable data on what roles DSOs and EHs have to play, and definitely should not play, and how tensions could be resolved. The participatory process helped in building a shared language and actionable steps toward a desired future. In the following paragraph, the notable observations will be described. Then, the analysis showing 'the preferable' scenario is presented, along with boundary conditions mentioned by participants.

5.4.1 Observations

Implications for the preferred scenario

- Role of batteries in EHs

Participants agreed that batteries should, at this moment, primarily serve the EH collective by offering flexibility within the EH, supporting business continuity. In other words, the business case is that capacity becomes available. Batteries are seen as a buffer when other flexible resources are not sufficient, as highlighted by PC4: "The battery is really seen as a safety mechanism for the participants", "We are not putting it there to earn money, but to relieve the energy grid". Only when excess capacity exists should batteries be made available for grid services or trading on electricity markets.

- Infancy new contract forms

Participants expressed their concern over the immaturity of new contract types, especially those relevant for battery coordination. While some group contracts (e.g., Group TO, C-CBC) are being piloted, there are still internal struggles highlighted by PC1: "The organization is not yet set up for group contracts. We are developing them now, but they sometimes bite each other within the organization". Furthermore, the development of some non-firm types that might be applicable when batteries are placed in the EH is not even being piloted. A major challenge remains the lack of clear terms and conditions, which creates uncertainty for implementation.

- Non-readiness DSOs

DSOs are not yet ready to systematically support EHs. There is currently no consistent data structure, no suitable contracts, and no internal processes to actively facilitate EHs. This causes delays, friction and uncertainty. PC1 indicates "We do not yet have the right calculation methods to decide whether an energy hub is a good idea." "We are simply not ready for it yet". Furthermore, there is an internal dilemma at DSO organizations about how to deal with the risks and responsibilities around group capacity in EHs. Specifically, the discussion is also about what should happen if the capacity is exceeded.

Preferences

It becomes clear that neither scenario is preferred, although DSO participants tend to scenario 1, and EH developers tend to scenario 2. The EH participants indicate that scenario 2 looks more like the current situation; however, they need steps from scenario 1 as well. Furthermore, DSO participants indicate that while they prefer more authority over the process, like in scenario 1, they do not have the capabilities, and this is not their role.

5.4.2 The preferable

The participants explored two divergent future scenarios for battery storage in EHs. While each scenario had its strengths and limitations, the session discussion revealed shared values and conditions that stakeholders considered essential for a feasible, desirable, and viable future. What emerged was not a preference for one scenario over the other, but rather a vision of a hybrid collaborative model that integrates the strengths of both. The goal was to find a way to design a negotiated future, integrating stakeholder needs, trade-offs, and mutual benefits. Note that the answer is not a scenario; it is a set of conditions needed to support collaborative decision-making that benefits all.

The preferable

The ideal 'to-be' scenario is a hybrid collaborative model where:

- EHs initiate and manage their own energy optimization using batteries.
- Storage is used first for local optimization, then for generating revenue through trading and grid support.
- DSOs provide transparent data, predictable tariffs, and operational boundaries.
- Alternative flexible group transport agreements, with a fixed and a flexible 'layer'.
- The EH collective is mainly responsible for the risks, as well as, if traceable, the problem caused. A shared risk insurance for multiple parties (including DSO) could be an opportunity.
- The longer-term flexibility strategy is to integrate batteries with other energy carriers (e.g., hydrogen) to enhance resilience even more.

In the next sections, each identified tension will be addressed based on the findings, including its consequences. During interviews as well as in the discussions of the workshops, several boundary conditions emerged. These are shown in this section as well, and visualized in Table 6.

DSO as a facilitator of EHs, not a controller of grid use

Addressing T1: operational control of the battery

It became clear during the sessions that **authority** is an important value for EH developers. In scenario 1, according to the EH developers, the DSO has too much authority, which is not in place. DSOs should help in facilitating the EH, but they should not have a direct say in how assets are operated or planned. However, participants agreed that the long-term success of an EH is in the interest of both the DSO and the EH collective. This is highlighted by PC3: "Better to start where it makes sense since forming a group takes effort, so let's guide it to the right places". DSOs can support EH development best by creating insight into grid constraints, but the EH developers indicated that currently, there is no easy and transparent way this is shared by the DSO. DSOs have information about their asset (cable and transformer) loads in kW, the power limits per asset in kW, existing power reservations (current and future), and grid topology and configuration of the network, including modifications that are planned. This information often determines and is needed to determine whether the location of the business terrain is promising for the development of an EH. EH developers indicated that it is important to them to have the assurance that they will benefit, and they (or the investors) get paid back, before they invest in a battery system and EH infrastructure. Drawing from scenario 1, participants indicated that an ideal scenario starts with the identification of the EH location, and whether forming an EH is a feasible and viable option in the long-term.

Boundary conditions:

Criteria have to be set up to evaluate feasibility and viability, but not by the DSO according to participants, but by an advisory engineering firm. One participant indicated this is on a small scale happening in Brabant through a so-called EH "kansenkaart" (chances map). This would ensure that investments are made where they

deliver the highest value. In order for this to happen on a larger scale, an independent third party (advisory/engineering firm) should define criteria for a successful EH in the long term in collaboration with DSOs, municipalities, and provinces. These criteria are based on grid topology, congestion urgency, and complementary energy profiles among businesses.
Furthermore, to improve the availability of the aforementioned required data from the DSO, the metering of transformer substations needs to be improved. It was mentioned that metering is currently not always real-time or accurate enough (especially at lower voltage levels). Furthermore, participants talked about the idea of having a dynamic, login-based platform where available capacity at the substation level, the current load and forecasts and peak/off-peak profiles can be seen. This way, project engineers can then start calculating the potential for the EH early on.

Building trust by delivering EH plans and protocols before commitment
Addressing T2 & T3: capacity allocation & risk distribution
The DSO needs grid stability and predictability; therefore, it is important for them to **trust** who is at the other end of the cable. This is clearly highlighted by PC1: “What is the minimum role we have to play, or have to do, and where can we trust the market to do it and take over?”
There are several uncertainties that emerged from the DSO perspective. They need a long-term guarantee of the EH's existence, they need hardware and software from service providers and batteries to be reliable, and they need the EH locations to be promising for the future, as also mentioned in the paragraph above.

First of all, it became clear that the DSOs want to ensure the EH develops a long-term plan, so businesses do not just drop out, or the hub fails after a year. Therefore, it is required that each participating business deliver a long-term plan, including their expected energy use in the future, and their plans to install solar PVs, EV charging stations and other assets that might have an impact on the hub. The DSO then validates this against capacity limits and system goals. This early exchange avoids mismatched expectations and supports tailored design. This is highlighted by PC3 “We want them to think five years ahead, and show they’ve considered failure scenarios like no solar or a battery glitch.”

Furthermore, it was highlighted during the workshop, as well as in interviews, that the malfunctioning of batteries can lead to dangers for the grid, including outages. The biggest concern for grid operators is that the EH control system will fail when congestion really occurs. Trust in reliability is therefore crucial not only in design but also in operational fallback mechanisms. PB5 highlighted “You can demonstrate that you can anticipate, but suppose the control system doesn’t work. What then?”. Therefore, assurance about the hardware and software for the battery system is needed, as well as for the complete EH hardware and software, like EMS, etc. The DSO would like to advise EHs on this topic.

Boundary conditions:
Before committing to an EH, in an early stage of development, all participating companies of the EH, and even more desired: every company on the terrain, have to hand in an expected future (short and long term) energy consumption and production report. Advisors and project developers will evaluate the viability of the EH in the long term and report this to the DSO.

Furthermore, during the workshop, ideas emerged about what needs to happen to facilitate this trust. The DSO, in collaboration with governmental parties and experts, should define standards for safe and interoperable EMS and BMS systems and develop a certified vendor list for EMS, BMS, and installers. EHs must implement a certified battery storage system and EMS, with compatible communication and control software (APIs).

Also, in case of outages or deficiencies, both DSO and the EH collective, along with their service provider, need to make protocols. This should describe step by step what is needed to do and who is responsible for crisis situations.

Hybrid flexible contracts
Addressing T1 & T4: Operational control & contractual uncertainties
Participants agreed that incentivizing EHs with battery storage to relieve grid congestion would be a great option to be able to use the grid as efficiently as possible. However, as indicated by PC4, “If you want them to help solve congestion, you have to give them a reason, not just a list of requirements.”, and also PC1 indicated “So we would benefit if companies also made an effort to shift their profile over time or lower their peaks. That would give us space that we can give to other customers somewhere else in the network who can't do anything now. That willingness to lower peaks is quite low in the pilots. Because that is often not beneficial for the business case”.
It is important to make the business case positive for EHs, and therefore **fairness** is an important aspect that all participants acknowledge. Incentives must reflect the effort and risks of EH participants; therefore, a network tariff reduction is desirable from their viewpoint. Currently, the Group TO has lower transport tariffs because the collective capacity is less than the sum of individual transport agreements (Netbeheer Nederland, 2023b), but how much difference this makes remains unclear, also for the workshop participants.

Participants acknowledged that it is likely that in the future, contracts will evolve to reflect the hybrid nature of battery-enabled flexibility. Although no formal hybrid group contract exists today (CBC exist next to individual ATO), both DSOs and EH developers acknowledge the need for flexible contracts. The co-creation session revealed strong support for exploring this direction as it could be an enabler for scaling battery integration.

This hybrid flexible contract includes:
- A firm base capacity ensuring predictable operations
- A non-firm or flexible layer, allowing participation in grid-support mechanisms like GOPACS.

Although such group contract types do not yet exist, both the DSO and EH stakeholders mentioned that they are willing to explore this direction for future implementation. If EH collectives agree to these specific contract types, the DSO could offer an even more favorable tariff or compensation in return for the operational flexibility this provides. This type of mutual benefit was identified as a missing, yet valuable incentive.

Boundary conditions:
To realize these types of contracts, several developments are needed. First of all, DSOs require improved forecasting and monitoring techniques and internal coordination on new contracts.
Secondly, the contracts can be defined. These must define group limits, fallback mechanisms, and possibly liability protocols.

This reflects the real behavior of batteries in EHs, as EHs need a reliable core capacity to operate, but they can also offer flexibility if incentivized to do so. This kind of transport agreement is operated accordingly: The DSO grants a total firm group capacity and a partial non-firm capacity. The firm layer is allocated based on essential needs, and the non-firm layer is used for market participation or grid flexibility. In times of grid stress, the non-firm layer can be curtailed or activated for support via GOPACS or DSO request. The service provider that controls the EMS system and CSP will be taking in these signals and operating the EH accordingly. In exchange for accepting a non-firm component, EH collectives receive lower transport tariffs, access fee discounts and compensation via GOPACS or congestion-based incentives. This turns flexibility into a negotiated value, not just a technical feature.

Monitoring and Feedback Loops
Addressing T3: risk allocation
Liability and sharing risks remain an issue between EH participants themselves, but it is also an ongoing discussion within DSOs. Should they be able to press the red button to curtail or shut off the EH when they see the energy profile fluctuate or exceed limits? P1 highlighted “We’ll intervene only if things go wrong, but we might also advise: could you help us here with that battery?”. This indicates the preference for a safe grid infrastructure and reliability. If the DSO remains involved after commissioning by continuously monitor compliance (of group limits) and optionally advise on adjustments (e.g. battery dispatch timing) based on grid needs. This enables a dynamic optimization loop without undermining the autonomy of the EH. This is currently not in the DSO's responsibilities and powers.

Boundary conditions:
EH collectives need to appoint the liability and risks of curtailment and power outages or system deficiencies internally. EH collectives appoint internal coordinators, commit to collective behavior, and ensure certified equipment. Then, EHs must enable continuous monitoring (via EMS dashboards), while DSOs should intervene only when agreed thresholds are reached. This mechanism preserves EH autonomy while ensuring system safety.

5.4.3 Conclusion

This section describes the design and outcomes of the co-creative workshop, and aims to answer sub question 3:

In what way can a participatory design process facilitate collaborative decision-making about battery storage within energy hubs?

Through three co-creation sessions with a total of five different participants, two contrasting scenarios were explored and refined. Neither a purely DSO-controlled nor a purely EH-led scenario could adequately address the tensions highlighted in section 4.2. Instead, the discussions revealed the importance of designing a balanced process, enabling discussion. The participatory process proved valuable in surfacing shared values, enabling joint sensemaking, and identifying practical boundary conditions for future collaboration.

Important takeaways are:
- Batteries should initially serve EH collectives for local optimization, with opportunities for grid support or market participation emerging as system maturity develops.
- DSOs must evolve from grid controllers to facilitators of EHs, supported by improved data transparency and consistent operational standards.
- Trust-building measures, such as clear protocols, certified systems, and dynamic feedback mechanisms, are critical for safe and reliable EH operation.
- The immaturity of current contract structures and the operational readiness of DSOs present significant barriers to implementation, underscoring the need for co-developing standardized agreements and clear technical and organizational frameworks.
- A hybrid group contract, combining firm and non-firm capacity, is viewed as essential to balance predictability and flexibility while aligning business cases with system needs.

In sum, the participatory process not only validated the relevance of the research approach but also surfaced the conditions and collaborative frameworks required to realize battery-integrated EHs in practice. These insights will be used in developing the final catalyzing concepts, which will be presented in the next section

Table 6: Overview of key findings,

	Tension addressed	Associated value	Boundary conditions needed to achieve
DSO as a facilitator, not a controller	Addresses tension 1: Operational control over battery	Authority	1. Insight available capacity substations 2. Early on evaluation of the EH’s potential
Building trust by delivering EH plans and protocols before commitment	Addresses tension 2 & 3: Capacity allocation & Unclear risk allocation and liability boundaries	Trust	1. EHs deliver long-term plan all businesses on terrain 2. Protocols for crisis situations 3. Introduce certifications EMS & BMS systems
Hybrid contracts	Addresses tension 1 & 4: Operational control & Uncertainties about emerging contracts and tariffs.	Fairness	1. Develop & pilot flexible group-TO’s including fixed layer and flexible layer. 2. Improve grid metering and forecasting
Monitoring and Feedback Loops	Addressing tension 3: Unclear risk allocation and liability boundaries	Reliability	1. Authorize DSOs to advise battery use

6.

CATALYZING CONCEPTS

From insight to acceleration

This chapter presents the final design concepts along with an explanation. The aim is to find the answer to sub-question 4: *What tools can be designed to help the participatory process in order to catalyze the integration of battery-based energy hubs to reduce congestion in the Netherlands?*

This is the final part of the design process and aims to catalyze the development of battery-integrated EHs, to support our energy system and enable economic and sustainable growth. Catalyzing concepts that are developed based on previous findings, to accelerate the realization of batteries in EHs:

- Morphological chart: as a navigation tool to oversee the complexity of EH configurations
- Roadmap: as an overview of how the system integration of EHs with batteries can look

It is important to distinguish between the roadmap, as a holistic overview of the niche EHs to become part of the institutional level (Geels, 2002), while the morphological chart helps with the decision-making process within the niche EH configurations.

6.1 From insights to concepts

This chapter builds on the findings from Chapters 4 and 5 to introduce two design outcomes: a morphological chart to support collaborative EH configuration and a strategic roadmap to guide the integration of battery-integrated EHs (EHs) in the energy system (Figure 29).

In chapter 4.1, it is shown that elements of EHs are interconnected, resulting in complexity. Furthermore, the co-creation workshops and scenarios proved helpful for discussing and aligning stakeholder needs; however, a more practical tool would be needed in specific cases. There is a need for a shared frame of reference to navigate these complex EH design trade-offs. To support this, a morphological chart was developed. This tool makes configuration choices explicit and discussable. The morphological chart is explained in 6.2.

While the morphological chart helps stakeholders configure EHs in concrete cases, the strategic roadmap provides a broader, system-level perspective. Drawing on the Multi-Level Perspective (Geels, 2002), current EHs are still a niche innovation that need alignment with regime institutions (e.g., DSOs, regulation). Through the co-creation workshops, insights into these alignments are found, and the preferred future collaboration was formulated (5.4.2). The roadmap outlines a phased trajectory toward long-term systemic integration. Each horizon reflects increasing levels of coordination, maturity, and standardization of contracts. It maps how EHs can evolve and what is needed to get EHs from pilot projects into embedded components of a flexible and decentralized energy system.

The development of these tools is grounded in the literature, interviews and co-creation outcomes, and draws from design and roadmapping methodology (Van Boeijen & Daalhuizen, 2010) (Simonse, 2024). Both tools were developed through an iterative process. Draft versions were repeatedly refined through feedback loops, including discussions with (academic) supervisors.

Together, these tools aim to facilitate dialogue, align expectations, and support intentional, context-sensitive system change.

