MING YANG

Analyzing the Application of Battery Technologies and Strategies in Positive Energy Districts

A Case Study in Sluppen, Trondheim

Master's thesis in Urban Ecological Planning
Supervisor: Dirk Ahlers
Co-supervisor: Ellen Loxley-Slåttsveen
June 2023

Master's thesis

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Norwegian University of Science and Technology
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ABSTRACT

This thesis delves into the utilization of battery technologies and strategies in positive energy districts (PEDs), focusing specifically on the case study of Sluppen, Trondheim. The research aims to analyze how battery technologies can be integrated into the planning and development of PEDs to enhance energy efficiency, sustainability, and overall urban planning outcomes. Through an extensive case study in Sluppen, the research investigates the practical implementation of battery technologies and evaluates their effectiveness in achieving the objectives of PEDs.

The thesis employs a mixed-methods approach, combining qualitative and quantitative analyses. The research methodology encompasses a comprehensive literature review, site visits, stakeholder interviews, and data analysis. Various aspects related to the application of battery technologies in PEDs are examined, including technological advancements, policy frameworks, economic viability, and social acceptance.

The findings of this thesis present the energy consumption data of Sluppen after the integration of flow battery technology, as well as the perceptions of stakeholders involved in Sluppen. Through rigorous data analysis, the paper demonstrates the value of battery technology and its pivotal role in PEDs. This research fills the data gap of battery technology in Positive Energy Districts, and is also the first data analysis based on flow batteries in Norway.The findings contribute to a deeper understanding of the role and impact of battery technologies in fostering sustainable urban planning in PEDs. The data analysis indicate that the deployment of flow battery technology can effectively integrate the local energy system and reduce electricity costs, thus making a substantial contribution to the establishment of positive energy districts. However, the interview results reveal a prevailing profit-driven and market-oriented approach among current stakeholders and decision-makers, with limited consideration for human-centred perspectives. The decision-making processes and governance structures predominantly favour corporate entities, with minimal involvement of the general public.

The thesis concludes with recommendations for policymakers, urban planners, and stakeholders involved in PEDs; for the case of Sluppen, the authors propose related models for future development. The proposed recommendations and models aim to facilitate the successful integration of battery technology and the future development of positive energy districts. They address technical, economic, regulatory, and social aspects, providing a comprehensive framework for stakeholders to consider. The research findings presented in this thesis hold significant implications for the study and implementation of battery technology in positive energy districts and can serve as a valuable reference for the governance of such districts.

Keywords: positive energy districts (PEDs), battery, energy efficiency, sustainability, urban planning, stakeholder, governance.

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Thanks to my grandparents—From them I learned courage and the pursuit of truth.

Thanks to my parents—From them I learned love, freedom of will and undeviating steadiness of purpose.

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I want to remind myself of those previous dark days, I walk through the valley of the shadow of death but never give up. For there is no fear in love; only thing we have to fear is fear itself.

The Russo-Ukraine conflict has caused widespread turmoil and unrest across the globe. However, I firmly believe in the eventual triumph of peace and love, particularly in my homeland. But let judgment run down as waters, and righteousness as a mighty stream.

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ABBREVIATIONS

AS	Aksjeselskap(Limited companies)
EU	European Union
LCA	Life Cycle Assessment
NSD	Norsk senter for forskningsdata
NTNU	Norges teknisk-naturvitenskapelige universitet
PED	Positive Energy Districts
UN	United Nations
SWOT	Strengths, Weaknesses, Opportunities, and Threats

CHAPTER
ONE

INTRODUCTION

1.1 Overview

Norway aims to become a low-emission society by 2050 (*Norway's National Plan No. 269/2019* 2019), urban areas play a crucial role, as they are identified as the main area for global emissions(Matthias and Daniela 2021). A PED is an urban area that produces more renewable energy than it consumes, creating a surplus of clean energy that can be shared with neighbouring districts (Derkenbaeva et al. 2022; Vandevyvere 2020). Norway has several ongoing projects focused on creating PEDs, including in the cities of Trondheim and Bergen (Baer et al. 2020). These projects incorporate a variety of sustainable design features, such as energy-efficient buildings, smart energy systems, and green spaces. They also prioritize community involvement and collaboration between stakeholders, including residents, businesses, and the local government (+CityxChange 2022).In the context of climate change and the energy crisis, the Norwegian government has established a battery strategy at the national level (*Norway's battery strategy* 2020). Battery technology holds great potential in the development of PEDs as Norway has an almost entirely renewable-based electricity system (Birol 2022). This research paper relies on the author's internship project in Sluppen to explore the role of new battery technology in the localization of PED, and then examine it from the perspective of sustainable urban development.

1.2 Problem statement

The problem statement for Positive Energy Districts (PEDs) is rooted in the urgent need for sustainable urban development in the face of climate change and increasing global energy demand (Matthias and Daniela 2021). Traditional urban development practices often prioritize short-term economic growth over long-term sustainability, resulting in a range of environmental, social, and economic challenges that threaten the well-being of communities and the planet. PEDs represent a promising solution to these challenges, providing a framework for creating urban areas that produce more renewable energy than they consume (Derkenbaeva et al. 2022). The PEDs are now developing all over Europe, but urban planners and decision-makers have little knowledge of how the PED concept is implemented nationally and how first PED projects develop within the specific national contexts(Matthias and Daniela 2021). So far, positive energy districts and neighbourhoods (PEDs) have been predominantly researched from a technological and energy perspective, often with a focus on electricity and related to new buildings. While the building level is clearly regulated with known possibilities for intervention, this is not the case for the district- and neighbourhood level (Joubert and Cicmanova 2023). There are two main challenges in the process of promoting PEDs—on the one hand, the challenge of technology application, and on the other hand, the localization challenges evolved from the concept of PEDs (Pan et al. 2022; Nielsen et al. 2019; Geneletti et al. 2017).

Pinson (2004), in his paper about the challenges of urban planning, states that planners require an accurate appropriation of what is discovered in other fields; then, they require an up-to-date identification of what constitutes the city. Battery technology has advanced rapidly in recent years, and all stakeholders should be well aware of the promise of this technology and be prepared to judge its role in localizing PEDs (Crownhart 2023).

Various issues to face when localizing PEDs, one is the need for a clear regulatory framework and policies to support their development. The current legal and regulatory framework in the EU does not explicitly address the PED concept, and this can lead to conflicts with existing urban planning and building regulations (Krangsås et al. 2021). There is a need for a clear policy framework that supports the localization of PEDs and addresses issues such as land-use planning, building regulations, energy infrastructure development, and funding mechanisms.

Compared to other Nordic countries, Norway has a higher degree of liberalization. Public and decision-makers focus more on technology and market-driven solutions, particularly being monopolized by big tech companies (Almaas 2020). According to the data and interviews presented in this thematic issue, some planners in Trondheim Kommune are relatively passive in promoting the battery strategy, lacking the vision to integrate it into PEDs and the overall master plan. This has created a fragmented and isolated situation between Norway's national strategy and the vision of the PEDs. In particular, the dominance of large corporations has contributed to a greater pursuit of economic efficiency. While this is an important aspect of PEDs, it can lead to a neglect of other crucial factors, such as social and environmental sustainability, and the needs and aspirations of local communities (Falleth et al. 2010).

(Mee et al. 2021), in their paper about energy urbanity and citizen participation, state that a PED can be comprehended as a deep collaboration between citizens and technology. This active "co-production" is key to observations and assertions this paper will make about the potential effectiveness of active citizen participation
.

With regard to the above questions, Trondheim as one of the Smart City and Communities lighthouse project cities, with several ongoing PED projects, and also ongoing battery application projects, is a valid background for this paper to investigate from an urban planning perspective.

1.3 Background of the research

In response to these global trends, different Horizon 2020 projects have been exploring solutions to facilitating just transitions. Through the +CityxChange project, the European Lighthouse City of Trondheim has established two projects for PEDs: Brattøra and Sluppen. The demonstration projects will be used to validate and improve the model using an iterative approach (+CityxChange 2022). The model will then be exploited to develop a framework for how these demonstrations can be scaled up and replicated across a district, a city and the wider European region. The success of the demonstration projects will then be monitored and evaluated, and the results will be used to refine these processes and technologies so that they can be replicated in the Following Cities and beyond (Hinterberger et al. 2018).

Sluppen-Tempe is one of Trondheim's major transformation areas. It has a massive focus as a sustainable urban development area with corporate, public buildings and dwellings. The area is a targeted Zero Emission Area. A new school and a health and welfare centre at Sluppen will be built together with a large number of new dwellings.Sluppen-Tempe includes both electrical and thermal loads (+CityxChange 2022). In the context of urban planning, energy positive districts represent an innovative and exciting opportunity to create sustainable and resilient communities. This article is a graduation thesis based on internship. The author cooperates with Bryte Batteries on the project in the Sluppen area. Based on the academic theory of the Urban Ecological Planning project, combined with the actual work results, the thesis is completed.

1.4 Aims and objectives of thesis

This paper endeavours to contextualise batteries within the framework of positive energy districts (PEDs) and analyse the potential application of batteries in PEDs, highlighting the prospects, opportunities, and challenges associated with their implementation. Through internships with companies, the author collects data on the operation of batteries and other equipment, then proves their role and efficacy in energy technology. Moreover, the paper addresses the multidimensional aspects of the Application of battery technology under PEDs, encompassing regional, environmental, social, economic, and technological factors. The research questions also delve into the significance of stakeholder relationships and their impact on the project's success.