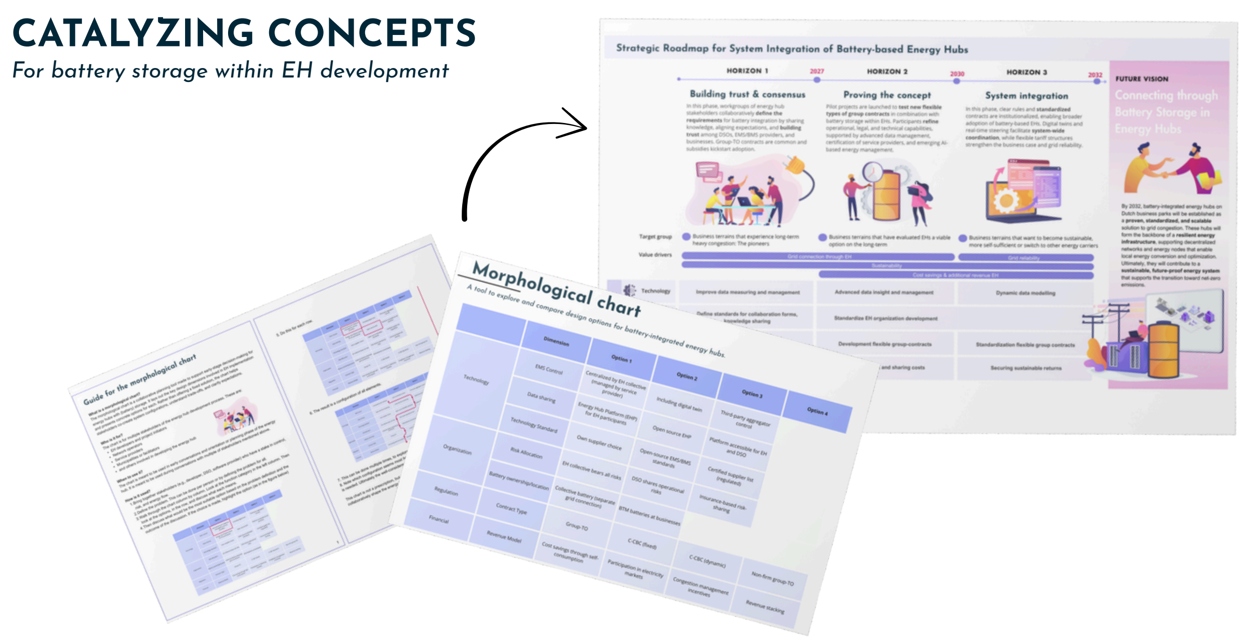


Figure 29: The catalyzing concepts

6.2 Morphological chart

The morphological chart is one of the catalyzing concepts and can be seen in Figure 29.

As EH configurations can differ from case to case (found in 4.1), technically, organizationally, contractually, and the type of revenue streams, a morphological chart helps map and visualize these configurable elements systematically. The morphological chart is a method to split the EH's elements and show all possible ways to fulfil a function (Van Boeijen & Daalhuizen, 2010). The functions in the left column are based on findings presented in chapter 4.1.

The chart a flexible framework that can be tailored to specific EH contexts, depending on local actors, technologies, and site characteristics.

Bringing the chart to discussions in EH initiation phase, makes it possible for stakeholders to early on construct tailored, configurations and aligning expectations. It enables them to explore design choices, visualize potential configurations, and systematically compare trade-offs in specific cases. It can therefore be seen as a navigating tool.

It also helps move from abstract discussions ("we need flexibility") to tangible choices ("Do we want a non-firm connection with a shared battery or firm with individual ones?").

This morphological chart shows not all options, but according to this research, it shows the most important ones discusses. It is recommended the chart will be supplemented in future research. Also, possibly more options for one function (EMS and digital twin) are feasible in one design.

Guide
This morphological chart can be used in the initiation phase of an EH for collaborative planning, as also seen in the detailed roadmap in horizon 1. A complete user guide for the morphological chart can be found in Appendix XV.

In essence, the morphological chart enables actors to navigate complexity through structure. By offering a chart for EH design, it facilitates a more productive stakeholder dialogue and more clear decision-making.

	Dimension	Option 1	Option 2	Option 3	Option 4
Technology	EMS Control	Centralized by EH collective (managed by service provider)	Including digital twin	Third-party aggregator control	
	Data sharing	Energy Hub Platform (EHP) for EH participants	Open source EHP	Platform accessible for EH and DSO	
	Technology Standard	Own supplier choice	Open-source EMS/BMS standards	Certified supplier list (regulated)	
Organization	Risk Allocation	EH collective bears all risks	DSO shares operational risks	Insurance-based risk-sharing	
	Battery ownership/location	Collective battery (separate grid connection)	BTM batteries at businesses		
Regulation	Contract Type	Group-TO	C-CBC (fixed)	C-CBC (dynamic)	Non-firm group-TO
Financial	Revenue Model	Cost savings through self-consumption	Participation in electricity markets	Congestion management incentives	Revenue stacking

Figure 30: Morphological chart

6.3 Roadmap

A strategic roadmap is made based on outcomes of the workshop, specifically on the needed boundary conditions for coordination of battery-based EHs with the electricity grid, as indicated by the participants. The reason for creating the roadmap is to show how and in what order organizations within the sector can act, to enable the preferred stakeholder collaboration for EH-with-battery storage development in the future.

The roadmap provides insights that lead toward the missing 'picture on the box of the puzzle', and who needs to lay what piece. It shows how these battery-based EH innovations can be a part of, and support, the socio-technical energy system (Geels, 2002).

A roadmap is defined as: "a visual portray of design innovation elements plotted on a timeline" (Simonse, 2024). They enable organizations and decision makers to devise creative responses to future strategic challenges, in this case: an increase in congestion and renewables. It is a strategic dialogue instrument that helps organizations align long-term vision with actions. A roadmap is a way to make planning accessible across disciplines, with the help of visuals (Simonse, 2024). The purpose of this roadmap is not to simplify complexity, and it does not 'solve the problem', but it shows high-level objectives that can act as a guide for organizations toward a preferred future as indicated by the participants of this study.

The roadmap is made for multiple audiences (and not for one company): regulators, DSOs, EH developers, and other experts from the industry. It can be used by regulators and DSOs as a plan that highlights what actions they can undertake for the integration of battery-based EHs in the energy system to help solve congestion, and it can be seen as a guide for EH developers to foresee future plans.

The roadmap highlights necessary developments across different pacing layers (Simonse, 2024): technical, organizational, regulatory and financial dimensions. A detailed roadmap is made, complementary to the strategic roadmap (Figure 32). It provides specific information about the interconnection of actions, trends, and values, and can be used for in-depth guidance.

Future vision
The envisioned future is that by 2032, battery-integrated EHs on Dutch business parks are a proven, standardized, and integrated part of the electricity grid. A group transport agreement with firm and a non-firm capacity is standard and by automated grid coordination with the EH, real time available capacity is shared, which enables EHs and companies to be able to use more energy or deliver flexibility for the grid at certain times. This can ultimately add to a more resilient future energy system. For this roadmap, it is assumed that around 2032 grid congestion will be less of a problem due to grid expansions between now and 2035 by the Dutch TSO, Tennet (Tennet, n.d.; ACM, 2024). Therefore, the roadmap goes until 2032.

Horizon 1: Building consensus & trust
In this horizon the foundation of EHs will be laid down, by sharing knowledge and perspectives about EH formation, currently already ongoing, but possibly though additional co-creative workshops. This is currently ongoing. In horizon 1 Group-TOs will be more common, and requirements of potential valuable EHs will be defined. In this phase, the DSOs as well as the EMS and BMS service providers of EHs need to increase their asset data measurement and management. Technical and operational contract templates are being shared among EH developers. These are ways to enhance trust among multiple stakeholders. In this phase the EH development is still a new process and a risk for investors and companies, that needs to be kickstarted by subsidies.

Horizon 2: Proving the concept
In this second horizon, group contracts combining firm and non-firm capacity are piloted to validate their value and assess their technical and operational feasibility.
Pilot projects are launched to test battery storage within EHs (EHs) operating based on incentives from DSO and to explore the implementation of these new hybrid contract forms. Stakeholders have developed requirements, and now begin to test, and refine the operational, legal, and technical capabilities required to support the model effectively. Technologically, the focus is on data management and analysis, with artificial intelligence (AI) playing an enabling role in steering energy use. Organizationally, certification processes are initiated to accredit service providers and battery energy storage system (BESS) hardware to ensure safe and reliable operations. From a regulatory perspective, efforts focus on defining and formalizing hybrid contract structures, including clarifying how these agreements function in practice. Financially, mechanisms for risk and cost sharing among DSOs, governments, and third parties are implemented to support equitable distribution of risks and returns.

Horizon 3: System integration
By this stage, EHs with battery storage are widely recognized as effective mechanisms for restoring and expanding access to the electricity grid. Opportunities to integrate with other energy carriers (e.g. heat or hydrogen) within EHs also emerge, enhancing the system's overall flexibility and resilience. The deployment of digital twins of the grid provides real-time insights into grid loads, facilitating the automated steering of the non-firm capacity layer of EHs through platforms such as GOPACS. Furthermore, the contracts governing these hybrid arrangements must be embedded within the organizational structures of DSOs, thereby enabling standardized operations across the company. Financially, the combination of rewarding compensation structures or differentiated tariffs, alongside reduced reliance on grid-supplied energy, will enhance the business case for EH adoption, ensuring its viability and attractiveness to stakeholders.

6.4 Conclusion

The aim of this chapter was to answer sub question 4: *What tools can be designed to help the participatory process in order to catalyze the integration of battery-based energy hubs to reduce congestion in the Netherlands?*

This chapter presented two concepts that support the collaborative and systemic implementation of battery-integrated EHs: a morphological chart and a strategic roadmap. To support early-stage, case-specific collaboration between stakeholders, a morphological chart was developed to structure key design decisions and clarify trade-offs.
In addition, a strategic roadmap was constructed to articulate a phased trajectory toward the preferred future scenario, as envisioned by participants.

Together, these tools translate the research findings into actionable frameworks for decision-making. They offer both a structured foundation for case-specific collaboration and a forward-looking pathway for system-wide embedding of flexible, battery-enabled EHs.

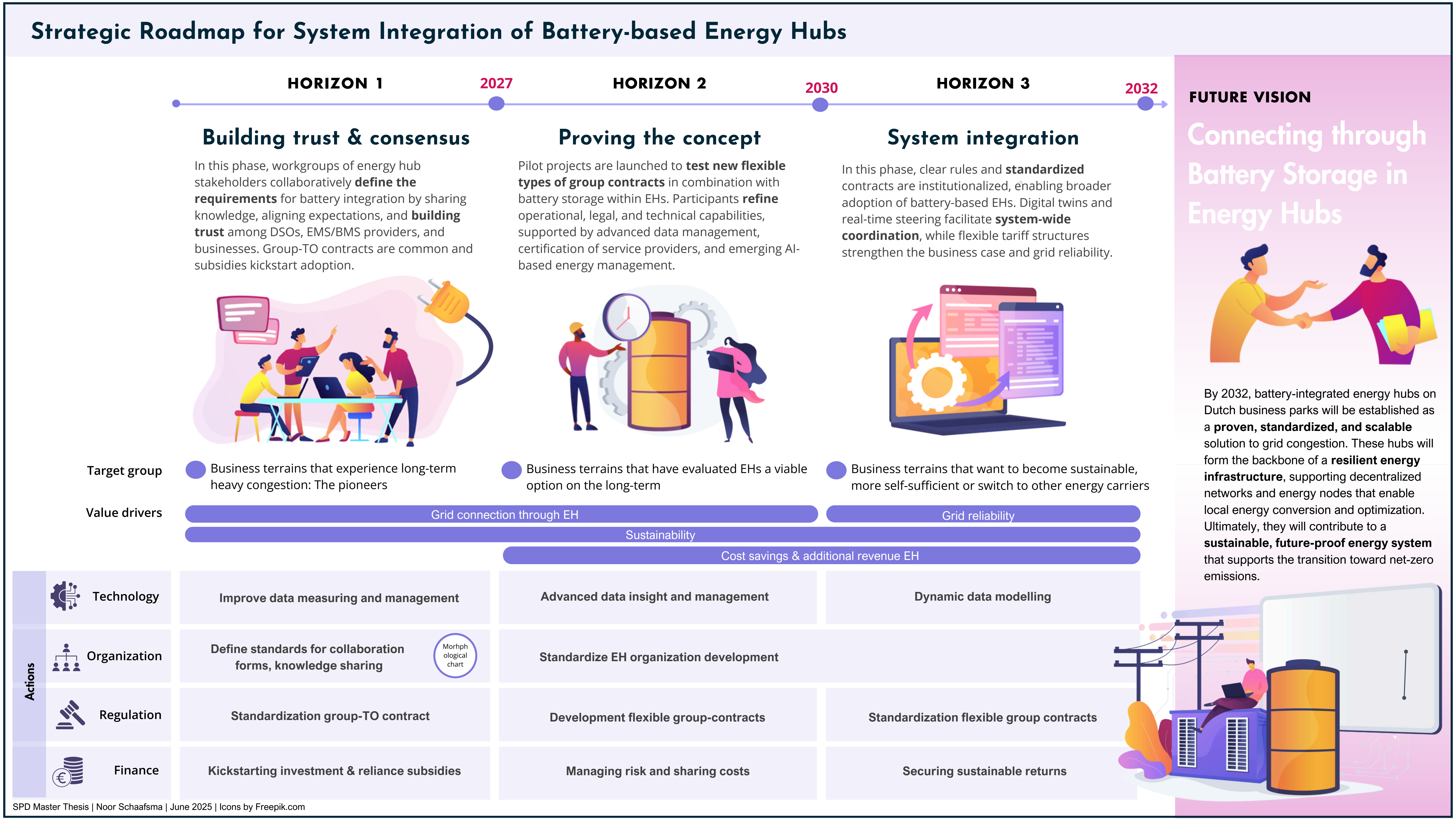


Figure 31: Strategic roadmap

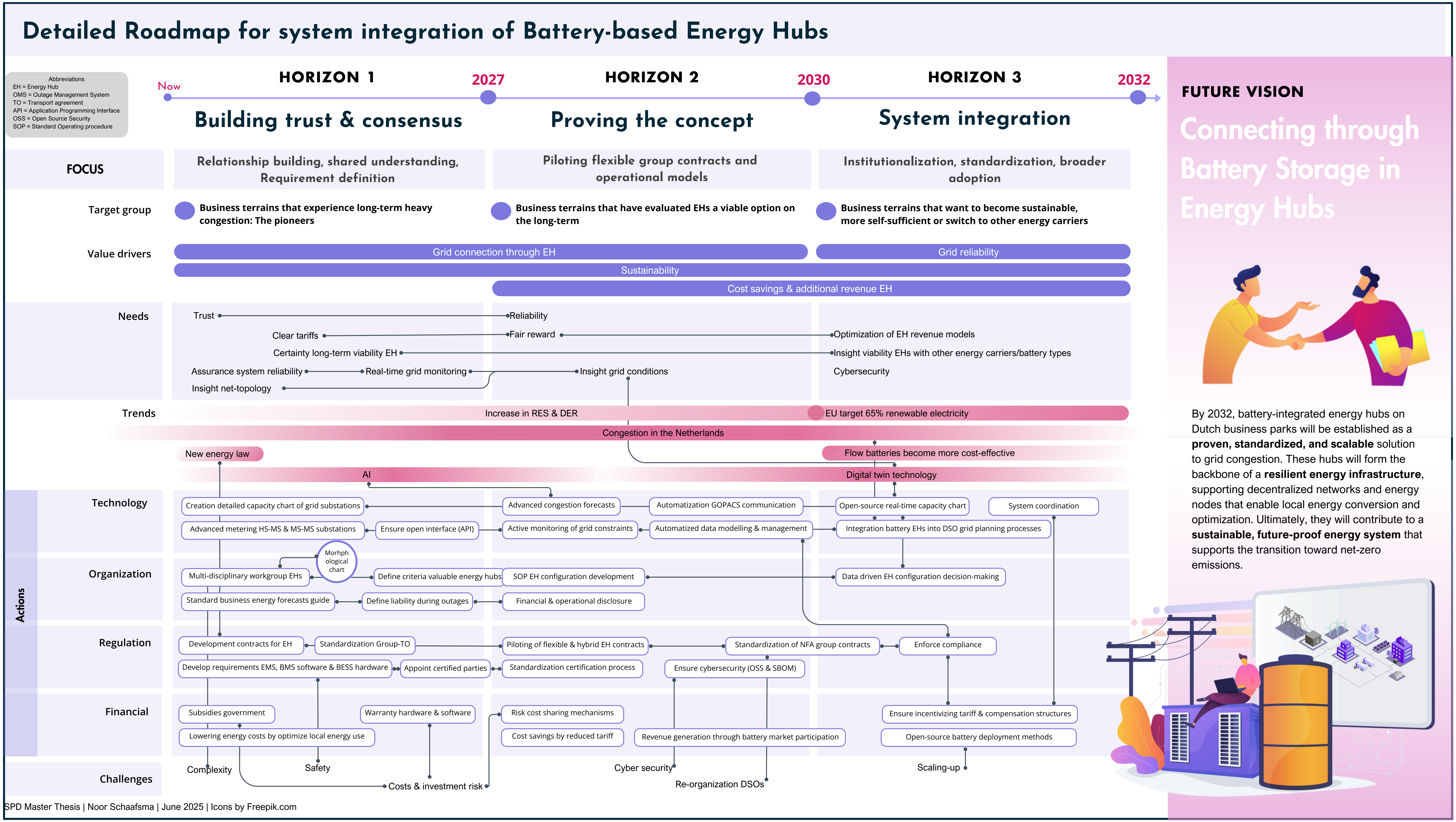


Figure 32: Detailed roadmap

7.

DISCUSSION & CONCLUSION

Concluding the project

In this section, the results will be discussed, and a conclusion of the project is formulated. Up to this point, the research has built a broad understanding of energy hubs (EHs), the interconnected elements, the barriers and drivers influencing battery storage integration, and the tensions between key actors, especially distribution system operators (DSOs) and EH collectives. These insights have been developed through a combination of literature review, stakeholder interviews, and participatory design methods.
In this chapter, the findings are interpreted and critically reflected upon to answer the broader research question: *How can collaboration between network operators and EH collectives be designed to integrate battery storage on Dutch business parks and help reduce grid congestion?*

Section 7.1 presents the discussion about the results and the interpretation thereof, the research limitations, the project's value and impact and recommendations. Section 7.2 concludes with a summary and answer to the main research question.

7.1 Discussion

7.1.1 Results & implications

The goal of this thesis was to explore how collaboration between network operators and EH collectives can be designed to facilitate battery storage integration and help reduce grid congestion. The project contains multiple findings drawn from literature, interviews, and co-creative workshops, and their interpretations. The goal of this section is to discuss these interpretations and their connection to the broader project goal.

Interpreting results

A literature review resulted in the finding of different EH elements: technology, organization, regulation, and finance. Systems thinking contributed to understanding the interdependencies between these elements. EHs were found to be socio-technical systems shaped by these four interconnected elements. The Multi-Level Perspective (MLP) further clarified how niche innovations like EHs interact with regime-level structures (e.g. DSOs, regulations).

The results of the interviews were four tensions between the EH collective and DSO. These often seemed to reflect regime-level resistance (e.g., institutional norms). This showed that the development of batteries within EHs is not just a technical challenge, but one embedded in institutional and relational complexity.

Presenting two speculative scenarios enabled stakeholders to experience possible future decision-making processes, which helped surface values and assumptions that are often implicit, and needs for future EH development and battery deployment (Van Der Velden & Mörtberg, 2015). Shared values that can be leveraged were found and extensively discussed in section 5.4. The preference for a hybrid model shows that stakeholders are not isolated, but instead recognize the need for shared responsibility. There is a need for a form of systemic trust (different from trusting an individual person), while authority should remain on the EH collective's side.

In summary, the results indicate that successful battery integration in EHs depends less on technology and more on designing organizational and collaboration structures that allow for shared control, negotiated risk, and transparent coordination thereof. The co-creation process itself becomes a method to build trust, reveal assumptions, and possibly (with the help of the designed concepts) accelerate institutional adaptation.

Validity

Through triangulation of literature, interviews and the workshops, validity was enhanced. Findings from interviews could be drawn back to findings from the literature explained in section 4.1. For example, B2, initial EH formation, was also confirmed by CE Delft (2024). Validity of findings was also confirmed during the workshop, as participants highlighted that these scenarios indeed reflect the ongoing discussion and problem. PC1 mentioned, "These two scenarios are indeed exactly the problem we face". This validation supports the relevance of scenario planning as a design method to surface and structure collaborative decision-making around battery storage. Throughout the project, findings were continuously examined for validity. The outcomes of the project should not be seen as

Broader implications:

EHs with battery storage are not THE solution
In some cases, individual or alternative measures may be more effective for certain types of companies or business parks. Existing mechanisms, like as congestion management, can provide grid relief. Furthermore, in many situations, large-scale implementation is not viable due to long-term congestion patterns, unfavourable grid topology, or financial and spatial constraints. Other energy storage technologies (e.g. hydrogen) or individual measures might be a better solution in some cases. While battery storage in EHs offers potential, it is not *the* solution to congestion.

What if congestion is resolved?
Another interesting discussion that emerged during some of the interviews is "*What happens if grid congestion is no longer an issue?"* There is a chance that EHs will not be necessary anymore. However, next to solving congestion, which is currently the primary driver of developing EHs, there are other benefits as well. EHs ensure resilience in the energy system, especially if the EHs can offer much flexibility in different ways. Furthermore, EHs with battery storage enable more integrated RES. Therefore, this research concludes that EHs with battery storage offer value in the long term, and not only solve congestion, but also add to a more resilient and sustainable energy system.

7.1.2 Limitations

In this section, acknowledged limitations to this research are discussed.

Participant recruitment
Throughout the project, it was challenging to recruit participants for both the interviews and the co-creation workshops. Business owners were especially underrepresented. To still be able to gain information about these actors, the information was gathered from other actors that have been in contact with business owners like EH developers and project managers. Furthermore, in contact with ongoing research from Saxxion, shared findings from their interviews with business owners of the EIGEN EH. These findings validated the findings from the interviews in this research as well.
This challenge also resulted in three workshops with a limited number of stakeholders. While this allowed for more in-depth discussions and individual attention, which was valuable given the complexity of the topic, it also limited the diversity of perspectives. Business owners especially were missing out on this research. To compensate, it was ensured that EH developers were present, as these participants are in close contact with business owners and have the perspective of the EH collective.

Consistency interviews
During the data collection phase, different interview scripts were used depending on the phase of the research and the participant's expertise. While this allowed tailoring each stakeholder group, it may have influenced the type and depth of responses. The variation in format could have introduced inconsistencies in data collection. However, this limitation was partially mitigated through a uniform thematic analysis method, which systematically coded and categorized all responses under the same analytical framework. Nevertheless, future research would benefit from a more standardized interview protocol to ensure complete comparability across interviews.

Due to time constraints, the catalyzing concepts and final roadmap were not tested with the broader group of stakeholders involved in the earlier stages. Instead, they were reviewed and refined in collaboration with mentors from Accenture. Additional validation was done by comparing the roadmap to similar ones developed within the company for DSO clients. While this internal feedback helped ensure practical relevance, external stakeholder validation would be essential to refine the roadmap for broader application and to verify assumptions.

Single researcher bias
As this research was conducted by a single researcher, there is a risk of bias in data collection and analysis. This subjectivity may have influenced outcomes. To mitigate this, validation was found through some literature, and debriefing of findings was done with mentors from the company and the university. A future study would benefit from a collaborative research team to improve objectivity and peer validation.

Scope
The scope of this research focused on collective battery storage within EHs, rather than on individual company investments in batteries. While previous research (De Graaf et al., 2024) has shown that collective solutions are often more cost-effective due to shared infrastructure and services (e.g., advisory, EMS, battery systems), this is not universally the case. In some instances, individual business investments may be more viable depending on energy profiles, financial models, or site-specific constraints. The research acknowledges this complexity but does not explore it in depth. Future work could investigate the comparative advantages of collective versus individual battery deployment strategies, including hybrid solutions.

7.1.3 Contribution & Value

The research is relevant for battery storage implementation for about 400 business terrains. Furthermore, while the focus of the thesis lies on business terrains, insight can be used to guide battery storage integration in mobility hubs and EHs in residential areas as well. Furthermore, it can help in integrating other energy carriers (e.g., hydrogen, heat) into EHs as well.
Below is highlighted what value is generated for society, network operators and policymakers, academia and Accenture.

Society
As highlighted in the introduction, the transition to clean energy is an urgent necessity to mitigate climate change. This research accelerates the energy transition by enabling local flexibility and supporting the achievement of national decarbonization targets. By enhancing grid resilience, this research contributes to a more stable energy system that is less dependent on fossil fuels and better able to absorb supply fluctuations. Moreover, given that business parks are key economic drivers in the Netherlands that ensure employment and contribute significantly to GDP, the findings of this thesis offer societal value by supporting the continued growth of these areas despite current grid constraints.

Network operators and policymakers
This research facilitates strategic grid planning by clarifying where batteries can most effectively alleviate congestion. It provides a roadmap for the implementation of collaborative contracts and tariff structures that balance grid stability with the business case viability for EH participants. By introducing new hybrid contract models (combining firm and non-firm capacity layers), the research fosters innovation and aligns grid requirements with market-driven flexibility. Additionally, the research strengthens stakeholder collaboration

by clarifying roles, responsibilities, and risk allocation between distribution system operators (DSOs) and EH collectives.

Academia
This research addresses an urgent gap at the intersection of battery storage integration in EHs and participatory decision-making. Furthermore, this research proceeds on the recent calls in academics of participatory and context-specific approaches to storage governance that move beyond technical or economic analysis (Saldarini et al., 2023; Stecca et al., 2020). By demonstrating how strategic design can facilitate collaborative decision-making between network operators and EH collectives, this thesis contributes a practical, actionable methodology for addressing socio-technical challenges in energy system transitions.
The qualitative dataset, including interviews and workshop outcomes, offers a valuable foundation for future research, both for empirical validation and for further exploration of governance, business models, and institutional innovations.

Accenture
This research supports Accenture's utility team in realizing innovations in the energy sector. The participatory methods as a method to approach complex socio-technical systems offer a new perspective on managing transitions in the energy sector. The research provides foresight into probable developments in this part of the energy sector, and therefore it highlights areas where Accenture can add value for its clients.

7.1.4 Recommendations

This section outlines several recommendations for further research and development.

Co-creation sessions with stakeholders from a specific case
To ensure the validity of the co-creation session outcomes, it is recommended that the session be held with stakeholders who are currently involved in EH projects in the orientation and planning phase. Including all stakeholders from one specific project can actually help negotiate tradeoffs in the specific case, making outcomes more specific and actionable. Furthermore, this can actually help accelerate decision-making for the specific project. The outcomes of this research would benefit and be strengthened by this type of extra validation test.

Quantify the research
While this thesis used a qualitative approach to understand stakeholder perspectives and design tensions, future research should seek to quantify the benefits and impacts of battery storage integration in EHs. This can be done by case studies on several different types of business terrains, or by using data about potential business terrains in general. This quantitative research could include economic analyses, by assessing cost-benefit tradeoffs of batteries under different contract scenarios, or by evaluating this potential next to other individual solutions for companies. Furthermore, the modelling of the impact of different battery dispatch strategies on local grid conditions can help understand the impact different contracts have on local grid conditions. With this information, risks for different stakeholders are made more absolute, which will enhance understanding of the severity of the problem.

Foster knowledge sharing
The development of battery-integrated EHs requires a strong ecosystem of trust, knowledge-sharing, and ongoing collaboration. Initiatives such as joint learning platforms, open-source EMS development, and standardization of technical interfaces should be pursued to ensure interoperability and reduce implementation barriers.

Support DSOs
It is found in the co-creation sessions that DSOs struggle to keep up with changing demands from their customers, especially with respect to grid congestion and the integration of distributed flexibility assets like batteries. Internal conversations within DSOs seem to often remain fragmented across technical, operational, and regulatory domains, which slows down effective action. Therefore, it is recommended to help DSOs in developing internal capabilities, facilitate organizational change by the creation of multidisciplinary action teams that explore the development of non-firm contracts, and other new contracts. Furthermore, defining clear risk allocation frameworks to help DSOs manage uncertainties in battery operation. This requires that guidelines will be developed in co-creation with the affected stakeholders, specifying accountability for system imbalances, failures, or congestion issues.
By taking these steps, the DSOs can change into proactive facilitators of decentralized energy systems that help overcome congestion and ultimately lead to a more sustainable energy system.

Research business terrain archetypes
This thesis highlights that EH configuration is dependent on the archetype of the business terrain. Although the author sought energy use profiles for different types of business parks (e.g., logistics, mixed-use, industrial), no detailed studies were found. Total energy demand figures exist, but there is a gap regarding the near-real-time energy profiles of different terrain archetypes. This knowledge is essential to determine the feasibility and design potential of EHs, but also to anticipate future grid congestion risks. Addressing this data gap is urgently needed for research and policy.

Test the catalyzing concepts
Due to time constraints, the catalyzing concepts could not be tested in a real-world planning process. Further research is recommended to test and operationalize these tools in applied settings, like EH feasibility studies or DSO meetings.

The roadmap can be refined and specified based on real-world pilot projects. An opportunity exists to develop an interactive version of the roadmap, showing specifications per horizon.
For the morphological chart, the same recommendations hold. The map can be specified and tested in real real-world project, to enhance usability.

Recommendations for Accenture
This research shows the potential of EHs and grid congestion reduction by the use of batteries. Accenture can play a critical role in supporting the acceleration of battery integration into EHs by supporting DSOs in developing the organisational and technical capabilities needed to facilitate EH implementation. This includes looking for improved data sharing, improved grid management, and the development of flexible contracts for groups to contribute to congestion management. DSOs, policymakers as well as EH developers, could use help in defining the rules for developing these EHs and making strategic decisions.

7.2 Conclusion

This thesis explores how battery storage can be integrated into EHs on Dutch business parks to help alleviate grid congestion.
The main research question is: How can collaboration between network operators and EH collectives be designed to integrate battery storage on Dutch business parks and help reduce grid congestion?

Collaboration between network operators and EH collectives should be designed through participatory processes that align technical, contractual, and operational expectations early on. A hybrid model where EHs optimize battery use locally and DSOs provide data, boundaries, and flexible contracts offers the most promise. Tools like a morphological chart and roadmap support structured decision-making and help reduce grid congestion through coordinated action

The project generated a threefold value: insight into the nature of the problem, the preferred future collaboration model, and the catalyzing tools to facilitate the structured dialogue and collaboration.

Nature of the problem
While battery storage is increasingly acknowledged for its technical potential to balance local energy supply and demand, this research reveals that the real bottlenecks lie within organizational inertia.
Through literature review and stakeholder interviews, four tensions were found that slow down battery storage adoption in EHs. These are:

- Operational control: DSOs fear unpredictable battery behavior, while EH collectives seek autonomy.
- Capacity allocation: EHs want guaranteed access, whereas DSOs face uncertainty in offering firm capacity.
- Risk allocation and liability boundaries: Unclear ownership and fallback procedures create trust issues for DSO and the EH collective.
- Emerging contracts and tariffs: DSOs struggle with setting up the contracts needed for EHs, while EHs collectives need these rules to be clear to be able to make investment decisions.

These tensions reveal that battery integration is not merely a technology deployment issue, but a systemic coordination problem between decentralized actors and centralized institutions.

Preferred future collaboration model
To address these frictions, a participatory design approach has proved very useful. Scenario building is needed to show stakeholders different possible futures and to enable discussions on where and how their interests can be aligned.
In this case, a structured dialogue was initiated. Two contrasting scenarios were introduced:
1) DSO-led flexibility, where the grid operator retains control of the boundaries
2) EH-led market autonomy, where the EH determines its own operational strategy.

The workshops led to a preferred scenario: A hybrid model where EHs manage their own battery optimization, while DSOs provide data, clear contracts, and operational boundaries through a partly firm and partly flexible group contract.
The dialogue also revealed a number of boundary conditions, as can be found in Table 6. These conditions are taken into account in designing the roadmap as one of the catalyzing concepts.

Facilitating the structured dialogue and collaboration
Effective collaboration between the EH collective and DSO can be achieved through a participatory model that aligns technical, contractual, and operational expectations early in the process.

Co-creation processes, such as collaborative scenario planning, help bridge conflicting interests, build trust, and define viable paths forward, making battery-based EHs a practical tool for reducing grid congestion.
By using interpreting and ideation of the outcomes of the co-creation workshops, the designed scenarios, and all the information that was gathered in this research, it was possible to deliver catalyzing concepts that will improve future collaboration. These are:

- A morphological chart
- A roadmap

Ultimately, this thesis demonstrates that the full potential of battery storage in EHs can only be unlocked if all parties involved are aware that this needs deliberate collaboration. This collaboration should be designed according to principles of participatory design and can be helped by using catalyzing tools that were delivered in this thesis. If a participatory process is followed (towards collaboration), it is possible to successfully realize an EH with integrated batteries and thereby help prevent netcongestion.

REFLECTION

Throughout my studies I've experienced how urgent it is to transition to a sustainable energy system, for the sake of our future planet. Through this project, I aim to do my part in this bigger picture and learn a lot myself. Congestion is very urgent in the Netherlands, and this needs to be tackled. While I acknowledge battery storage is not the ultimate solution, they are needed, especially in a strategic way, like in EHs. I really do believe EHs, as decentralized systems, will be the future, not only in business terrains but also in residential areas. Energy is not something we should take for granted anymore. We need to think about when to use it and how to use it most efficiently.

I had several personal goals going into this project. To begin with, I set very high goals and expectations. I want to reflect on that. Setting ambitious goals can be motivating, I enjoy a challenge, but it can also backfire if the goals are too high. As an individual doing a thesis project, the realization you cannot solve all problems is essential. For me, it created more pressure than needed, and I've learned that good is enough, and that aiming for perfection can get in the way of the overall process. A recommendation to other graduate students is to keep the project small. You are just solving one piece of the big puzzle, not the whole puzzle. The key is to do this piece really well!

One of my personal goals was to adopt a participatory design approach, and, through co-creation sessions, engage stakeholders. I enjoy communicating with diverse stakeholders, and I was curious about this method in this sector. This was more challenging than I thought. In environments where people have worked within institutional constraints for years, or have a very exact background, it can be hard to encourage out-of-the-box thinking. Many participants thought in terms of limitations rather than possibilities. While I succeeded in triggering participants to give their opinions about the scenarios, it was hard in some conversations to let them explore new possibilities. This made me realize that design, and my fresh perspective, is very valuable. Furthermore, conducting these sessions enhanced my communication skills. Refining the co-creation session's design together with my mentors and peers helped me.

Another personal goal for me was to learn more about our energy system, and I can proudly say that I've learned an incredible amount in a relatively short period of time. From technical systems and regulatory frameworks to stakeholder dynamics and market structures, the energy domain revealed itself to be both complex and interesting. This report captures the core findings relevant to my research, but there is much more that I absorbed along the way, market structures, nuances and perceptions, that didn't all make it into the final document but have certainly shaped my thinking.

Next to reflecting on my personal goals, there are something else I want to reflect on.