Research Question:

1. **What is the role of batteries in advancing PEDs?**

   following sub-questions were formulated:

   A. How can batteries be integrated into the energy systems of PEDs?

   B. What is the impact of using battery technology?

   C. How can battery storage help to mitigate the intermittency of renewable energy sources in PEDs?

   D. What types of batteries are best suited for use in PEDs and sustainable urban planning?

2. **What are the roles and interests of stakeholders in developing the PED?**

   Overall, this article focuses primarily on Norway and the Sluppen case study will serve as a source of inspiration for the future design of PEDs and various urban energy transitions. The Author wishes to contribute to the growing body of knowledge and practical experience in the field of sustainable urban development, and energy positive districts and to provide insights and recommendations for policymakers, planners, and researchers working in this area.

1.5 Structure of the thesis

This thesis is based on internship and fieldwork, which combines theories presented in the research background with findings from the fieldwork to achieve the stated objectives. The theory chapter investigates existing knowledge to form the foundation for this essay.

The first chapter of this thesis elucidates the concept of positive energy zones, providing a comprehensive understanding of their significance and objectives. Furthermore, it delves into the current state of battery technology development, shedding light on the contextual background of the era.

The second part explores several concepts, with the positive energy community as the core, related to The Right to the City, Urban Transformation, and Community Development, focusing on the role of battery systems in these concepts. The chapter also presents examples of technologies used in PEDs and reviews previous studies. The theoretical chapter concludes with a framework for analyzing the application of battery technology in PEDs.

The third chapter is about methodology. It describes the approach used to develop this essay, including data collection methods and case study data gathering. It also mentions the challenges and limitations faced during the data gathering process.

The fourth chapter investigates the context of the case study, which is based on the work of Sluppen. It provides details about the history and identity of Sluppen and notes the current studies, plans, and companies directly involved in Sluppen projects that provide relevant information for future planning.

The fifth chapter of this thesis undertakes an in-depth analysis of the practical implementation of battery technology in Sluppen, utilizing the proposed framework. It comprehensively examines the outcomes and discoveries derived from this analysis, covering various dimensions. This section visually presents and elucidates the significance of the data gathered during the internship, investigates the potential opportunities and challenges associated with the adoption of battery technology, and explores the diverse stakeholders involved in positive energy districts and their surroundings.

The final chapter provides the findings and implications of this study. It discusses the analysis and reasoning and connects all the gathered data to argue as a whole. Recommendations are given based on the argument, and related questions beyond the scope of this thesis are suggested for further investigation. The conclusion chapter sums up the thesis.

CHAPTER

TWO

THEORY

In this chapter, prior research and pertinent theories and trends in urban planning are examined. The second subsection presents previously established frameworks and concludes with the proposal of a PEDs framework.

2.1 Research background

A literature review is an essential component of research as it helps to identify gaps in existing knowledge, provide direction for future research and support or challenge research questions or hypotheses. The primary goal of a literature review in research is to offer a comprehensive overview of the relevant research within a given area (Naepi 2023).

2.1.1 Positive Energy Districts

Positive Energy Districts is a relatively new concept, first proposed by the European Union. In the framework of the EU's SET Plan Action 3.2, JPI Urban Europe and the EERA Joint Programme on Smart Cities have set out to detail an operational definition of PEDs (*SET-Plan ACTION n°3.2 Implementation Plan* 2023). This initial definition is used as the working basis for the present fact sheet. It states: *"Positive Energy Districts (PED) are mixed-use energy-efficient districts that have net zero carbon dioxide (CO2) emissions and actively manage an annual local surplus production of renewable energy (RES). They require interaction and integration between buildings, the users and the regional energy, mobility and ICT system, while ensuring social, economic and environmental sustainability for current and future generations."* (Hinterberger et al. 2018; Wyckmans et al. 2019)

They require integration of different systems and infrastructures, and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability" (Hinterberger et al. 2018).

Since then, many countries and cities around the world have embraced the concept of PEDs as a way to reduce greenhouse gas emissions and achieve energy independence. The idea is to create districts that produce more energy than they consume, often through the use of renewable energy sources and energy efficiency measures. This can lead to economic, social, and environmental benefits, making PEDs a promising solution for sustainable urban development. This is achieved by integrating renewable energy systems and energy storage as well as improving the energy efficiency of the district by optimizing the energy flows between the energy consumers, producers and storage (Laitinen 2020).

According to Vandevyvere (2020), selecting the appropriate scale for PEDs is crucial. (See Figure 1.) Although it is possible to achieve a near-zero energy standard for individual buildings and make a city energy-positive and climate neutral, this approach may overlook several opportunities for technical and financial optimization, as well as the advantages of district energy systems, energy flexibility services, and collective energy production and storage. Similarly, from a non-technical perspective, a city is not simply a collection of buildings; integrated urban functioning is a fundamental objective regardless of the perspective taken.

Figure 1: PEDs from different scales (Vandevyvere 2020)

Combining the original definition and viewpoint of PEDs, we can draw a deduction: A Positive Energy District is the integration of various energy systems at different urban scales. For the question of scale and aggregation, D. Ahlers et al. (2022). integrated different theories and proposed three models, see Figures 2 to 4. The interpretation of the boundary is shown in Table 1.

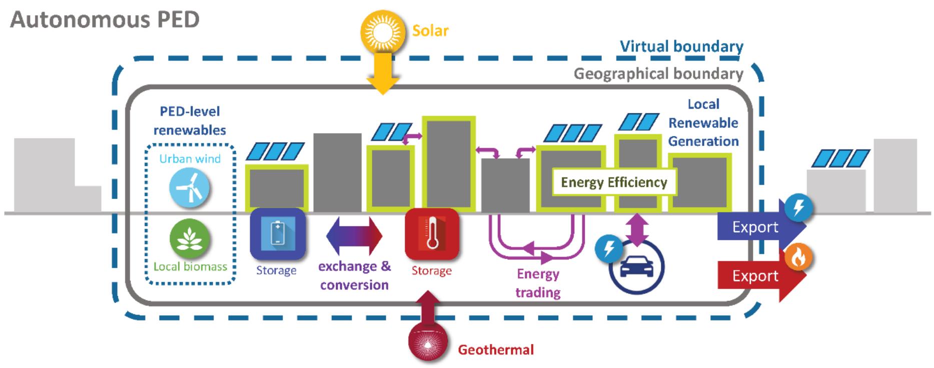

Figure 2: Graphical explanation of an Autonomous PED. (D. Ahlers et al. 2022)

The Autonomous PED means "plus-autarkic", net positive yearly energy balance within the geographical boundaries of the PED and internal energy balance at any moment in time (no imports from the hinterland) or even helping to balance the wider grid outside, not expected as a common case (D. Ahlers et al. 2022).

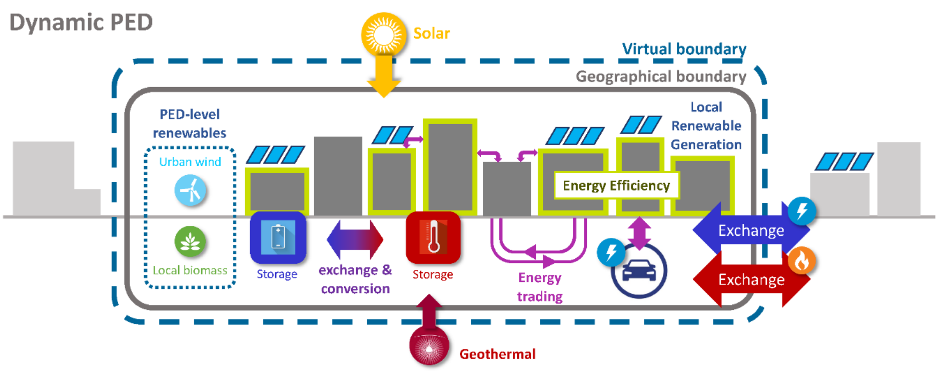

Figure 3: Graphical explanation of a dynamic PED (D. Ahlers et al. 2022)

The dynamic PED means net positive yearly energy balance within the geographical boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages (D. Ahlers et al. 2022).

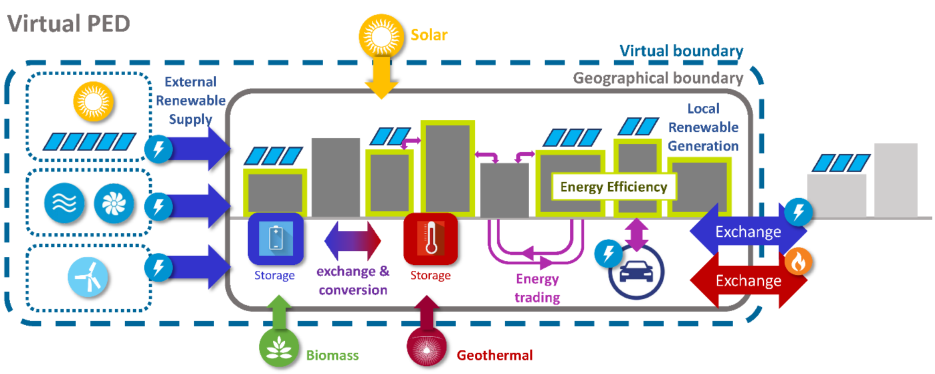

Figure 4: Graphical explanation of a virtual PED (D. Ahlers et al. 2022)

PED virtual means net positive yearly energy balance within the virtual boundaries of the PED but dynamic exchanges with the hinterland to compensate for momentary surpluses and shortages (D. Ahlers et al. 2022).

Table 1: Types of Boundaries (Source: D. Ahlers et al. (2022), edited by author)

Types of Boundaries	Interpretation
Geographical boundary	Spatial-physical limits of the PED in terms of delineated buildings, sites and (energy) infrastructures—these may be contiguous or in a configuration of detached patches
Functional Boundary	Limits of the PED in terms of energy grids, e.g., the electricity grid behind a substation that can be considered as an independent functional entity serving the PED; a district heating system that can be considered as a functional part of the PED even if the former's service area is substantially larger than the heating sector of the PED in question; or a gas network in the same sense
Virtual Boundary	Limits of the PED in terms of contractual boundaries, e.g., including an energy production infrastructure owned by the PED occupants but situated outside the normal geographical PED boundaries.

Based on different physical scale and urban population density, Lindholm et al. (2021) Propose an onion model for PED networks, where most of the PEDs are constructed in the outer-most layers, i.e., the districts furthest away from the city centre. These outer-layer PEDs produce more renewable energy than they consume and can thereby export excess renewable energy to the inner layers of the city. This way, networks of PEDs can increase the renewable energy share of the city centre and the self-sufficiency of the whole metropolitan area. Figure 5 is a visual explanation of the onion model.

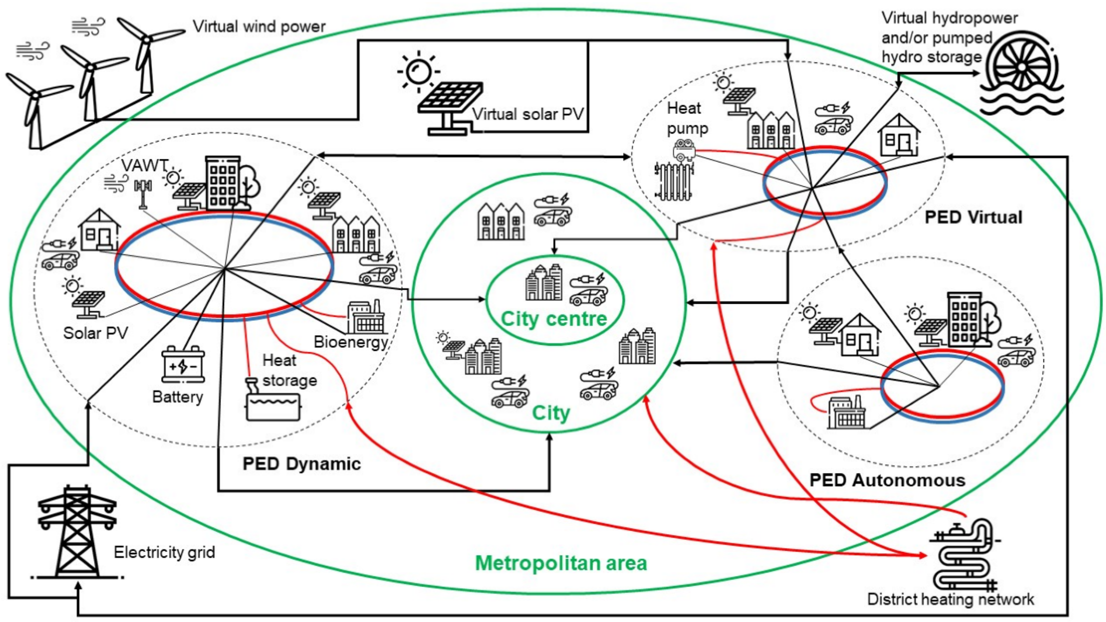

Figure 5: Different PEDs implemented in the onion model (Lindholm et al. 2021)

The PED definition is still in the conceptualization phase, and further research is therefore needed in order to initiate a discussion on a societal level. PEDs are moreover not exclusively about energy and climate. According to the concept, it is important to adopt whole systems approach and aim at realizing integrated sustainability, a principle which is already reflected in the definition above. Given this broad set of conditions, other solutions and strategies than a PED may exist, depending on the specific urban context at stake.

Krangsås et al. (2021) state that in the context of Positive Energy Districts (PEDs), there is a growing emphasis on technological advancements and the implementation of high-tech solutions, while investigations that focus on residents' perspectives and experiences are lacking. It is essential to consider people's experiences while integrating innovations to ensure continuous development of the area. Developing a participatory method and culture is crucial to establishing a feedback loop and community-centred processes, which should be integrated with local planning and decision-making approaches. This approach should be a fundamental principle behind the creation of PEDs. The definitions and descriptions of the PED factors that are developed for this work reveal the interrelationship and overlaps between them (see Figure 6). This implies that no single parameter can be considered in isolation of the others and that no factor can be left out in order not to skew an assessment of PEDs.

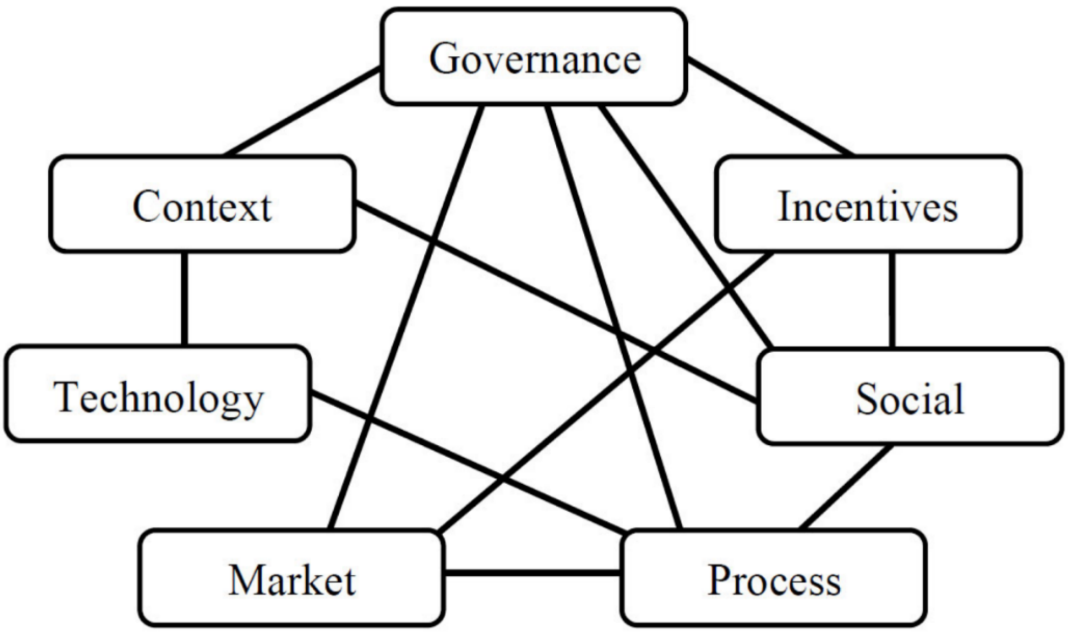

Figure 6: Integrated and holistic PED framework (Krangsås et al. 2021)

Casamassima et al. (2022) proposed 6 fators for designing PEDs, see Figure 7. This can be used as one of the reference theoretical frameworks for urban designers.

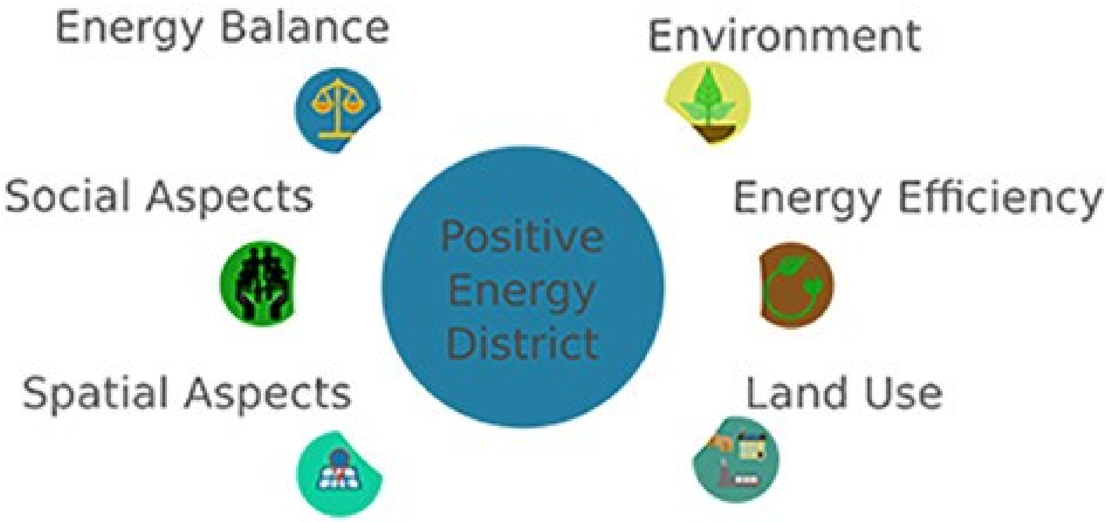

Figure 7: Main aspects and principles of Positive Energy Districts design (Casamassima et al. 2022)

2.1.2 Governance

Governance is the process of making and enforcing decisions within an organization or society. It is the process of interactions through the laws, social norms, power or language as structured in communication of an organized society over a social system. It is done by the government of a state, by a market, or by a network (Bevir 2012; Pierre and Peters 2020).