I have learned during this project that building relationships is very important. One participant mentioned: "In the end, it's all humans".
For me, working together in a group gives me energy. I noticed that discussing, or in Dutch "sparren" about a topic, something we often do among designers, really helps me structure thoughts. It made me realize the value of collaborating with others on the same project, and I look forward to this in the future.

Thank you for taking the time to read this thesis. I hope it is the starting point of new ways of thinking and will start new discussions. If you have questions, you can reach out to me.

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APPENDICES

APPENDIX I Time Planning

	Weeks in the year	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	27
	Dates	20 jan	27 jan	3 feb	10 feb	17 feb	24 feb	3 mrt	10 mr	17 mr	24 mr	31 mr	7 apr	14 ap	21 ap	28 ap	5 mei	12 me	19 me	26 me	2 jun	9 jun	16 jun	23 jun	30 jun	1 jul
	Weeks of Thesis	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**23**
	Working days		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	115
	Kick off																									
Discover	Understanding the ecosystem																									
	Underdstand the energy system																									
	Literature research																									
	Underdstand the battery landscape																									
	Literature research																									
	Understand the process & collaboration form																									
	Literature research																									
	Analyze case study																									
	Explorative expert interviews																									
Define	Define the needs and barriers																									
	In depth interviews stakeholders																									
	Interview data analysis																									
	Problem framing																									
Develop	Co-design the opportunity																									
	Design scenario's																									
	In depth interviews stakeholders & test scenario's																									
	Co-create ideal timeline & collaboration form																									
	Cluster insights																									
Deliver	Process & Deliver																									
	Finalize end 'product'																									
	Drafting up chapters of thesis																									
	Implement feedback																									
	Prepare presentation & submission																									
Tasks																										

APPENDIX II Approved Project Brief

IDE Master Graduation Project

Project team, procedural checks and Personal Project Brief

In this document the agreements made between student and supervisory team about the student's IDE Master Graduation Project are set out. This document may also include involvement of an external client, however does not cover any legal matters student and client (might) agree upon. Next to that, this document facilitates the required procedural checks:

- Student defines the team, what the student is going to do/deliver and how that will come about
- Chair of the supervisory team signs, to formally approve the project's setup / Project brief
- SSC E&SA (Shared Service Centre, Education & Student Affairs) report on the student's registration and study progress
- IDE's Board of Examiners confirms the proposed supervisory team on their eligibility, and whether the student is allowed to start the Graduation Project

STUDENT DATA & MASTER PROGRAMME
Complete all fields and indicate which master(s) you are in

Family name	Schaafsma
Initials	N.R.
Given name	Noor
Student number	4871995

IDE master(s): IPD ☐ DfI ☐ SPD ✓
2nd non-IDE master:
Individual programme (date of approval):
Medisign ☐
HPM ☐

SUPERVISORY TEAM
Fill in he required information of supervisory team members. If applicable, company mentor is added as 2nd mentor

Chair	Sine Celik	dept./section	Design, Organisation and Strategy
mentor	Mahshid Hasankhani	dept./section	Sustainable Design Engineering
2nd mentor	Koen van Heuveln		
client:	Accenture		
city:	Delft	country:	The Netherlands
optional comments			

! Ensure a heterogeneous team. In case you wish to include team members from the same section, explain why.
! Chair should request the IDE Board of Examiners for approval when a non-IDE mentor is proposed. Include CV and motivation letter.
! 2nd mentor only applies when a client is involved.

APPROVAL OF CHAIR on PROJECT PROPOSAL / PROJECT BRIEF -> to be filled in **by the Chair** of the supervisory team

Sign for approval (Chair)

Name Sine Celik Date Signature

CHECK ON STUDY PROGRESS
To be filled in **by SSC E&SA** (Shared Service Centre, Education & Student Affairs), after approval of the project brief by the chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total ___ EC
Of which, taking conditional requirements into account, can be part of the exam programme ___ EC

X	YES	all 1st year master courses passed
	NO	missing 1st year courses

Comments:

Sign for approval (SSC E&SA)

Name K. Veldman Date 18-2-2025 Signature

APPROVAL OF BOARD OF EXAMINERS IDE on SUPERVISORY TEAM -> to be checked and filled in by IDE's Board of Examiners

Does the composition of the Supervisory Team comply with regulations?

YES	V	Supervisory Team approved
NO		Supervisory Team not approved

Comments:

Based on study progress, students is ...

V	**ALLOWED** to start the graduation project
	NOT allowed to start the graduation project

Comments:

Sign for approval (BoEx)

Name Monique von Morgen Date 19/2/2025 Signature

Personal Project Brief – IDE Master Graduation Project

Name student Noor Schaafsma Student number 4,871,995

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Designing a strategy for DSOs to integrate batteries in 20302040

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

The Dutch energy sector is undergoing a transition. There is a growing demand for electricity because of electrification and climate policy. (Sijm, 2024) Unfortunately the capacity of the current grid cannot handle the rising demand and peak moments in multiple areas in the Netherlands. (Nethbeheer Nederland, no date). This is called net congestion and because of this "traffic jam" on the grid, the Distribution System Operators (DSOs) are forced to cancel new construction projects, and energy initiatives from either drawing additional electricity or feeding it back to the grid. Figure 1 shows the congestion of demand and supply in the Netherlands, and this is projected to grow even more in the future.
Batteries have become more developed and advanced. for distribution system operators (DSOs), batteries offer a promising solution by providing flexibility and diminishing net congestion. Batteries can store excess energy during production peaks and release it during demand peaks. This is shown in figure 2. (Van Cappellen, Groenewegen, Rooijers, et al.,2023)
The main stakeholders are the DSOs. They have a primary interest in providing a reliable electricity supply to the consumer. Other stakeholders are the government, municipalities, investors, consumers, coördinators and the national network operator. I want to know their roles, concerns and goals.

→ space available for images / figures on next page

introduction (continued): space for images

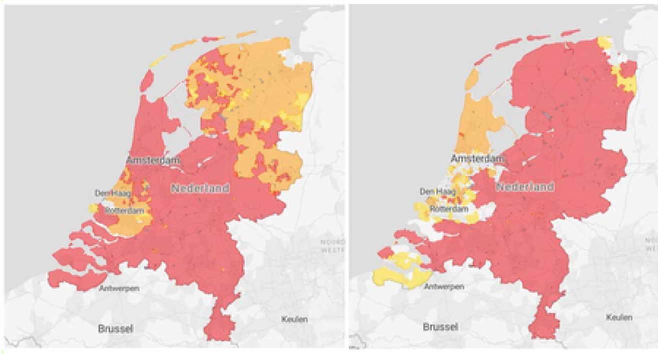


image / figure 1 Demand (left) and supply (right) congestion. Red areas show rejected transport capacity applicatio

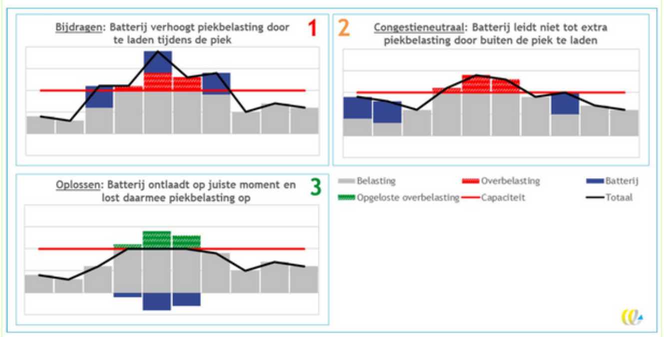


image / figure 2 Overview of contributing to, neutral and solving the offtake of net congestion (Van Capellen, Groen

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The role of DSOs has changed from supplying electricity to active management of grid capacities and distributed energy sources, like batteries. Battery storage solutions can provide balance and flexibility of the grid to alleviate congestion, but their adoption by DSOs remains limited due to organizational, financial, and regulatory uncertainties (Eurelectric, 2023; CE Delft, 2022). This research will focus on the organizational uncertainties. What are the organizational uncertainties for battery integration and how can organizational structures and collaborations with stakeholders help DSOs with battery integration in the grid?
By helping DSOs to create insight in the necessary capabilities, this study adds value by accelerating battery adoption and improving overall grid resilience. The research will benefit DSOs, policymakers, and technology providers by offering a roadmap for addressing these uncertainties and enhancing collaboration among each other.
Sub questions:
How do batteries affect the grid?
Who are the stakeholders and what are their interests?
What are the current applications of batteries in the electricity grid? Are there case studies?
What are the organizational barriers and drivers for the use of batteries to support grid flexibility?

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for.
Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format*:*

Design a strategy for DSOs to establish collaboration and organizational structures for integrating battery storage into the grid for enhancing grid flexibility in the Netherlands between 2030 and 2040.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

The project's approach will be according to the double diamond design process. In de discovery phase, the goal is to understand the current system, analyze current applications of different types of largescale batteries, and the stakeholders and their roles. This will be done through document analysis and interviews with the stakeholders. In the define phase, the problem will be reframed. This will be done by analyzing and clustering the data gathered in the discovery phase. Then in the development phase, a solution to the problem will be designed. Different designs of the strategy will be developed and through a participatory design workshop, stakeholders will be included in the design process. Finally in the delivery phase, a the strategy will be detailed and a strategical roadmap can be provided as an end product.

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a ***kick-off meeting***, ***mid-term evaluation meeting***, ***green light meeting*** *and* ***graduation ceremony***. *Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	28 Jan 2025
Mid-term evaluation	28 Mar 2025
Green light meeting	27 May 2025
Graduation ceremony	26 Jun 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

The energy transition is very urgent, because our climate is in danger. During SPD projects and through my EcoRunner Dream Team experience I have developed an interest in energy systems. I have seen how complex this system is, and how hard it is to transition. This is not just in terms of technological feasibility, but also in adapting organizational structures, and achieving social acceptance for change. Through my thesis project I want to contribute to the energy transition by adressing grid congestion in the Netherlands.
With this project, I want to use competencies I've developed throughout my studies, like stakeholder analysis and creative problemsolving, in a real situation. I want to challenge myself to dive into this complex system. I see my role as a designer as envisioning the possibilities and being able to communicate these with stakeholders.
One of my personal learning ambitions is to use the participatory design method something I learned about in theory in practice. Furthermore, I would like to enrich my knowledge of the energy sector.
This project brings together my skills, ambitions and interests and offers the opportunity to make an impact.

APPENDIX III Table of academic sources

This table presents an overview of literature explored during the orientation and framing phase of the research. Not all sources listed are directly cited in the main thesis text.

Article	Title	Summary	Method
Babayomi et al. (2022)	Smart grid evolution: Predictive control of distributed energy resources—A review	There are four involved actors of local flexibility markets: namely the DSO, the market platform, aggregators and the customer-owned DERs. There are technical barriers to BESS: Location and sizing of storage are critical (placing storage poorly can even worsen congestion) Need for smart energy management systems (EMS) to optimize battery operation Successful deployment requires good coordination between DSO and storage operators, otherwise storage may not provide the intended grid benefits. They also mention that economic profitability is still tricky unless batteries can participate in multiple flexibility markets.	comprehensive literature review
Babayomi et al. (2022)	Coupling energy management of power systems with energy hubs through TSO-DSO coordination: a review	Integrating EHs into the power system operation remains a significant challenge due to the complex interaction between the transmission system operator (TSO), distribution system operator (DSO), and EHs. Energy price and flexibility are among the dual variables of the problem. To simultaneously calculate these variables and the main variables of the problem, an integrated model of the suggested scheme based on the penalty function technique is extracted. Eventually, numerical results validate the capability of the scheme in enhancing the operation, economic, and flexibility status of the proposed scheme, in which renewable sources along with storage and responsive load in the energy hub can obtain 100% flexibility conditions for the networks.	Literature review and trend research
Hirsch et al. , 2018	Microgrids: A review of technologies, key drivers, and outstanding issues	Conclusion: The costs of solar photovoltaic generation and battery storage are rapidly dropping. As a result, microgrids could manage this transition to prosumers and DERs by balancing supply and demand locally. Whether microgrids remain niche or not depends on two things: 1. to what degree regulatory and legal challenges can be successfully surmounted 2. whether the value they deliver to property owners and communities in terms economic benefits (eg. power quality and reliability) outweigh any cost premiums incurred to capture those benefits.	Literature review
Koralia et al., 2018	Community energy storage: A responsible innovation towards a sustainable energy system?	The decreasing cost of energy storage and increasing demand for local flexibility are opening up new possibilities for energy storage deployment at the local level. Community energy storage (CES) has the potential to be part of the solution to confront the challenges of the present energy systems. The benefits are competitive energy prices, investment returns, helping in fighting climate change, developing cooperation among neighbors and providing added-value to the local economy.	Literature review, and applying system innovation and socio-technical transition frameworks
Mohammadi et al., 2018	Optimal management of energy hubs and smart energy hubs – A review	Future energy systems will be in the form of sustainable multi-energy systems. The optimal operation of such systems requires an integrated energy management system for optimal planning, control and management. Energy hubs can be applied across a wide range of settings, including residential, commercial, industrial, agricultural sectors, and entire geographic areas like cities or rural regions. In micro hubs, the objective is the optimization of energy consumption from a consumer perspective and in a macro energy hub, the objective is the optimization of energy consumption in the entire system from the controller viewpoint.	Literature review
Mohammadi et al., 2017	Energy hub: From a model to a concept – A review	Four major EH features and functionality include input, conversion, storage and output. EHs are a promising option for integrated management of multi energy systems (MES). Various types of energy sources and energy supply technologies can be used as input in the EH model. The paper also discusses BESS in EHs and highlights that battery energy storage systems (BESS) are essential to mitigate variability from renewable energy sources (solar, wind) by smoothing supply-demand mismatches. Batteries can provide multiple services: • Frequency regulation • Peak shaving • Congestion management • Load shifting The profitability of storage depends heavily on: • Stacking multiple revenue streams (not relying on one service) • Market design (are there clear incentives to provide flexibility?) The optimal size and control of batteries depends on local conditions — energy profiles, market prices, and grid needs.	Literature review
Norouzi et al. (2022)	A review of socio-technical barriers to Smart Microgrid development	This study has a multidisciplinary, socio-technical approach and addresses the factors that have been hindering the development of smart microgrids (SMGs) and how these barriers interact, by including perspectives from different actors. There are technical barriers to microgrids like control issues, protection issues. Furthermore there are technical barriers to smart grids like smart devices and requirements, need for frameworks that reduce complexity in design, and need for assessment. Identified regulatory barriers to smart microgrids are the current market structure and market performance, cybersecurity, investment barriers, lacking incentives for consumers, and conflicting incentives between actors. There are social acceptance barriers like acceptance at multiple levels in society. Lock-in and inertia to change the structure of the energy system because existing rules and infrastructures support the centralized system. Furthermore there are difficulties in decision- making and investment. There is a need for future research on context-based analysis to study the inter-dynamics between institutions, technology and actors. A broader systemic perspective of socio-technical innovations is required.	Systematic literature review
Rohde & Hielscher, (2021)	Smart grids and institutional change: Emerging contestations between organisations over smart energy transitions	Smart grids are promoted as promising pathways for dealing with new grid challenges that have arisen by the introduction of renewable energies. The article shows how organisations in Germany struggle to divide roles, rules and responsibilities around smart grids. Significant difficulties are conflicts about data management, grid flexibility and demand management. These struggles are driven by divergent interests and beliefs of actors, and without a shared vision or clear regulation, smart grid developments will lag behind expectations.	mixed-methods qualitative research: in-depth interviews and a document review.

Article	Title	Summary	Method
Koohi-Kamali et al. (2013)	Emergence of energy storage technologies as the solution for reliable operation of smart power systems: A review	The role of energy storage systems in increasing the stability of distribution networks has increased. in collaboration with RESs, energy storage devices can be integrated into the power networks to bring ancillary service for the power system and hence enable an increased penetration of distributed generation (DG) units.	Literature review
Parra et al. (2017)	An interdisciplinary review of energy storage for communities: Challenges and perspectives	Community energy storage provides local flexibility, helps in renewable energy integration, and reduces peak demand. Compared to home batteries, CES benefits from economies of scale, and a more stable demand profile. Challenges for CES are: • economic viability: currently, thermal storage is most cost-effective, but battery storage is expected to grow. • Regulatory & market barriers: Policies and regulations are often designed for large-scale storage, which makes CES implementation complex • Stakeholder complexity: CES involves residents, DSOs, energy cooperatives, and policymakers, which makes governance and business model important. There's a need for stakeholder involvement, & the design of new governance models and business strategies are crucial to make CES work.	Systematic literature review. identifies challenges and success factors by comparing CES models
Nozari et al. (2022)	Development of dynamic energy storage hub concept: A comprehensive literature review of multi storage systems	The paper discusses the critical role of energy storage devices, such as batteries and thermal storage, in balancing supply and demand within EHs. Several chemical, mechanical and electrochemical energy storage technologies have been examined in literature to increase the energy hub performance. There are some technical deficiencies: technical advantages of interconnected storage, multi discharging capability and modeling real operational constraints of facilities, for multi energy storage phenomena in hybrid energy systems. Incorporating RES like solar and wind into EHs is highlighted as a means to reduce CO_2 emissions and operational costs. However, the intermittent nature of RES introduces variability, necessitating robust storage solutions and control strategies. Advanced optimization techniques are presented for the efficient operation of EHs, considering factors like cost minimization and emission reduction. Integrating different energy storage systems in an energy hub for further developments is recommended, especially optimizing mathematical models, and techno-economic optimization.	Literature review
Hooshmandian et al. (2025)	A two-stage framework for the joint planning and operation of battery-integrated renewable generation in microgrids coupled with energy hubs and electric vehicle parking lots	There is a need for RES integration into modern power grids, which presents challenges for network operators. Battery storage within microgrid offer a solution to provide operational resilience. The model created in the research demonstrates that battery storage within microgrids, despite RES uncertainties, improves system flexibility. The capacity is increased, the operating costs are reduced, and the CO2 emissions decrease.	Modelling
Zarate-Perez et al. (2022)	Battery energy storage performance in microgrids: A scientific mapping perspective	Microgrids integrate renewable resources, like photovoltaic and wind energy, and battery energy storage systems. Batteries allow for the seamless integration of renewables into the grid. Many papers focus on optimization methods in battery energy storage systems are important for this research field. The most common challenges in developing a BESS system are the economic factors as researchers focus on cost–benefit analysis. To reduce costs the state of charge, the degradation rate, and battery life should be considered. Developing an optimal battery energy storage system must consider various factors including reliability, battery technology, power quality, frequency variations, and environmental conditions.	Literature review: systematic and bibliometric approach to evaluate the performance and challenges in applying battery energy storage systems in microgrids

Article	Title	Summary	Method
Dusonchet et al. (2018)	Technological and legislative status point of stationary energy storages in the EU	The significant growth of renewable energy sources (RES) in the EU results in grid balance challenges. Energy storage (ES) systems are becoming increasingly competitive due to research and innovation, making European energy supply more secure, sustainable, and affordable.The main challenges for ES deployment include the need for more education among stakeholders, cost competitiveness, legislative and administrative barriers, and the lack of a clear definition of ES in the EU legislation.	data analysis from databases (DOE storage database)
Islam et al. (2024)	Improving Reliability and Stability of the Power Systems: A Comprehensive Review on the Role of Energy Storage Systems to Enhance Flexibility	Energy storage systems are crucial for integrating renewable energy sources, enhancing grid stability and supporting the energy transition. The role of energy storage to enhance power system flexibility in the power distribution system has the following applications: • provide backup during outages • Demand side management • Support microgrids for DER integration • Ancillary services	Literature review
Kooshknow et al. (2022)	Are electricity storage systems in the Netherlands indispensable or doable? Testing single-application electricity storage business models with exploratory agent-based modeling	ESS is not profitable in most scenarios, with "wholesale arbitrage" generally leading to more profit than "reserve capacity." ESS economic and technical characteristics play a more significant role in the value of ESS than market conditions and carbon pricing. The analysis considers uncertainties in ESS technical and economic characteristics, market conditions, and regulations.	Agent based modeling analysis
Mohler & Sowder. (2017)	Energy Storage and the Need for Flexibility on the Grid	Flexibility in the context of an electric power system is the ability to vary the performance characteristics of resources to maintain a balanced and efficient power system. Energy storage can provide multiple services, like frequency regulation, voltage control, peak shaving, load smoothing. These all help maintain grid stability and integrate renewable energy sources.	Literature review, case studies
Proka et al. (2020)	When top-down meets bottom-up: Is there a collaborative business model for local energy storage?	Exploration of neighborhood battery as collaborative solution between DSOs and local renewable energy initiatives. Challenges are: • regulatory barriers: DSO cannot own or operate batteries under EU unbundling laws. • Diverging stakeholder interests: DSOs prioritize grid stability, and local energy initiatives prefer financial and social benefit. • Economic feasibility: uncertain business models can make investment in local storage risky. DSOs face a dilemma: They need storage for congestion management but lack a clear role due to regulatory restrictions. Local energy cooperatives hesitate to invest due to uncertain financial returns and operational complexity. Unclear ownership & control structures create barriers to implementation. conclusion: successful collaboration is possible if barriers are overcome > participatory design can help address stakeholder misalignment, and explore new governance models.	case study two Dutch community energy projects. Qualitative interviews with stakeholders, and review of policy documents. Applies governance theory and business model innovation
Stecca et al. (2020)	A Comprehensive Review of the Integration of Battery Energy Storage Systems Into Distribution Networks.	Battery electric storage systems (BESS) can provide various services to grid operators: including power quality improvement, voltage control, peak shaving, load smoothing, and frequency control. Sizing and location in distribution networks are important. Different models for managing and operating BESS are: local, decentralized, centralized and distributed control. There are challenges in designing a control system for BESS, like communication infrastructure and handling uncertainties.	Literature review, comparative analysis, case studies
Saldarini et al. (2023)	Battery Electric Storage Systems: Advances, Challenges, and Market Trends	BESSs are crucial for integrating renewable energy sources (RESs) into the grid, enhancing grid stability, and supporting the energy transition. lithium-ion batteries are the dominant choice of battery chemistry due to their high energy density, long cycle life, and relatively low self-discharge rates. There is an increase in investments in large-scale BESS projects driven by government incentives, renewable energy targets, and the need for grid stabilization. There' s a need for advanced battery management systems (BMS) and energy management systems (EMS) to ensure safe and efficient operation	Literature review, & empirical data analysis in current state of BESS diffusion
Truesdale & Ruzzenenti. (2024)	An econometric analysis of the driving forces behind growth in grid-scale battery storage capacity in the EU	Drivers for growth in Grid-scale batteries: -Access to FCR/FRR markets (Frequency Containment/Restoration Reserves) is a significant determinant of battery storage growth, as batteries excel at short-term flexibility services. -Countries with low energy dependency (self-sufficient in electricity production) show higher adoption of grid-scale battery storage, suggesting that countries that rely heavily on imports may not prioritize storage. -A high share of intermittent energy sources (solar & wind) is strongly correlated with battery deployment, indicating that storage grows as variable renewables increase. -Low household electricity prices are linked to greater battery deployment, potentially due to favorable policy frameworks rather than direct economic incentives. Barriers for battery adoption: -Regulatory Issues: Despite recognition of storage in EU Directive 2019/944, national-level policy implementation is lagging. Many countries still double-charge storage facilities (grid fees, taxes), reducing financial viability. -Many battery storage projects are not profitable under current market conditions, requiring policy support or innovative business models. -Unclear Policy Implementation: While battery storage is acknowledged as crucial for the energy transition, no clear, standardized policy approach across EU countries exists, leading to uncertainty for investors.	8 countries (including NL) analyzed over 2007-2020. Data regression
Van Den Boom (2023)	Experimenting with co-ownership of energy storage facilities: A case study of the Netherlands	Grid managers see batteries as potential tool for increasing grid flexibility, but are legally restricted from owning or operating storage under EU " unbundling" regulations. Private market participants want batteries to be economically viable, often causing more congestion. This leads to stagnation: neither market or grid operator can act, which delays battery deployment. Shared ownership could be a potential solution: between DSOs and private parties: balance investment incentives while ensuring that batteries are used effectively for congestion management. >there's a legal and governance barrier	Single case study of Dutch battery storage project. policy and legal document analysis Interviews with stakeholders

APPENDIX IV Stakeholder table

Stakeholder	General responsibilities
DSO	Manages local grid stability and ensures efficient energy distribution.
TSO	Responsible for balancing supply and demand in the national electricity grid.
End users/ businesses in EH	Busy with day-to-day operational activities to keep business running.
EH collective	Is the (legally) responsible party for all participating businesses in the energy hub.
Service provider	Often calculates business model and operational plan. Provides Energy Management System and is able to participate in electricity markets.
Local government	Is responsible for area management.
Government and Regulatory Bodies	Develops policies and regulations for battery storage and electricity markets.
Investors (financiers)	Provides funding. This can happen through direct investments, leasing, or power purchase agreements. Evaluates the economic feasibility and risk profile of battery storage.
Energy suppliers	Offer energy that is not already available in the energy hub.
Advisors (& project engineers)	Offer guidance on technical feasibility, regulatory compliance, and financial viability of EH with battery storage projects.
Insurers	Assess and mitigate financial risks associated with battery storage.

APPENDIX V Interview script

Explorative interviews

The interview themes and questions are presented below.

Theme 1: Network operators
- Can you describe your experience with regional grid operators in the Netherlands?
- How do you see the role of regional grid operators evolving in the context of the energy transition?
- What challenges will grid operators face in the future up to 2050?

Theme 2: Batteries
- In what applications and situations do you see opportunities to use batteries in the electricity grid?
- What are the key changes and challenges for regional grid operators when more batteries are connected to the grid?

Theme 3: Stakeholders and collaborations
- Which parties would be involved in the realization and management of a battery connection to the electricity grid?
- What factors related to collaboration between these parties influence the successful integration of batteries in the low-voltage and medium-voltage grid?
- Are there any initiatives or projects where regional grid operators are already testing the integration of batteries in MV or LV grids together with other parties?
- How are new contract and collaboration models being developed within regional grid operators?

Theme 4: Future developments
- What future developments are taking place within regional grid operators, and what strategic themes are they addressing?
- What do you think are the most important (policy) measures and collaborations needed to support the integration of batteries (or other technological innovations)?

Theme 5: Additional information
- Is there additional information you would like to share

In-depth interviews

Introduction
1. What exactly is the role of [org X] in developing energy hubs?
2. For which purposes are energy hubs most often used (cost savings, sustainability, grid relief, flexibility, etc.)?
3. What do you think are the biggest barriers and uncertainties in the implementation of an energy hub?

Definition of battery storage within energy hubs
1. What is the (potential) role of battery storage in energy hubs? And what functions and services do batteries fulfill within energy hubs?
2. What do you think are the biggest barriers for battery applications on business parks with group contracts (energy hub collective)?

Grid connection and capacity
1. How do stakeholders define and determine the required capacity for energy hub installations?
2. How are the responsibilities of grid operators and developers divided in decisions about capacity allocation, and to what extent is there coordination to achieve an optimal balance between grid reinforcement and the use of local flexibility?
3. Who determines the use and objectives of batteries within an energy hub?

Operation
1. How is it determined on a daily basis where the capacity is allocated to (when energy is stored or used, or fed back to the grid), and how is this communicated?
2. Which systems or methods are used to predict energy demand and supply within the energy hub, and in the grid, and how reliable are these in your experience?
3. How does [Org X] deal with multiple stakeholders in one energy hub, for example with decisions about maintenance and the allocation of costs and benefits?

Financing (incentives)
1. How is investment in required assets such as batteries made within an energy hub, and which factors influence the acquisition of investments?
2. How do developments in electricity demand, flexibility needs or policy influence the planning and investment in battery storage?
3. What do you think are the biggest uncertainties when estimating the payback period of a battery system in an energy hub?

Regulation and tariff structures
1. What role do uncertainties in government policy and subsidy schemes play in implementing an energy hub?
2. What opportunities and barriers do you see in alternative schemes such as ATR 85, where companies are partially disconnectable? How are the potential discounts for non-fixed transport rights or flexible grid use decided?
3. What influence does the uncertainty of future grid tariffs have on the implementation of energy hubs and investment in battery storage?
4. Do you think there is sufficient incentive for battery storage to get these technologies off the ground on a large scale?

Organization & collaboration
1. What challenges do you experience in collaborating with other parties around the implementation of batteries?
2. What is the relationship between parties (e.g. grid operator, energy hub collective, municipality) within decision-making on the above-mentioned themes?

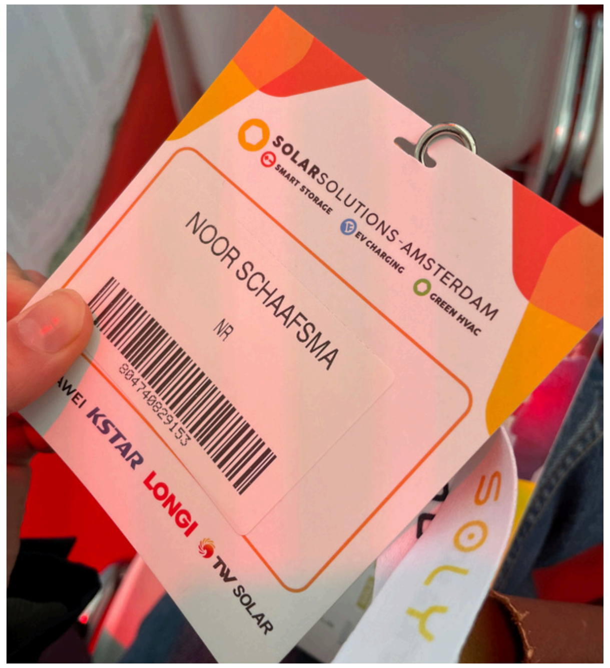
In conclusion:
1. What role do you see in the further growth of energy hubs, and which partnerships do you think are crucial for success?
2. Are there any other factors or challenges that have not been discussed but that play a major role in the development of energy hubs?

APPENDIX VI Interviewed participants

Participant	Role	Interview script
1	Advisor	Explorative
2	Advisor	Explorative
3	Advisor	Explorative
4	DSO	Explorative
5	DSO	Explorative
6	DSO	Explorative
7	Battery supplier	Explorative
8	Battery supplier	Explorative
9	Battery supplier	Explorative
10	Government	Explorative
11	Government	Explorative
12	DSO	In-depth
13	DSO	In-depth
14	Project developer	In-depth
15	Project developer	In-depth
16	Battery supplier	In-depth

APPENDIX VII Attended events

	Event name	Organized by	Date	Location
E1	Renewables and Smart Storage Fair	Solar Solutions	10 mrt 2025	Expo Amsterdam
E2	Battery Investments in the	Aurora Energy Research	20 mrt 2025	Online



APPENDIX VIII HREC Participant consent form

Two consent forms can be seen below. One is for the interviews and one is for the workshop.

Interviews

Informed Consent form

You are being invited to participate in a research study titled "Collaboration toward the strategic integration of grid-scale batteries in the Netherlands". This study is being done by Noor Schaafsma from the TU Delft in collaboration with Accenture.

The purpose of this research study is to gain insight into drivers and barriers for the integration of grid-scale battery storage, as experienced by stakeholders. You will be asked about your experiences and opinions on the collaboration process between DSOs and storage asset developers. This research will take you approximately 45 minutes to complete.

Data will be collected by means of audio recordings and/or interview transcripts. The collected data will have controlled access, limited to the researcher and her two supervisors from TU Delft. Data will be stored in safeguarded storage solutions provided by TU Delft to mitigate the risk of data breaches. All data will be deleted within one month after the completion of this research project. The research findings will be published in the TU Delft repository, but only anonymized summaries and de-identified quotes will be included in the publication.

Your participation in this study is entirely voluntary, and you have the right to refuse to answer any question, withdraw from this research at any time without consequences, request access to, rectify, or erase your personal data at any point during the study.

If you have any questions or concerns about this research, do not hesitate to contact the researcher:

Noor Schaafsma

Signatures

__________________________ __________________________ ________

Name of participant | Signature | Date

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

_Noor Schaafsma_____________ ___ __26-02-2025______

Researcher name | Signature | Date

Co-creation workshop

Informed Consent form

You are being invited to participate in a research study titled "Collaboration toward the strategic integration of grid-scale batteries in the Netherlands". This study is being done by Noor Schaafsma from the TU Delft in collaboration with Accenture.

The purpose of this research study is to gain insight into drivers and barriers for the integration of grid-scale battery storage, as experienced by stakeholders. You will be asked for feedback upon a prototype. This research will take you approximately 1 hour to complete.

Data will be collected by means of audio recordings and/or transcripts, and pictures of the prototype with feedback post its on it. The collected data will have controlled access, limited to the researcher and her two supervisors from TU Delft. Data will be stored in safeguarded storage solutions provided by TU Delft to mitigate the risk of data breaches. All data will be deleted within one month after the completion of this research project. The research findings will be published in the TU Delft repository, but only anonymized pictures and citations will be included in the publication.

Your participation in this study is entirely voluntary, and you have the right to refuse to answer any question, withdraw from this research at any time without consequences, request access to, rectify, or erase your personal data at any point during the study.

If you have any questions or concerns about this research, do not hesitate to contact the researcher:

Noor Schaafsma

Signatures

__________________________ __________________________ ________

Name of participant | Signature | Date

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

_Noor Schaafsma_____________ ___ __26-02-2025______

Researcher name | Signature | Date

APPENDIX IX Script & materials co-creation session

Structure of the workshop
Including method & reasoning

1. Introduction
Goal: Let te participants introduce themselves, and introduce the goal of the session and the activities.
How: Present the goal with slides

2. Explain the narrative.
Goal: Let the participants recognize and validate the problem
How: A narrative will be told, and through images on the slides (like a comic) the participants can engage in the fictive situation. When the problem in this situation is presented, reflective questions are asked: “Do you recognize this problem?” “Are there aspects missing?” “Do you see this happening in practice?” “Can you share an example?”

3. Present the scenarios
Goal: Explain the scenarios generally, and explain how these scenarios help in understanding possible futures.
How: Slides present the scenarios, the method and goal.

4. Reflect on the scenarios
Goal: Engage participants, ensure participants understand, and gain insight in their opinions and values from their feedback on each scenario.
How: Each scenario is explained in depth, the steps within the scenario are shown on a slide or printed. Questions are asked to ensure participants understand, and then questions are asked to help participants express their thinking. The participants can indicate specific opportunities of them or barriers through post its (physical/miro).

5. Reflect on findings
Goal: Let participants formulate their conclusions, find misalignments and potential success factors.
How: The participants have given their feedback on the two scenarios, but ask them what this means.