Leftwich (1993) defines good governance as the following features: *"Good governance included some or all of the following features: an efficient public service; an independent judicial system and legal framework to enforce contracts; the accountable administration of public funds; an independent public auditor, responsible to a representative legislature; respect for the law and human rights at all levels of government; a pluralistic institutional structure, and a free press."* (Leftwich 1993) With the rise of liberalization, public affairs are no longer dominated by the government, but completed through collaboration; a situation in which the state becomes a collection of inter-organizational networks made up of governmental and societal actors (Rosenau 1992). So government is rule by direction; governance is rule by self-organising networks (Colebatch 2014).

Contemporary urban theory and practice in the post-industrial era is increasingly often turning towards an approach based on sustainable development. It puts in a new light the socio-cultural, ecological and energy-related aspects of space as well as its value and aesthetics (Badach and Dymnicka 2017). The spatial structure of cities has a direct influence on energy consumption. In turn, the availability of energy influences the physical and functional form of cities, human behavior as well as processes for social inclusion (Owens 1986).

PEDs and Norway's battery strategy is a cross-sectoral concept which covers a wide spectrum of issues in the urban context ranging from techno-economic to social, environmental and institutional factors. Thus, it conveys several implications for urban governance and city administration (Akrofi and Okitasari 2022). Good governance provides the necessary structure, policies, coordination mechanisms, and stakeholder engagement processes to support the development and success of PEDs. It helps create an enabling environment for the integration of battery technologies and other sustainable energy solutions, and ensures that PED initiatives are effectively planned, implemented, and monitored for their long-term sustainability.

2.1.3 Urban Transformation

The notion of 'urban transformation' has been gaining ground in science and policy debates. Urban transformations to sustainability and resilience are enshrined in the 2030 United Nations Sustainable Development Goals (SDGs) and the New Urban Agenda(United Nations 2022; UN-Habitat 2016). The discourse represents an entry point to address systemic causes of ecological degradation and social injustice, thereby providing solutions to intractable global challenges (Westman and Castán Broto 2022).

Urban transformation and Positive Energy Districts (PEDs) are closely related in terms of their goals and objectives. Both aim to improve the quality of life for urban residents while reducing negative impacts on the environment. Urban transformation is a comprehensive process that involves the rethinking and redevelopment of urban spaces, infrastructure, and services to promote sustainable development and enhance the overall livability of cities (Ibrahim et al. 2017). In contrast, PEDs are a more specific concept that focuses on energy systems in urban areas, aiming to create districts that generate more energy than they consume. The implementation of PEDs can be considered as part of the urban transformation process since they require changes to the physical infrastructure of urban areas (Vandevyvere 2020).

Hölscher and Frantzeskaki (2021) propose three perspectives on urban transformation: space, function and governance. The processing and localization of PEDs will provide opportunities to unveil interactions across multiple urban systems and scales. For instance, rapid changes in electricity systems can have knock-on effects for urban mobility or heat systems (S. Chen and B. Chen 2016; Chelleri et al. 2015). The relational geography perspective puts forth a differentiated view of urban systems: it zooms in on different boroughs, districts or neighbourhoods and raises questions such as how innovation and change in one location affects neighbouring locations (Wachsmuth et al. 2016). Based on Gouveia et al. (2021), the incorporation of urban transformation concepts into PEDs while adhering to the principles of urban transformation and human rights can result in the development of more sustainable, equitable, and livable communities that cater to the needs of all inhabitants. Participatory planning approaches, such as community charrettes or workshops, can help ensure that residents have a say in how PEDs are designed and implemented. This can also help build trust and cooperation between residents, local governments, and other stakeholders, which is essential for the success of PEDs.

Urban planners and other stakeholders argue for implementing and fusing different urban transformation models, as they are most beneficial for interweaving the social, economic, and environmental dimensions (Downs 2005). Lobner et al. (2021) proposed a "compact model" to integrate and analyze different urban transformation theories (See Figure 8). Transformational plans are urged to be incorporated everywhere, and a negotiation of new (transformational) methodologies has to be implemented, as all communities and stake holders are responsible to engage with active learning entities for establishing transformation at large (Seixas and Lobner 2018).

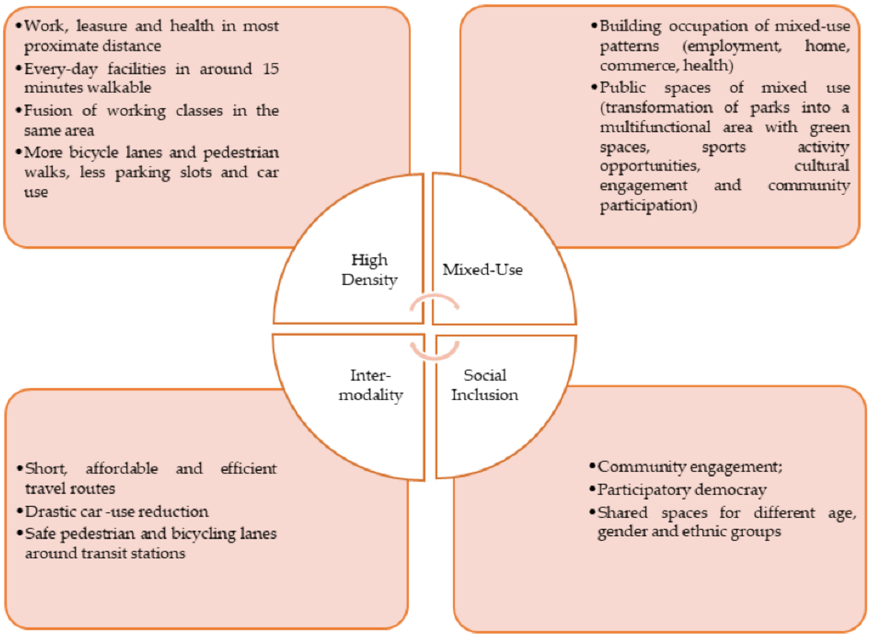

Figure 8: Modes of Compactivity (Lobner et al. 2021)

2.1.4 The Theory of Community Development

Over the past few decades, economic globalization and rapid advances in communication technologies have led many scholars to argue that place-based communities have been even further undermined. Warren (1987) argued that as communities became more reliant on extra-local institutions and sources of income, they were engulfed by forces that they could not control; important local decisions were increasingly made by people and organizations located hundreds or thousands of miles away (Warren 1987). Correspondingly, the calls to revive the community are getting stronger and stronger. This theory of community development, developed in the 1960s, emphasizes the importance of community involvement and empowerment in the planning process. The theory advocates for a bottom-up approach to planning, where the needs and desires of local residents are taken into account (lab 2023).

In the pre-1960s era, planning was typically carried out by skilled experts employed within local governments who operated under the supervision of planning commissions (Davidoff 1965). This approach to planning, known as top-down, was the result of historical planning practices. Top-down planning is characterized by authoritarian and undemocratic methods, where institutions and individuals plan without first engaging the various stakeholders involved in land use and development.

Putnam et al. (2009) argue that the shift towards individualism and the decline in community engagement have led to negative social, economic, and political consequences. He suggests that building social capital can lead to a more productive and democratic society. The goal of community development is to help “community people to become subjects instead of objects, acting on their situation instead of simply reacting” (Dillman 1982).

2.1.5 Norway’s battery strategy in the context of PEDs

Norway’s battery strategy presents 10 measures for how Norway will further develop a coherent and profitable battery value chain (*Norway’s battery strategy* 2020). Sintef’s report estimates that battery production in Norway is currently valued at NOK 800 million, but can reach NOK 10 billion and support 7 000 jobs by 2030, and NOK 50 billion by 2050 and 15 000 jobs (Valstad et al. 2020) The concept of PEDs emphasizes the application of renewable energy technologies, so a stable power grid is required as the basic infrastructure framework support (D. Ahlers et al. 2022).

In the context of PEDs, batteries can help to optimize the use of renewable energy and reduce dependence on fossil fuels. By storing excess energy from renewable sources, batteries can ensure a stable and reliable supply of energy to PEDs even when renewable production is low (Nielsen et al. 2019; Lindholm et al. 2021). This allows PEDs to achieve their goal of producing more energy than they consume, while also contributing to the overall stability of the grid. However, the current institutional landscape is heavily petroleum-oriented and the private sector is not capable of delivering the green transition alone (Kattel et al. 2023). While the Norwegian oil and gas industry has had several so-called ‘green flings’ in offshore wind, this has been a viable alternative when the price of oil has fallen, only to be reversed when the oil price rose again (Mäkitie et al. 2019). The current approach to innovation and industrial development in Norway is characterised by strong path dependence originating in the developmentalist petroleum policy of previous decades (Lie 2021). According to Gullberg, Norway will face many challenges in the short term. Norway’s politically viable contribution is to balance electricity with existing battery technology and in doing so integrate national strategies and technical means into the construction of PEDs (Gullberg 2013).

2.2 Theoretical framework

This section is a foundational review of existing theories that serve as a roadmap for developing the arguments which will be used. Based on the problem statement, research questions, and review of literature sources, the authors will propose frameworks and models for evaluating PEDs.

2.2.1 Identify Spatial boundaries of PEDs

Based on the content of the above literature review, PEDs (Positive Energy Districts) are still a relatively new and developing concept in the field of urban planning and sustainable development. Therefore, there is not yet a unified and precise analysis and evaluation system within the EU. Berry (1964) pointed out: "In so far as a science is a coherent body of empirically supported propositions which retain their stability within a particular theoretical framework." Therefore, based on existing experience and localized knowledge, an evaluation system for PEDs can be constructed.