Script

1. Present approach and goal
Approach: Different future pathways, but one is preferable. We try to find this and the process,
The question is: How do we design this process?
The goal is to:
- Co-develop scenario-based collaborative decision making processes.

2. Questions during narrative
- Do you recognize this problem?
- Do you have an example of this situation?

3&4. General questions about both scenarios:
- What advantages and disadvantages do you see in both scenarios?
- Are making agreements on this viable/does it enhance viability? And in which scenario is it better?
- How desirable is this process for you?
- How feasible is this scenario?
- Which cooperation structures provide the best balance between grid reliability and EH autonomy?
- What are the conflicts, and potential misalignments?
- What do EH operators and DSOs need to have/change? What capabilities do they need?

5. Reflective questions on findings
- Ask participants to share their findings: What would be the ideal scenario?
- Which cooperation structures provide the best balance between grid reliability and EH autonomy?
- What are the conflicts, and potential misalignments?
- What criteria should be used to determine which model is most suitable for specific locations or situations?
- How can both parties adapt to future market and regulatory changes?
- What is needed for this?

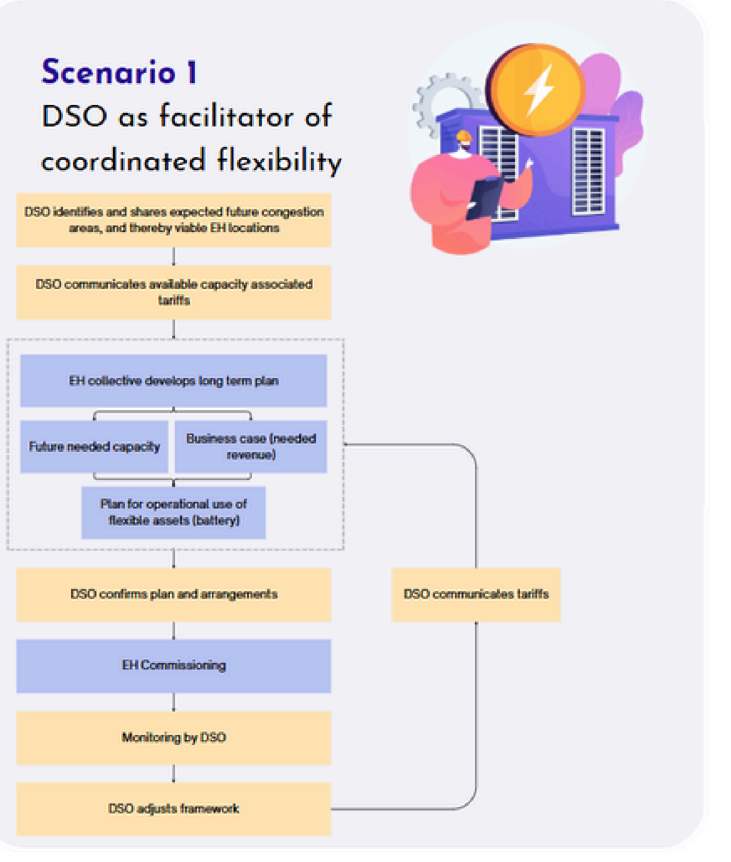
Narrative

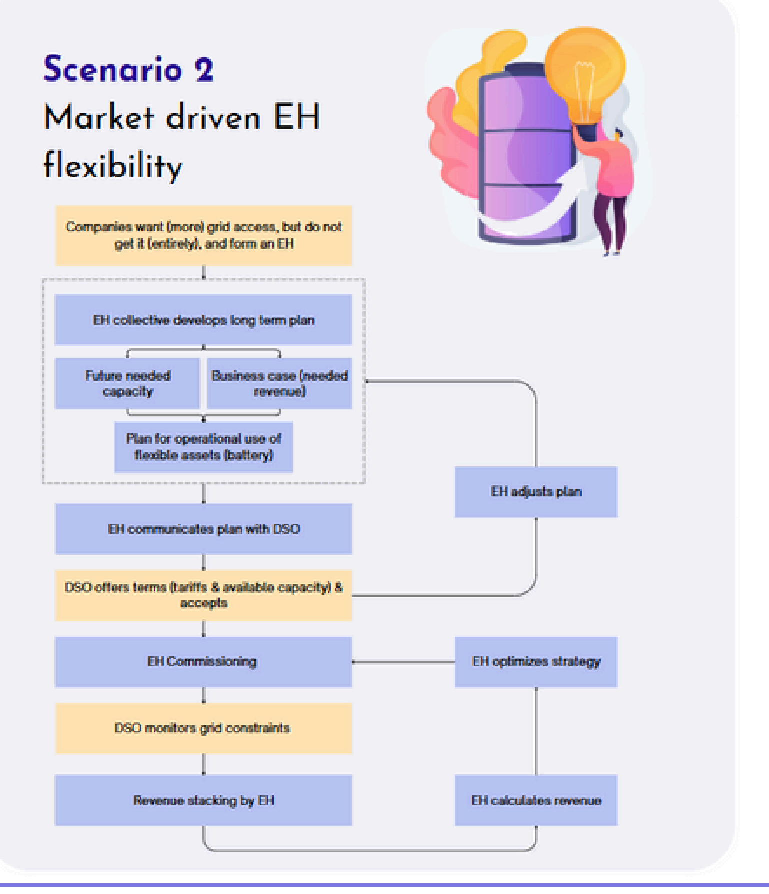
A. Greenform Industries, a manufacturer focused on sustainable products, faces a critical bottleneck. Despite plans to electrify their production lines and install solar panels, the company is unable to secure a larger grid connection. With congestion on the local network, their growth and sustainability ambitions are stalled. GreenForm must find alternative solutions, as waiting for traditional grid reinforcement is no longer viable.

B. Greenform collaborates with neighboring businesses to explore an energy hub. While the DSO needs assurance that grid usage stays within limits, the businesses seek certainty over operational continuity and energy returns. Uncertainty around who takes the lead, how costs and risks are shared, and what type of grid connection to pursue complicates progress.
An independent service provider models different energy hub configurations with shared battery storage for congestion management and local optimization, but questions remain about the business cases overall viability.

C. To achieve the successful implementation of an energy hub, clear agreements on grid usage, battery management and revenue sharing are needed. To explore the decision making over these aspects. Two contrasting scenarios were developed.

Scenarios



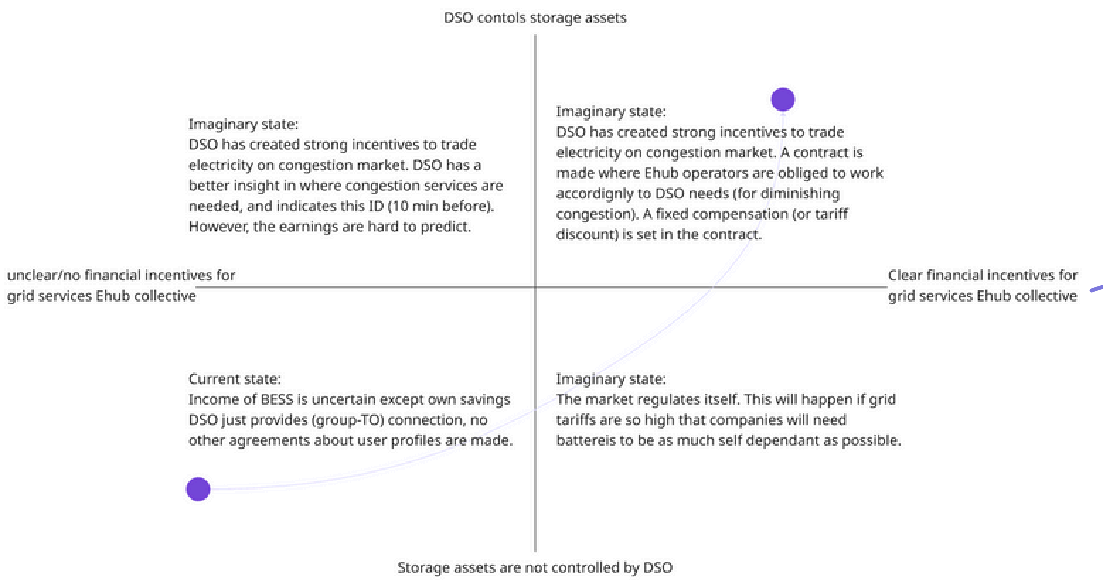


APPENDIX X Participants co-creation workshop

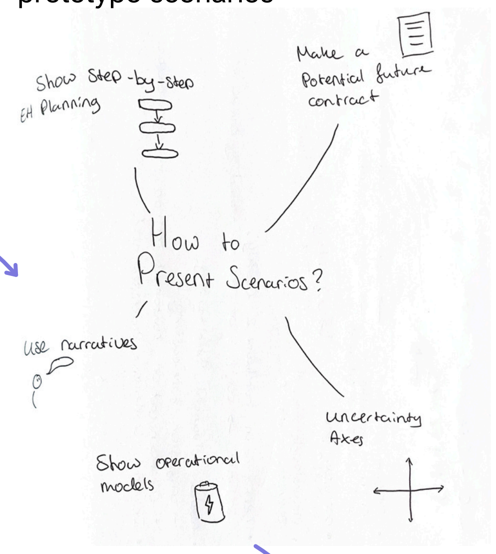
Participant	Role	Attended session	Setting
PC1	Project developer	Session 1	Online
PC2	Consultant	Session 1	Online
PC3	DSO innovation	Session 2	Online
PC4	Battery storage	Session 3	Physical meeting
PC5	Project developer	Session 3	Physical meeting

APPENDIX XI Scenario ideation

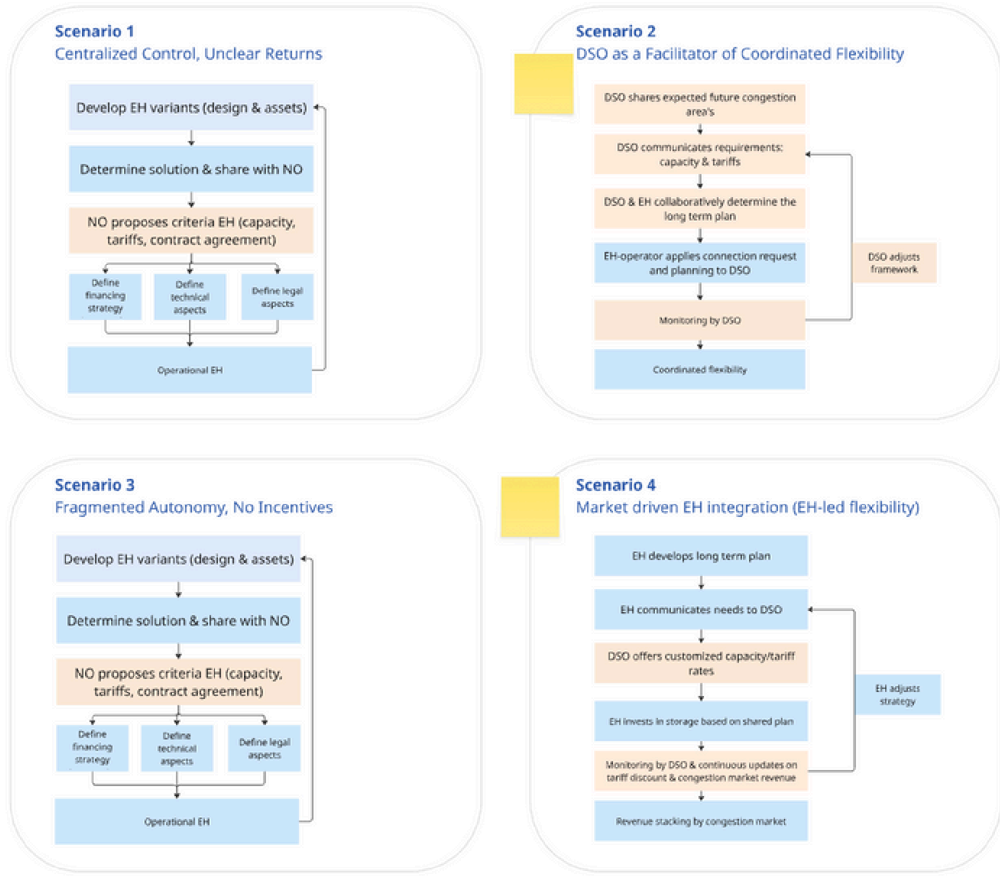
Uncertainty martix



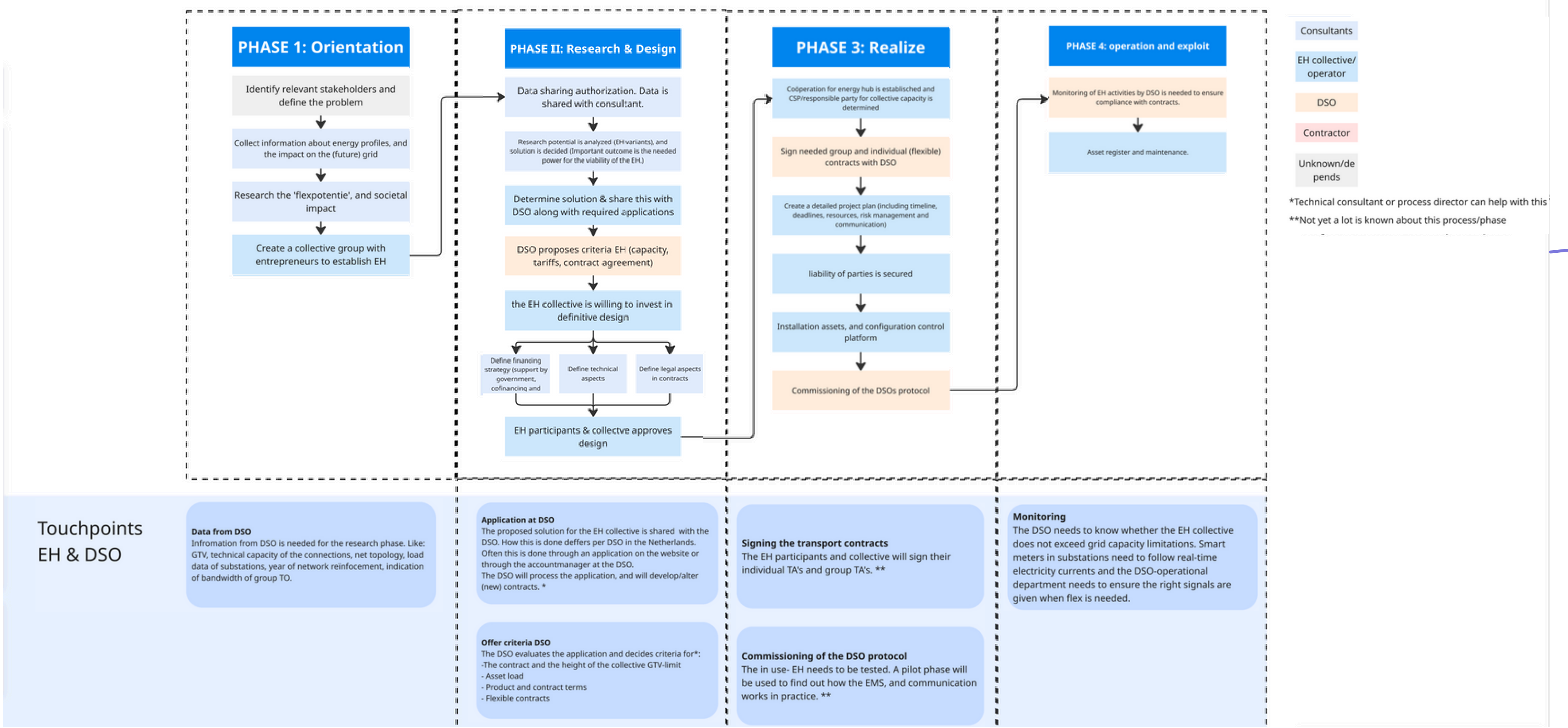
Short brainstorm on possibilities to prototype scenarios

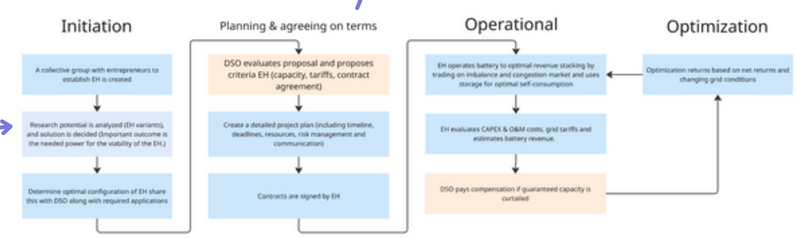


Mapping differing steps per scenario



Step by step plan mapped based on Kennisplatform energiehubs (2025). Note that these steps are not all currently executed this way.