As highlighted by Pfenninger et al. (2014), the spatial dimension is one of the challenges of modeling the current energy transition efficiently. As one can see from the results in lecture reviews, most of the concepts analyzed relate to the spatial dimension. By talking about small scale urban areas such as districts or communities, geographical boundaries are essential to understand what is inside or outside of a given system. PEDs exploit this aspect due to the various definitions currently in place. Lindholm et al. (2021). present the three definitions of Autonomous/Dynamic/Virtual PED that all include considerations with a geographical nature. Additionally, JPI Urban Europe (2020) mentions that the terms "regional" and "local" have been left open to allow some flexibility. The complexity of the system of a district may lead to different boundaries for each end-user sector considered Hermelink et al. (2013). describe the characteristics related to the system boundaries and they present how this has been considered in different cases around Europe. They point out how the system boundaries' definitions are needed to understand the available renewable energies options. Carlisle et al. (2009) mentioned that when talking about energy communities, except for the case of islands, the boundaries are arbitrary and can be either geographically but also politically defined. The U.S. Department of Energy (2015) defines the site boundaries as the "Line that marks the limits of the building site(s) across which delivered energy and exported energy is measured." Based on the research results of Casamassima et al. (2022), this paper adopts the identification scheme shown in Figures 9.

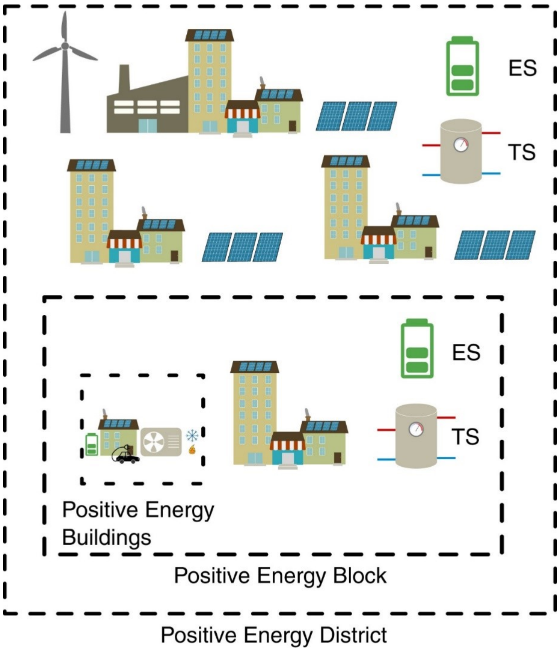

Figure 9: Spatial resolution for positive energy districts. ES, electrical storage; TS, thermal storage (Casamassima et al. 2022)

2.2.2 Factors for Sustainability Analysis

Sustainability analysis typically involves a comprehensive analysis of the project, program, or policy, examining the impacts of its activities on the environment, economy, and society. This includes identifying the positive and negative impacts of the project, program, or policy and determining the effectiveness of existing strategies for mitigating negative impacts and enhancing positive ones (Brattebø 2012). Sustainability evaluation involves many factors. Therefore, as Munasinghe (2007) proposed, this paper uses the "sustainability triangle" theoretical framework. (See Figure 10)

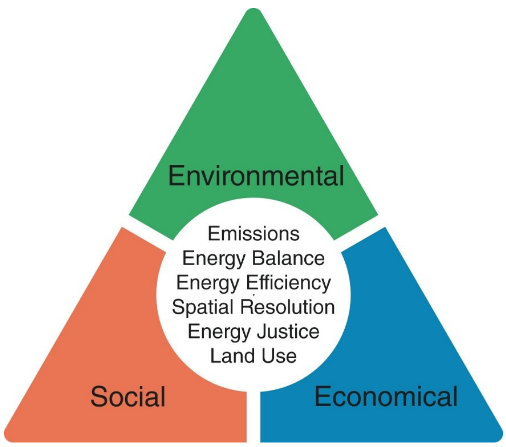

Figure 10: Criteria of analysis within the triangle of sustainability (Casamassima et al. 2022)

All of the six criteria of sustainability relate to each pillar of sustainability. Spatial aspects have repercussions on the economics of a project, the environmental and social impacts (Casamassima et al. 2022). This "Sustainability Triangle" is a framework used to analyze the relationships between the three dimensions of sustainability: social, economic, and environmental. It suggests that these dimensions are interdependent and should be considered together in order to achieve sustainable development. The triangle represents the three dimensions with the understanding that the goal is to create a balance between them that results in sustainable outcomes. The framework is often used in sustainability assessments and planning to help decision-makers consider the potential impacts and trade-offs of different options on each of the dimensions.

2.2.3 Stakeholder Management

Effective governance involves engaging and involving relevant stakeholders in the planning, decision-making, and implementation processes of PEDs. This includes local communities, businesses, government agencies, utility companies, research institutions, and civil society organisations. Stakeholder engagement ensures that diverse perspectives are considered, fosters ownership and support for PED initiatives, and promotes collaboration among different actors (Aina 2019).

Notably, besides technological novelty, a PED project entails challenges arising from the complicatedness of the stakeholders involved (Rankinen et al. 2022). As a district development undertaking, a PED involves multiple municipality agencies concerned with the planning, development, and governance of city districts. The other involved parties are energy system designers, contractors, housing companies, business owners, customers, and local residents in the area that hitherto might not have had relations with each other (**matthias2021case**; Dorobantu et al. 2018). As PEDs are planned and implemented as projects, and due to the previously highlighted technological and relational complexities, project management serves as a critical step toward achieving desirable outcomes. As complexity heightens, the significance of project stakeholder management concurrently increases (Aaltonen, Kujala, and Outinen 2008). Therefore, understanding the stakeholder environment and efficiently managing it would boost the chances of success (Aaltonen and Kujala 2016).

Applying the stakeholder management model involves identifying key stakeholders, such as local communities, government agencies, energy providers, technology developers, urban planners, and civil society organizations, and understanding their roles, relationships, and expectations regarding PEDs. It also involves conducting stakeholder analysis to assess the interests, needs, and potential conflicts among stakeholders, and to identify opportunities for collaboration and consensus-building. By applying the stakeholder model, researchers can gain insights into the complex network of stakeholders, their power dynamics, and their contributions to the development of the study project. This approach facilitates a comprehensive understanding of the social, economic, and political dimensions of PED and its relevant technology; and helps ensure that research outcomes are relevant, inclusive, and aligned with the interests of various stakeholders.

2.2.4 Suggested Analytical Framework

The final framework that is derived from the previously introduced factors to evaluate PEDs is shown in table 2. This framework will be also used as the basis for the analysis of PEDs in Sluppen.

Table 2: Positive Energy Districts Framework for Evaluating Sluppen,edited by author

Environmental	Livability
	Public and Green Space
	Pollution
Economical	Local Energy Cost
	Job Creation
	Housing Price
Social	Stakeholder Engagement
	Gentrification

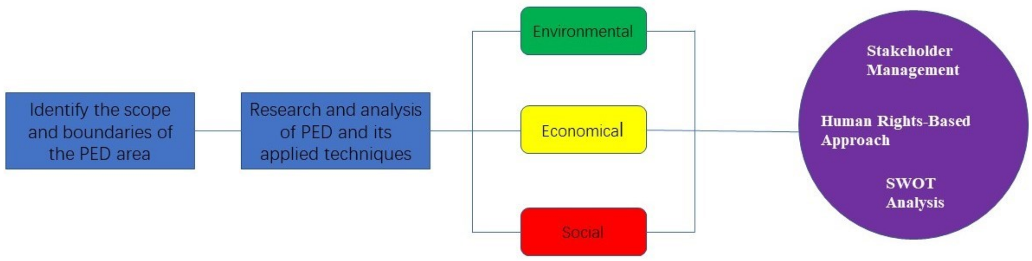

Figure 11: Analytical Model connecting the sustainability factors with a human rights-based approach, SWOT analysis in PED, and stakeholder management in PED.

CHAPTER
THREE

METHODOLOGY

In this chapter, the methodological approach utilized to address the research questions is presented. A variety of methods are implemented and thoroughly introduced. Furthermore, the conceptual framework of the research is demonstrated to structure the research concept effectively.

3.1 Methodological Approach and Research Scope

The thesis is Internship-based, through case studies and other approaches, combined with fieldwork content on fieldwork and relevant theories. Bryte Batteries provided the author with an internship opportunity. The main work area is Sluppen, Trondheim. The author is authorized to collect information and data on batteries and energy systems in the Sluppen, and to meet with various stakeholders.

The theory chapter provides a definition of PEDs, outlines the conceptual framework, and reviews the existing literature on PEDs and a set of factors for evaluating PEDs are introduced in the form of a framework. This part of the study also identifies the key elements that characterize PEDs and the benefits and challenges associated with their implementation. In the theoretical part, Norway's relevant planning policies and battery technology policies are also introduced. The case study and analysis are based on the theoretical framework, the author examines the development of PEDs and the application of battery technology in Sluppen from the perspective of urban planning theory. The related measures and innovative ideas are provided by the author in subsequent chapters. Case studies have been chosen as they allow for a deep understanding of the subject being studied and provide insights into real-life scenarios.

When surveying the literature on PEDs research and previous studies, I noticed that, in general, there are not many studies on the application of battery technology on PEDs, and there is also a lack of examining the development of PEDs from the perspective of urban planning, although these concepts are very related. The author aims to investigate the need for further research on the utilization of battery technology in Positive Energy Districts (PEDs) and its potential contribution to urban planning and development. By conducting analytical case studies, the study aims to validate or refute the hypothesis that battery technology plays a positive role in the progress of PEDs and urban planning.

A qualitative approach is employed in this thesis with an exploratory case study, using participant observation as the primary methodological tool (Hesse-Biber 2010; Farinosi et al. 2019). Furthermore, a combination of desk-based research and fieldwork has been employed to augment the primary data obtained through interviews with various stakeholders. At the end of this chapter, the author addresses the ethical concerns and limitations of the study while justifying the credibility and comprehensiveness of the data collected. This project does not involve personal data, and all data is based on public information and experimental data results of internship projects. The internship company has approved the data during the internship to be used as a master's thesis and made available to the public. This project does not involve personal data, and all data is based on public information and experimental data results of internship projects. The internship company has approved the data during the internship to be used as a master's thesis and made available to the public. All data complied with all ethical guidelines and procedures set forth by the Norwegian Center for Research Data (NSD).

3.2 Data collection

3.2.1 Literature Review

A review of prior, relevant literature is an essential feature of any academic project. An effective review creates a firm foundation for advancing knowledge. It facilitates theory development, closes areas where a plethora of research exists, and uncovers areas where research is needed (Webster and Watson 2002). A substantive, thorough, sophisticated literature review is a precondition for doing substantive, thorough, sophisticated research (Boote and Beile 2005). Each of the literature reviews resulted in fresh, new understandings and, in most cases, a significant reconceptualization of the mature topics reviewed (Torraco 2005). Because the concepts covered in this article are relatively new and have not yet undergone a comprehensive review of the literature, the review is more likely to lead to an initial or preliminary conceptualization of the topic (i.e., a new model or framework) rather than a reconceptualization of previous models (Rueda Castellanos and Oregi 2021; Torraco 2005). The Literature Review should include other people's work that gives a foundation and context for a study, whether the findings are used to support a case to extend something, or the researcher identified a problem and is conducting research to fix it (Candy 2006) The sources of the literature in the paper were mainly searched by using Oria which is the NTNU University Library and Google Scholar.

The primary search focus of this study is centered on "Positive Energy Districts (PEDs)" and the relevant literature is carefully reviewed and summarized. The author observed that the majority of works discuss the themes of technology application, spatial recognition, and urban planning. Upon further investigation, the author narrowed the focus to literature concerning the application of battery technology and urban planning. In the field of urban planning theory, the author specifically selected literature on Urban Ecological Planning, which aligns with the subject of their master's project. The literature review conducted by the author explores the historical and current state of the research topic and offers insights into future possibilities. The review also serves as a foundation for the thesis framework, which adopts an urban planning theoretical perspective for analysis. The author identified relevant literature that provided indicators and factors for assessing the development of PEDs and used it to build a sustainable analysis framework that is specific to this study.

3.2.2 Site Visits and Observations

Site visits and observations occur when persons with specific expertise and preparation go to a site for a limited period of time and gather information about an evaluation object either through their own experience or through the reported experiences of others in order to prepare testimony addressing the purpose of the site visit (Lawrenz et al. 2003). The Sluppen area in Trondheim is currently undergoing significant development by policymakers and various companies, indicating that major changes can be expected in the near future (Stoltz 2023a). On-site observations are essential for researchers to understand the spatial condition of Sluppen, including the different building units and potential stakeholders. Due to the ongoing development in the area, the timeliness and accuracy of satellite images or literature data may not compare to the value of on-site observations. Furthermore, the author was able to participate in numerous on-site activities during their internship with the company. The purpose of the author's site visits and observations is as follows:

Understanding the physical environment: Site visits and observations provide an opportunity to understand the physical environment of the location where the PED is being implemented. This helps in identifying the specific challenges and opportunities that are unique to that location.

Assessing the existing infrastructure: Site visits and observations help in assessing the existing infrastructure and identifying the gaps and opportunities for improvement. This is important for designing and implementing effective solutions that are tailored to the specific needs of the location.

Engaging with stakeholders: Site visits and observations provide an opportunity to engage with the local community and other stakeholders. This helps in understanding their needs, expectations and incorporating their feedback into the planning and implementation process. Validating data and assumptions: Site visits and observations help in validating the data and assumptions that have been collected through other research methods. This helps in ensuring the accuracy and reliability of the findings and recommendations.

Identifying unintended consequences: Site visits and observations help in identifying unintended consequences that may arise from the implementation of a PED. This helps in anticipating and mitigating potential negative impacts on the local community and environment.

3.2.3 Semi-Structured Interviews

Semi-structured interviews are a type of qualitative research method that combines aspects of both structured and unstructured interviews. In semi-structured interviews, the interviewer follows a predetermined set of questions or topics while also allowing for flexibility and open-ended discussion (Brinkmann and Kvale 2015; Pasian 2015). Unlike structured interviews that have a fixed set of questions and predefined response options, semi-structured interviews provide room for participants to express their thoughts, experiences, and perspectives in more depth (Dearnley 2005; Drever 2006).

The interviewees were categorised into four divisions of stakeholders and belonged to public, private, institutional, and business stakeholders. During the interview, all respondents were asked to answer four questions: their role in Sluppen, their hope for Sluppen and what it has already achieved, their ambitions for the future and their relationship with other stakeholders. For different stakeholders, some targeted questions will also be raised as appropriate. The primary purpose of this interview is to let the interviewees narrate their own complete stories through the form of "storytelling". It encourages interviewers to invite the interviewee to tell stories. A successful interviewer manages to shift the weight of responsibility to the other in such a way that he or she willingly embraces it (Josselson and Lieblich 1995). And based on the first-hand data collected by interviews, relevant analysis work is carried out and conclusions are drawn.

Table 3: Different stakeholder categories, edited by author

Stakeholder	**The role of the interviewee**	**Number**
R. Kjeldsberg AS	Architect & Energy Engineer	2
Bryte Batteries	Battery Engineer and Sales Leader	3
NTNU	Researcher	2
Trondheim kommune	Urban Planner	2

This interview is completely anonymous, and this article does not disclose any personal information of the interviewees. The way of talks is mainly in the form of private meetings and workshops. Note taking of interview materials is permitted during the interview and will be approved by the interviewee.

3.3 Case study

Case study research is consistently described as a versatile form of qualitative inquiry most suitable for a comprehensive (J. W. Creswell et al. 2007; J. W. Creswell and J. D. Creswell 2023). It allows for an in-depth analysis of a specific case, which can provide valuable insights into the complexities and nuances of PEDs. This method allows for the examination of the interplay between different factors and actors within the case, such as the technological, social, economic, and political factors. This can help to identify the strengths and weaknesses of the case and the potential areas for improvement. The results can provide a basis for comparison and contrast with other cases, allowing for the identification of commonalities and differences across different PEDs. The author can use the case study method to evaluate the effectiveness of different interventions and strategies in promoting the development and success of PEDs.

3.3.1 Case Study of Sluppen

The case analysis for Sluppen is based on the internship activities. As Denscombe (2017) pointed out: *When a researcher wishes to analyze a topic in-depth and give an explanation that can deal with the complexity and intricacy of real-life circumstances, the case study method works well.*

Sluppen is a developing area in Trondheim, Norway that is being developed into a positive energy district (PED). The area has been designated as a "living lab" for testing and implementing various sustainable solutions, including renewable energy sources, energy-efficient buildings, and smart grid technologies. Several companies and research institutions are involved in the development of Sluppen as a PED, and the Norwegian government has provided funding and support for the project. The aim of the Sluppen PED is to create a sustainable and energy-positive district that can serve as a model for future urban developments (+CityxChange 2022; Baer et al. 2021).

Sluppen's case study is valuable. Firstly, Sluppen is a developing area of Trondheim where policymakers and various companies are vigorously promoting the concept of PEDs. This makes it an ideal case study to examine the application of battery technology and industry in promoting PEDs locally, as well as to explore the role of urban planning in achieving this goal. Secondly, as a developing area, Sluppen provides an opportunity to observe the process of PED development, including stakeholder engagement and participation, planning and design, construction, and operation. Thirdly, Sluppen's case study can serve as an example for other cities and regions interested in developing PEDs, providing insights into the challenges and opportunities of such projects. Finally, as the author of the case study had first-hand experience as an intern with a company involved in Sluppen's development, they were able to gain insights and perspectives from multiple stakeholders, including developers, planners, and residents. The case study will help answer the main research questions of the paper, see 1.4.

3.3.2 Power Interest Matrix

The Power Interest Matrix is a two-dimensional matrix with four quadrants. It is a technique used to categorise stakeholders based on their power or influence and interest in a project (Oguz 2022). It helps identify key stakeholders and prioritize engagement efforts, allowing for more effective communication and decision-making (Mendelow 1984). The stakeholder identification process starts at the beginning of the project and ends at the end of the project. Identification of stakeholders and determination of their expectations, requirements, and interests are important processes for a successful project (Kremmer 2023). In the context of researching Positive Energy Districts (PEDs), stakeholder analysis is critical for understanding the various actors and their interests in the development and implementation of PEDs. By using the Power Interest Matrix, researchers can better understand the motivations and potential actions of stakeholders, and develop strategies for engaging and managing their involvement in the project.

3.3.3 SWOT Analysis

SWOT analysis (or SWOT matrix) is a strategic planning and strategic management technique used to help a person or organization identify Strengths, Weaknesses, Opportunities, and Threats related to business competition or project planning. It is sometimes called situational assessment or situational analysis (Weihrich 1982). Performing a SWOT analysis for the development of PEDs and battery applications in Sluppen can provide a comprehensive understanding of the current state and potential future direction of the area. By identifying the strengths, weaknesses, opportunities, and threats of the area, the author can identify the strengths of the area, such as the availability of renewable energy sources and supportive government policies, which can be leveraged to promote the development of PEDs and battery applications. Additionally, the analysis can identify the weaknesses of the area, such as limited public awareness and insufficient funding, which need to be addressed to overcome challenges and barriers to development. Furthermore, the analysis can identify the opportunities that exist for PEDs and battery applications in Sluppen, such as the potential for innovative business models and collaborations between stakeholders, which can be pursued to drive sustainable urban development. Lastly, the analysis can identify the threats to the development of PEDs and battery applications, such as potential regulatory or legal obstacles, that must be considered in planning and implementing strategies.