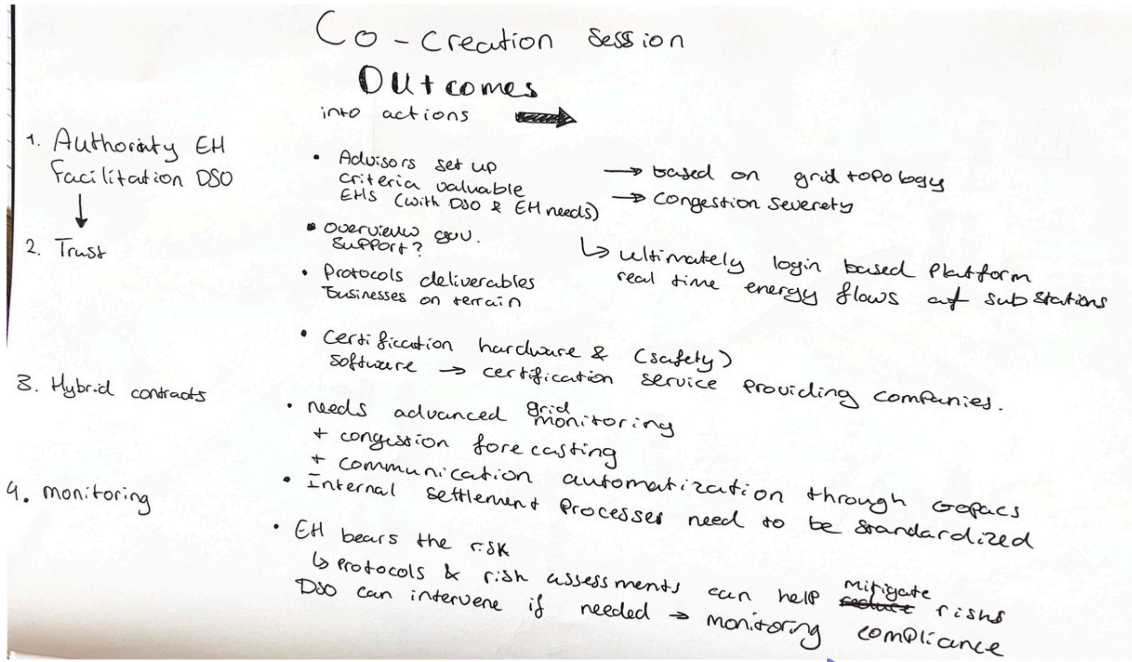


Creating a flow of most important points of action

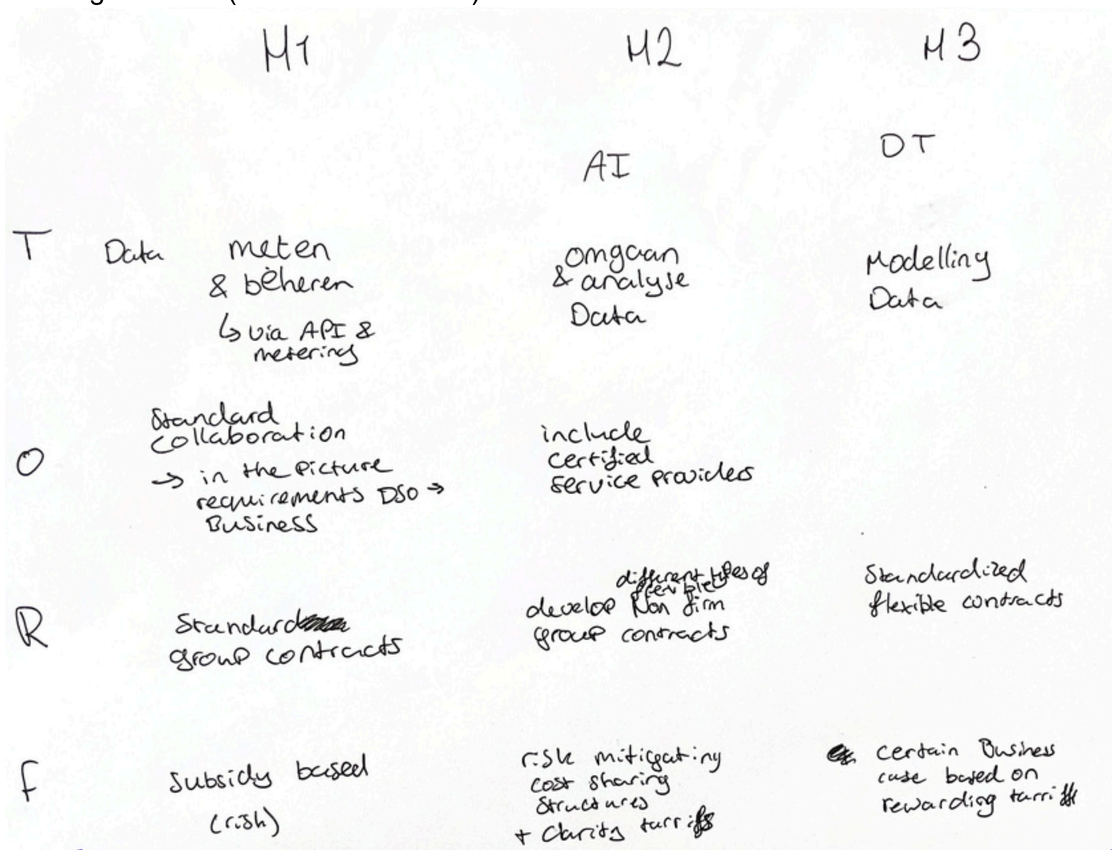
APPENDIX XII Ideation catalyzing concepts

Roadmap

Processing scenario outcomes



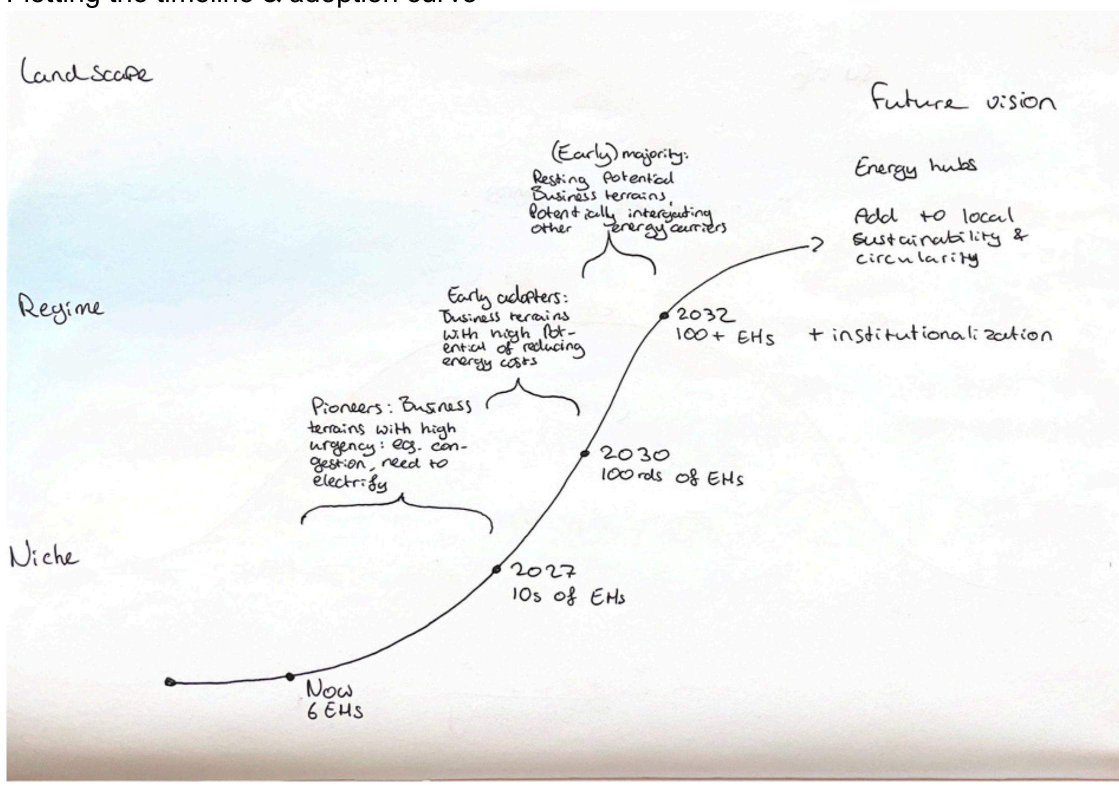
Ideating horizons (done several times)



Linking uncertainties, workshop outcomes, and boundary conditions to roadmap horizons

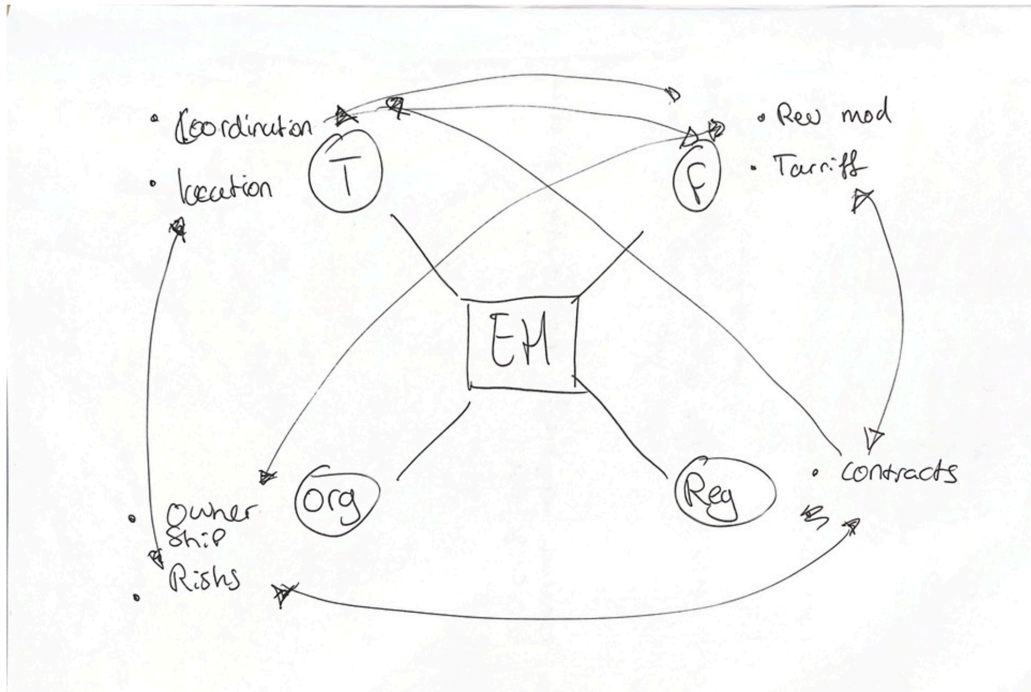
Scenarios	Uncertainty in DSO roles, lack of contract clarity, divergent authority models	Operational control shifting, hybrid contracting under development	System-wide governance, data transparency, and scalable flexibility models
Workshop Insights	Need for trust, clarity on roles and benefits, early EH feasibility assessments	Importance of flexibility incentives, fair risk-sharing, and system reliability	Desire for long-term system predictability, interoperability, and return on investment
Boundary Conditions	- EH location feasibility defined by independent criteria - Transparent grid data - DSO as facilitator, not controller	- Delivery of future energy plans by EH participants - Standardized EH protocols and fallback plans - Incentive-compatible hybrid contracts	- Certified EMS/BMS systems - Firm/non-firm transport agreements - Continuous monitoring & risk allocation mechanisms
Strategic Focus (roadmap)	Build trust & define shared goals	Prove technical, legal, and financial models	Institutionalize coordination, flexible contracting, and system-wide operational standards
	Horizon 1: create consensus & trust	**Horizon 2: testing**	**Horizon 3: system integration**

Plotting the timeline & adoption curve

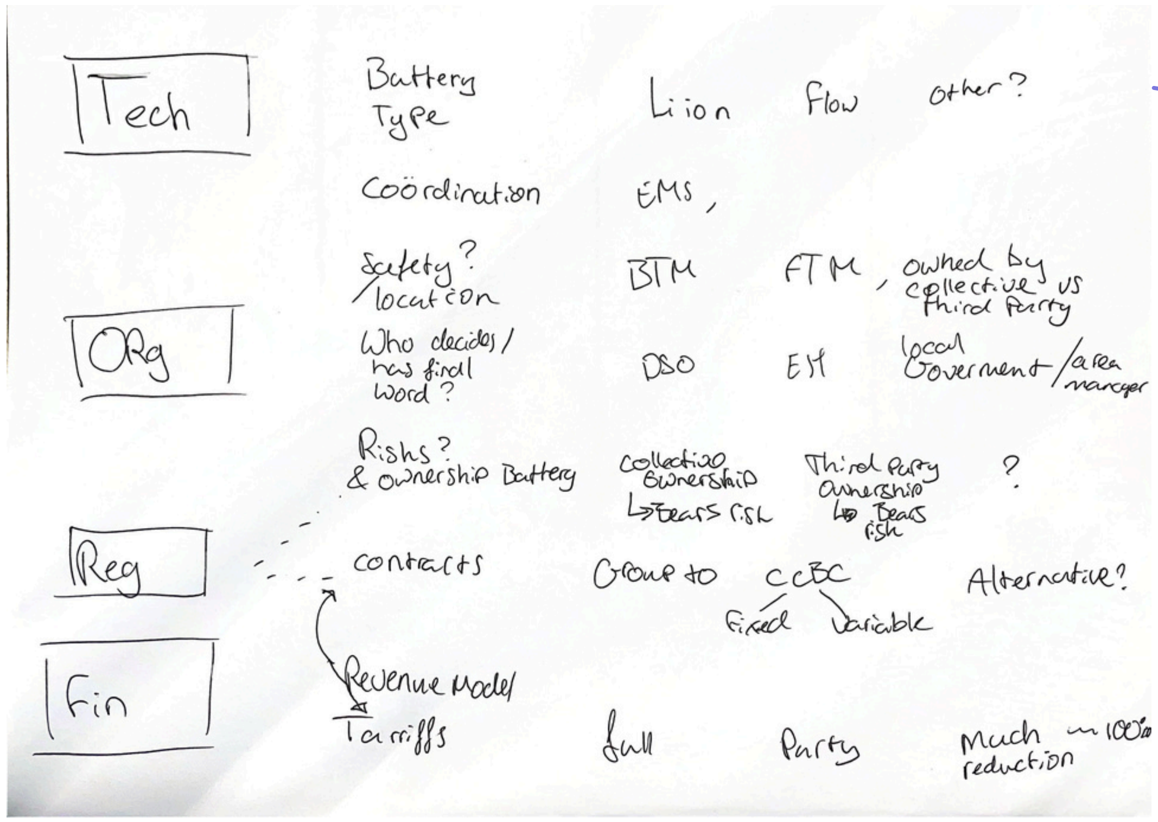


Morphological chart

Trying to map elements of the EH and the most important options. Arrows indicate linkages



Listing most important elements, and the option per element



Several refinements led to the final version

	Option 1	Option 2	Option 3	Option 4
Internal control of assets in EH	EMS	Digital twin for the EH system	Digital twin for the grid	
Type of connection contract	Group-TO (Firm)	C-CBC (fixed)	C-CBC (dynamic)	Non-firm group-TO
Monitoring	IoT monitoring of grid constraints	Predictive maintenance (anticipate equipment failures & congestion)		
Facilitate trust among involved stakeholders	Oper			
Ownership battery	Co			

Dimension	Option 1	Option 2	Option 3	Option 4
Battery Ownership	Individual company ownership	EH collective ownership	Third-party ownership (aggregator)	Leasing model
Battery location	Collective battery (separate grid connection)	BTM batteries at businesses	Mobile/temporary battery solutions	Co-located with renewable generation
EMS Control	Centralized by EH collective	DSO-coordinated control	Third-party aggregator control	
Contract Type	Group-TO	C-CBC (fixed)	C-CBC (dynamic)	Non-firm group-TO
EMS Control	Centralized by EH collective	DSO-coordinated control	Third-party aggregator control	
Revenue Model	Cost savings (self-consumption)	Participation in balancing markets	Congestion management incentives	
Grid Services	Peak shaving only	Frequency balancing services	Congestion relief via GOPACS	Service stacking
Data Sharing	Local real-time monitoring	Shared data platform with DSO	Blockchain platform	Cloud-based open data exchange
Risk Allocation	EH collective bears all risks	DSO shares operational risks	Insurance-based risk-sharing	
Technology Standard	Proprietary vendor choice	Open-source EMS/BMS standards	Certified vendor list (regulated)	

APPENDIX XIII Background on business terrains

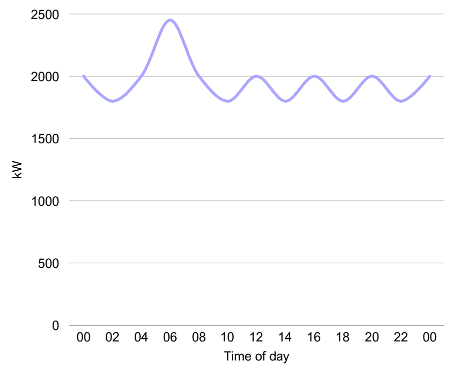
On business terrains, varying patterns in energy consumption are measured. Different types of business terrains can be categorized based on their electricity use. The following classification is made based on information based on De Graaf et al. (2023) and CE Delft (2023e)

Sustainability
There are several ways to reduce CO2 emissions in business terrains, for example, making the buildings gas-free, decarbonizing business processes and activities, fossil-free transportation of people and goods, and sustainable energy generation (CE Delft, 2023e). For industrial processes between 90°C and 200°C, electrification is considered the most suitable solution. For very high-temperature processes (above 200°C), decarbonisation requires case-specific solutions due to the limited number of viable options. For low-temperature processes (below 90°C), two main options exist: electrification of the process (for direct low-temperature heat) and connection to a low-temperature heating network are options (CE Delft 2023e).