CHAPTER
FOUR

CONTEXT OF THE CASE STUDY

4.1 Study Area

Sluppen is an area in Trondheim east of Nidelva, around 4 km south of the city centre. The area is dominated by heavy infrastructure and industry, which is to be transformed into an attractive urban area (Bratberg 1996). The buildings at Sluppen are both office buildings, industry/warehouses, apartments and a restaurant, and the total floor area is approximately 40,000 m^2 (Lauvland et al. 2023).

At Sluppen, the city is connected, both to the south and north, east and west. The main road into the center starts here and meets national roads, county roads, local roads and streets. It is important that better facilities are made for walking, cycling and public transport towards the center and Elgeseter (Stenstad 2022a).

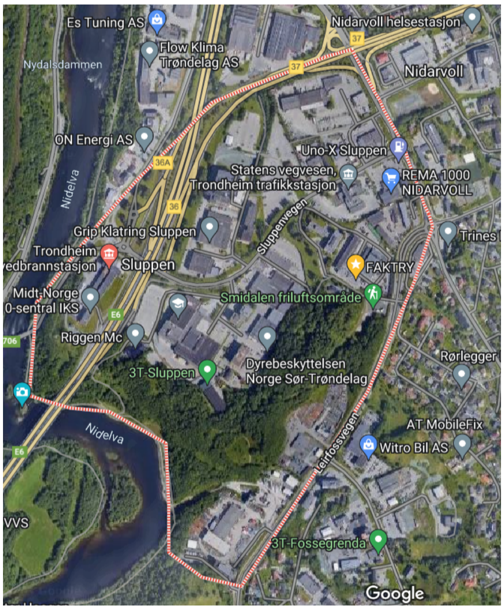

Figure 12: Sluppen location in Trondheim, map source: (Google Map) edited by author

Sluppen is part of the Trondheim Climate Action Plan. The Knowledge Axis (Kunnskapsaksen) is the area stretching from Sluppen in the south to the waterfront Brattøra/Nyhavna in the north. The area is called the "Knowledge Axis" as it is concentrated with many of the most prominent knowledge actors from research, education, industry and public sector in Trondheim. This knowledge-intensive area will be the arena of Trondheim's future growth, as a testing ground for economic, social and climate goals.(Climathon 2023)

The development within the Knowledge Axis will help to strengthen the city's position as an internationally recognized technology and knowledge city. Trondheim has a unique development potential along the axis through three concurring factors: NTNU City Campus, metro bus and large land reserves close to the city centre (Baer et al. 2020).

There are great opportunities for urban development in Sluppen. The municipal master plan shall facilitate the realization of the development potential, promote value creation and contribute to transforming Trondheim into a low-emissions society (Nord et al. 2019).

Sluppen's excellent location advantage and climate plan make this area an excellent place to study PEDs; in view of various new buildings and battery technology applications, it also makes this area a good platform to study the relationship between battery strategy and PEDs. This is also the main reason why this article chooses this place as a case study.

Figure 13: An above view of Sluppen (Stoltz 2023b)

4.2 History of Sluppen

The Sluppen was formerly a productive agricultural area south of historic Trondheim. The main building of Sluppen gård was located where Siemens is located today. At its largest, in 1917, the farm comprised 965 decares of cultivated land. The farm was an important milk supplier, and municipal agriculture was profitable from the start; later the deficits increased year by year, and in 1945 the municipality's farm operations came to an end. During the Second World War, the Nazi Germans built a large military settlement with 41 houses on 250 decares of Sluppen (Schreiner et al. 1958; Bratberg 1996). The farm was divided into industrial plots after the war, and most of the buildings were demolished. A part of the barn is still preserved. The Nidarvoll School is the oldest unit in the area which was established in 1884. The oldest building that remains on the school grounds today dates from 1904 (Rygh et al. 1898).

In 1819, the Sluppen had an area of 400 decares of cultivated land. In 1866, the cultivated area was 800 decares. When the municipality took over the farm in 1917, the total area was 965 decares (of which 700 decares was cultivated land), an area which in 1934 had been reduced to 508 decares (Bratberg 1996).

Trondheim municipality bought Sluppen in 1917. It used part of the farm as a landfill for the sewage treatment plant, and ran the rest of the farm as a larger farm at its own expense. In 1971, Sluppen began to stop being used as a landfill; in 1982, Sluppen began to be renovated, and many new office buildings began to be constructed (Marie 2023; Bratberg 1996).

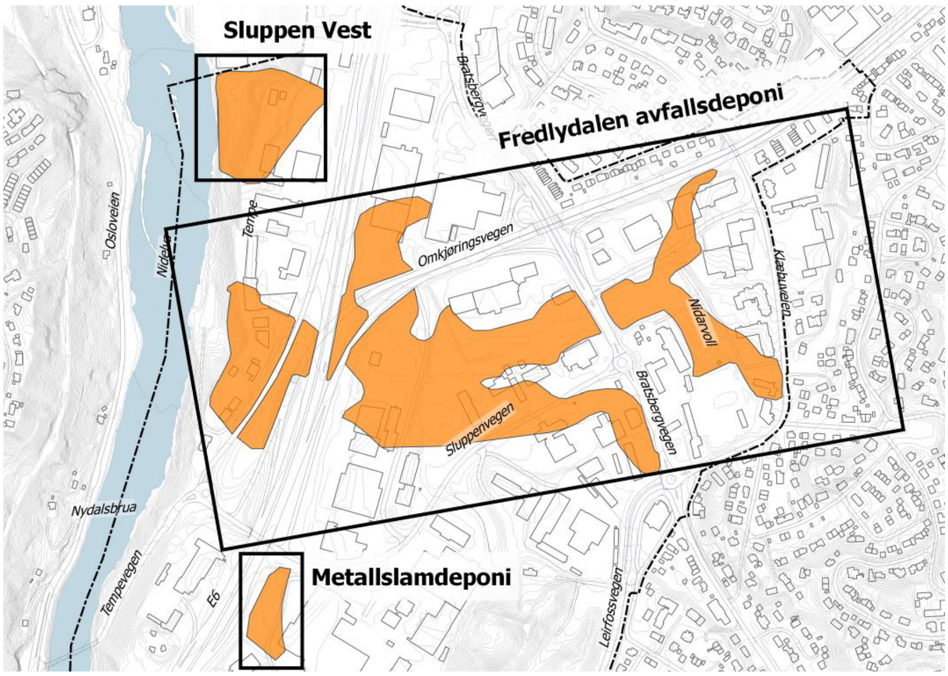

Figure 14: Old dump site (*Kommunedelplan for SLUPPEN K20210005* 2023)

Siemens Norway's branch in Trondheim is today located on the plot behind the main building and the garden. In 1961, Siemens AG purchased 69 acres of land from the Trondheim Municipality, mainly for industrial manufacturing. Local industrial activities flourished, immigrants moved in, agricultural activities gradually stopped, and the local area began to transform into an industrial zone (Brautaset and Vist 2018).

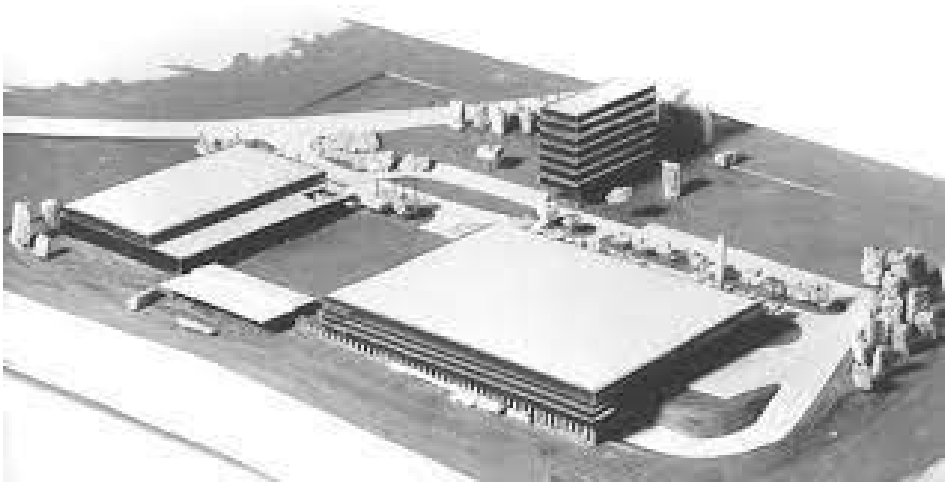

Figure 15: Design proposal for the Siemens building in the 1960s (Brautaset and Vist 2018)

As the figure on the page shows, it is the accessibility of the road network that has been the structuring element for the district since the 1960s. Siemens AS established industrial operations in 1964. Industry (industry, warehouse, eventually offices) aimed at car accessibility has dominated the area until today (Stenstad 2022b).