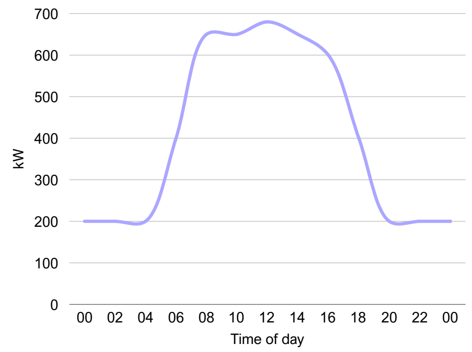
Furthermore, De Graaf et al. (2024) concluded that energy hubs with large-scale battery storage and congestion management offer a solution near HS-MS stations, and for an are with more than 3 years of expected demand congestion.

Conclusion
It can be concluded that medium-large business parks and electricity-intensive industries are the logical frontrunners for integrating battery storage systems. They typically experience peak demand and often already generate solar energy on rooftops. Batteries in these contexts enable smart use of grid capacity by facilitating self-consumption and reducing congestion.

Archetype 1
Business terrains with companies that have a high base load of electricity and some smaller peak loads. Examples are data centers, cold storage facilities, continuous production plants. They have limited options to vary their electricity use (RVO, 2025). Their energy profile is more flat and can be seen in Figure X.



Archetype 2
Business terrains with companies that have a low base load of electricity and high peaks during working days. These companies work 5 or 6 days a week. Examples are middle-large SMEs, production plants with discontinuous processes (like paper factories or dairy processing) (CE Delft 2023d).

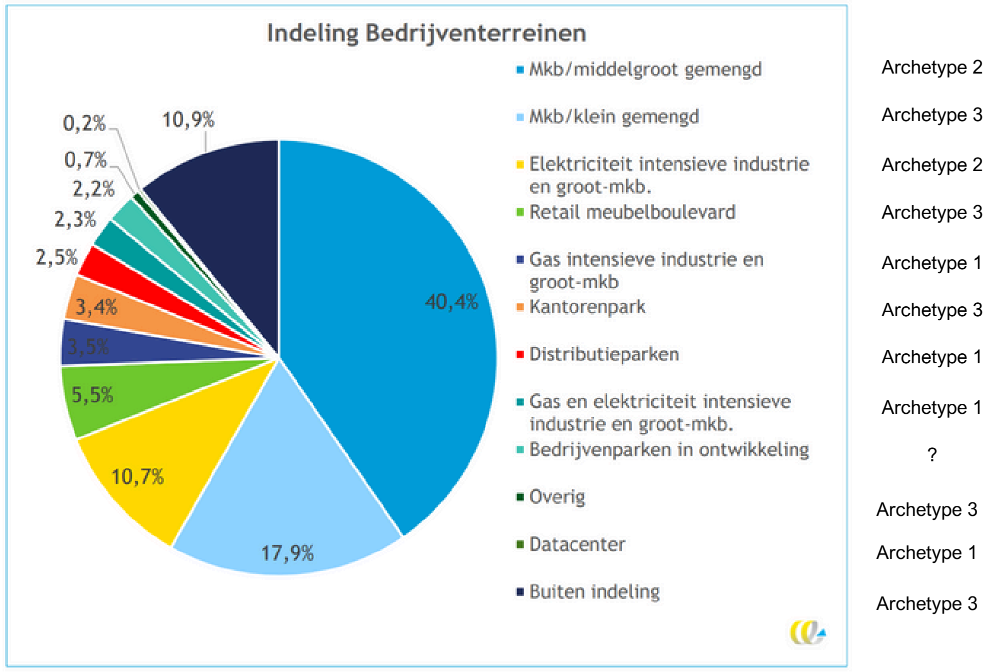


Archetype 3
This group represents the remaining industries, including retail & furnishment markets, MKB small, and other residual terains. Here, the load profile reflects a combination of fluctuating and steady patterns. This acknowledges the diversity of company sizes and operational needs within these sectors.

unknown/varying

Archetype 4
This is a business terrain with fossil fuel-intensive companies. Often, production process temperatures are high, and switching to electricity is not so easily possible.

unknown/varying



Categorization business terrains in the Netherlands. Source: CE Delft (2023d)

APPENDIX XIV Battery business case background

Assumptions

Assume that 2 times a day there's a peak at the business terrain. These peaks take 2 hours in the morning and evening.

Assume that also there is net congestion for supply 12:00-14:00 and for demand from 16:00-20:00

Smaller terrains:

- 4-hour battery
- Possibly 8 MWh, and 2 MW
- > because this can relieve peaks in production
- > because this can be used as backup in case of congestion

Bigger terrains:

- 4-hour battery
- Possibly 20 MWh, and 10 MW/5MW
- > because this can relieve peaks in production
- > because this can be used as backup in case of congestion

C-rate of 0.5 or 0.25 is preferred because then the battery can offer power for a longer period.

Figuur 14 - Resultaten businesscase inzet buurtbatterij op energiemarkten

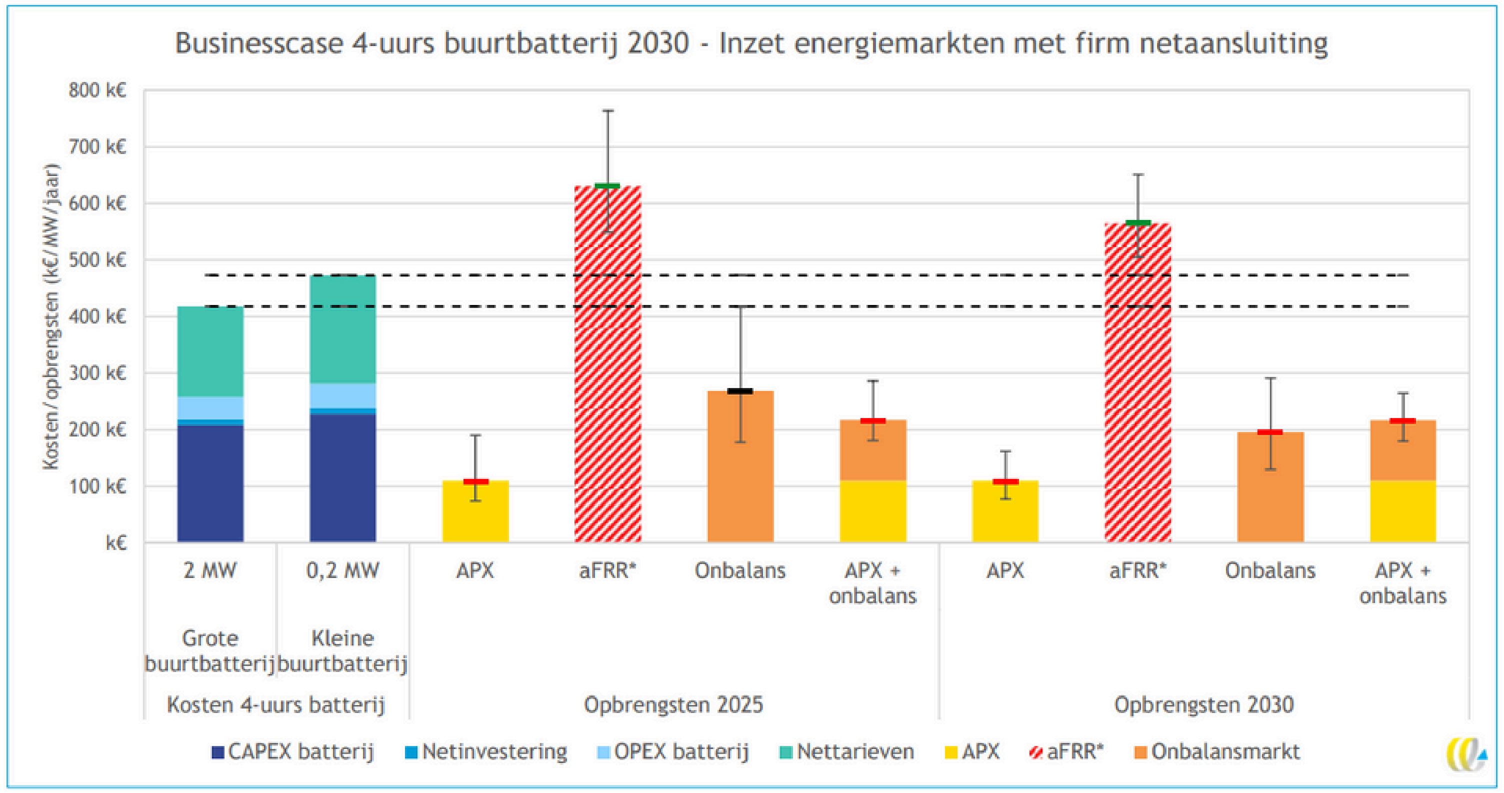


Figure: results of case study battery business case on different markets. CE Delft (2023c)

APPENDIX XV Guide for the morphological chart

Guide for the morphological chart

What is a morphological chart?
The morphological chart is a collaborative planning tool made to support early-stage decision-making for energy hubs with (battery) storage. It lays out the key design dimensions involved in EH implementation and presents concrete options for each. Rather than offering a fixed solution, the chart helps stakeholders co-create system configurations, understand trade-offs, and clarify expectations.

Who is it for?
The chart is for multiple stakeholders of the energy hub development process. These are:

- EH developers and project initiators
- Network operators
- Service providers
- Municipalities or facilitators
- and others involved in developing the energy hub

When to use it?
The chart is meant to be used in early conversations and orientation or planning phase of the energy hub. It is meant to be used during conversations with multiple of stakeholders mentioned above.

How is it used?

1. Bring together stakeholders (e.g., developer, DSO, software provider) who have a stake in control, risk, and energy flow.
2. Define the problem. This can be done per person or by defining the problem for all.
3. Walk through the chart column by column. Look at the function category in the left column. Then look at the options, in the row, and discuss what each means.
4. Then discuss what would be the most suitable option based on the problem definition and the outcome of the discussion. If the choice is made, highlight the option (as in the figure below)

	Dimension	Option 1	Option 2	Option 3	Option 4
Technology	EMS Control	Centralized by EH collective (managed by service provider)	Including digital twin	Third-party aggregator control	
	Data sharing	Energy Hub Platform (EHP) for EH participants	Open source EHP	Platform accessible for EH and DSO	
	Technology Standard	Own supplier choice	Open-source EMS/BMS standards	Certified supplier list (regulated)	
Organization	Risk Allocation	EH collective bears all risks	DSO shares operational risks	Insurance-based risk-sharing	
	Battery ownership/location	Collective battery (separate grid connection)	BTM batteries at businesses		
Regulation	Contract Type	Group-TO	C-CBC (fixed)	C-CBC (dynamic)	Non-firm group-TO
Financial	Revenue Model	Cost savings through self-consumption	Participation in electricity markets	Congestion management incentives	Revenue stacking

5. Do this for each row.

	Dimension	Option 1	Option 2	Option 3	Option 4
Technology	EMS Control	Centralized by EH collective (managed by service provider)	Including digital twin	Third-party aggregator control	
	Data sharing	Energy Hub Platform (EHP) for EH participants	Open source EHP	Platform accessible for EH and DSO	
	Technology Standard	Own supplier choice	Open-source EMS/BMS standards	Certified supplier list (regulated)	
Organization	Risk Allocation	EH collective bears all risks	DSO shares operational risks	Insurance-based risk-sharing	
	Battery ownership/location	Collective battery (separate grid connection)	BTM batteries at businesses		
Regulation	Contract Type	Group-TO	C-CBC (fixed)	C-CBC (dynamic)	Non-firm group-TO
Financial	Revenue Model	Cost savings through self-consumption	Participation in electricity markets	Congestion management incentives	Revenue stacking

6. The result is a configuration of all elements.

	Dimension	Option 1	Option 2	Option 3	Option 4
Technology	EMS Control	Centralized by EH collective	DSO-coordinated control	Third-party aggregator control	
	Data sharing	Near real-time monitoring	Local real time monitoring	Opensource platform	
	Technology Standard	Own supplier choice	Open-source EMS/BMS standards	Certified supplier list (regulated)	
Organization	Risk Allocation	EH collective bears all risks	DSO shares operational risks	Insurance-based risk-sharing	
	Battery ownership	Collective battery (separate grid connection)	BTM batteries at businesses	Mobile/temporary battery solutions	
Regulation	Contract Type	Group-TO	C-CBC (fixed)	C-CBC (dynamic)	Non-firm group-TO
Financial	Revenue Model	Cost savings (self-consumption)	Participation in balancing markets	Congestion management incentives	Revenue stacking

7. This can be done multiple times, to explore multiple configurations.
8. Note which configuration seems most feasible, where consensus exists, and where further discussion is needed. Ultimately the well-considered energy hubs configuration can be realized.

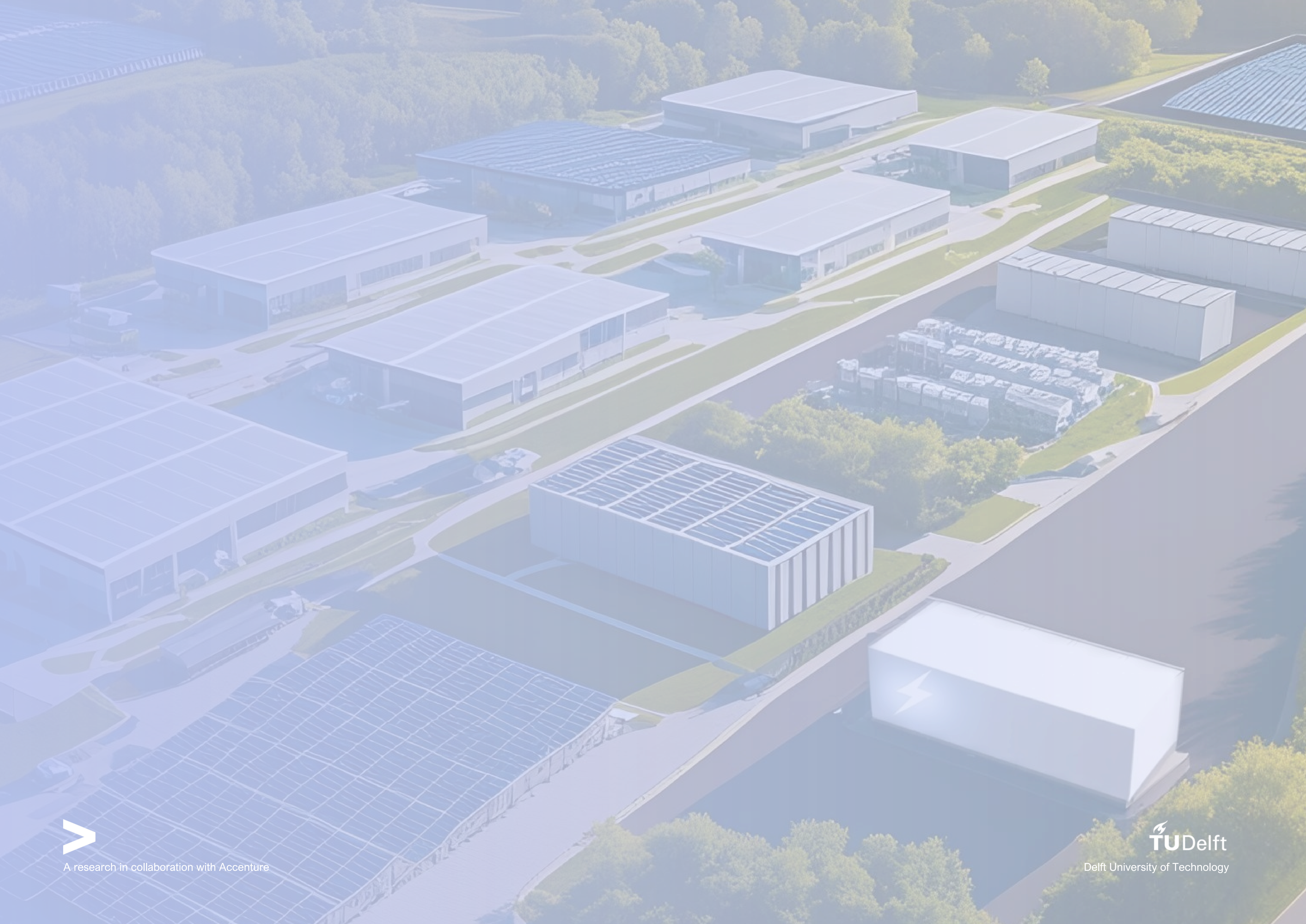
This chart is not a prescription, but a tool: use it to open conversations, clarify expectations, and collaboratively shape the energy hub model that fits your shared goals.

Good luck!

Morphological chart

A tool to explore and compare design options for battery-integrated energy hubs.

	Dimension	Option 1	Option 2	Option 3	Option 4
Technology	EMS Control	Centralized by EH collective (managed by service provider)	Including digital twin	Third-party aggregator control	
	Data sharing	Energy Hub Platform (EHP) for EH participants	Open source EHP	Platform accessible for EH and DSO	
	Technology Standard	Own supplier choice	Open-source EMS/BMS standards	Certified supplier list (regulated)	
Organization	Risk Allocation	EH collective bears all risks	DSO shares operational risks	Insurance-based risk-sharing	
	Battery ownership/location	Collective battery (separate grid connection)	BTM batteries at businesses		
Regulation	Contract Type	Group-TO	C-CBC (fixed)	C-CBC (dynamic)	Non-firm group-TO
Financial	Revenue Model	Cost savings through self-consumption	Participation in electricity markets	Congestion management incentives	Revenue stacking



A research in collaboration with Accenture

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