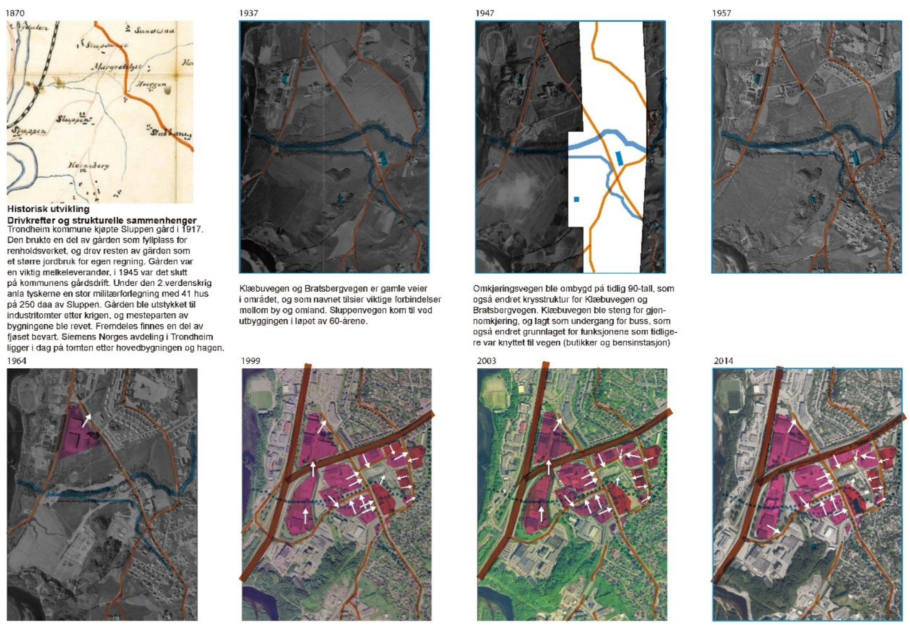

Figure 16: Historical development of Sluppen (Stenstad 2022a)

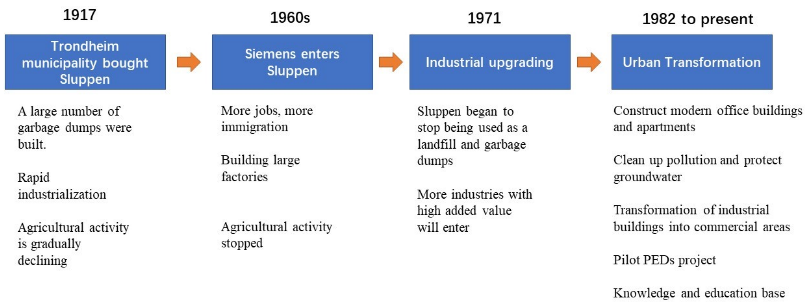

Figure 17: Timeline of Sluppen, edited by author

4.3 Related development plans and strategic plans on Sluppen

This section provides an overview of Norway's national plan for sustainable development, the Sluppen municipal sub-plan, the plan implemented by +CityxChange, and the renovation plan by Lager 11. Drawing on the author's fieldwork and observations, this section examines the current state of local energy planning and regional transformation, shedding light on the progress and initiatives in place. These plans and strategies play a significant role in shaping the development and implementation of Positive Energy Districts (PEDs) in Sluppen, contributing to its transformation into a sustainable and energy-efficient urban area.

4.3.1 Norway's action plan for sustainable development

Transition towards sustainability is probably the most important target in current urban planning. A denser urban environment, less dependent on car usage, is one of the significant characteristics of the sustainable city (Hernández-Palacio 2017). Countries and regions differ when it comes to geographic, demographic and economic situations, as well as their legal, democratic and governing systems. This again impacts what national, regional and local authorities experience as challenges when putting the SDGs into action (Satterthwaite 2017; Ascher et al. 2019). Norway already has a sustainable development plan at the national level. Through the action plan, the Government wishes to ensure that sustainable development is given a permanent place on the political agenda. The Government considers it important to link the sustainable development effort to central political processes and economic policy documents (Bondevik 2004). The strategy aims to promote sustainable practices, ensure the well-being of current and future generations, and address key challenges such as climate change, biodiversity loss, and social inequality. It provides a framework for integrating sustainable development principles into policy-making, decision-making, and implementation processes at the national, regional, and local levels. It is periodically reviewed and updated to align with international commitments, such as the United Nations' Sustainable Development Goals (SDGs). The national strategy clearly states to ensure access to affordable, reliable, sustainable and modern energy for all in urban planning; and to promote market solutions and citizen participation (Solberg 2023).

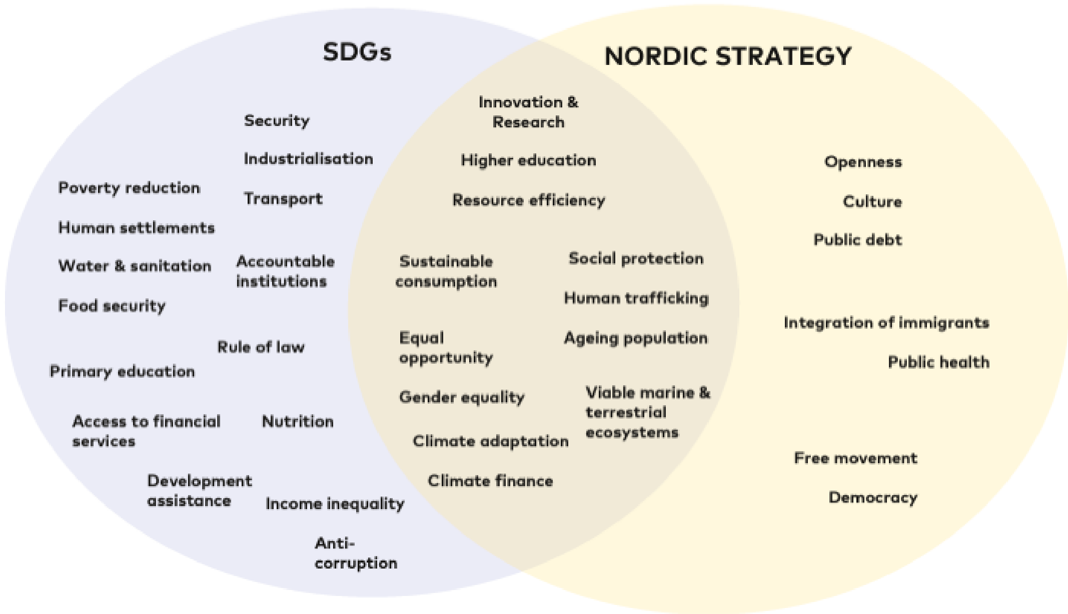

Figure 18: Comparison between SDGs and the Nordic Strategy areas (Huynh and Zelenkauskė 2023)

4.3.2 Sluppen Kommunedelplan (Municipal sub-plan)

In Norway, municipalities (a total of 356) have the principal authority to make decisions about land use. However, both regional and national authorities have a say in these processes and seek to influence local planning through national expectations, guidelines and planning provisions. At the regional level, county councils are responsible for ensuring holistic and coordinated planning across the municipalities but have no formal authority to dictate local planning. Rather, the counties seek to influence local planning through contributing knowledge, advice and guidance; but also facilitating networks and arenas for local planners, which is particularly important in small municipalities (Bardal et al. 2021).

The municipal sub-plan was processed by Trondheim Kommune on 15 June 2022. and put out for public inspection by the Bygningsrådet (Stenstad 2022a). The purpose of the plan is to facilitate sustainable urban development at Sluppen. The municipal master plan must be an effective and good management tool for further planning of the area in the short and long term, and lay down guidelines for the future development of the area (Sandberg 2019).

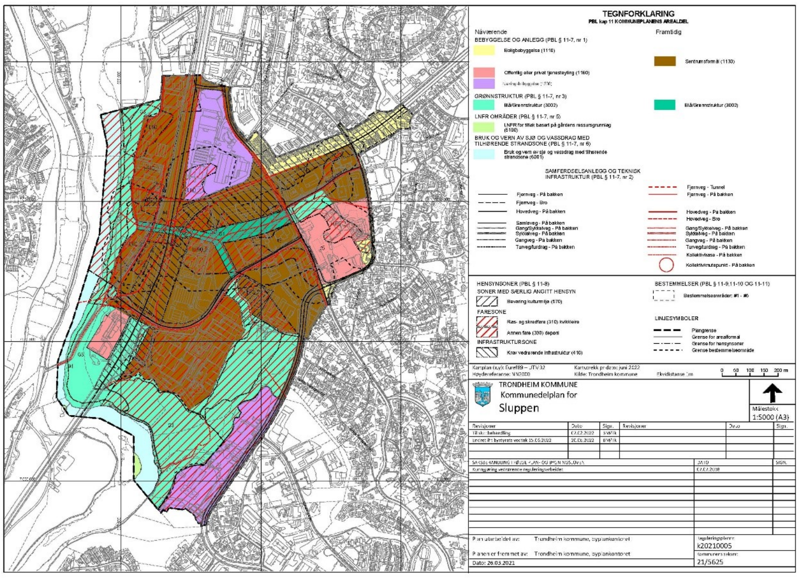

Figure 19: Kommunedelplan for Sluppen (*Kommunedelplan for SLUPPEN K20210005* 2023)

The planning proposal has three main measures for development:

- Sluppen will become a close and dense district, which facilitates pedestrians and cyclists through the design of buildings, a mix of functions, density and meeting places.
- Sluppen will become a green district, with a coherent and strengthened green structure, hiking trails and environmental ambitions.
- Sluppen will become an innovation district, where the area is secured for business and innovation is stimulated through attractive surroundings and good connections.

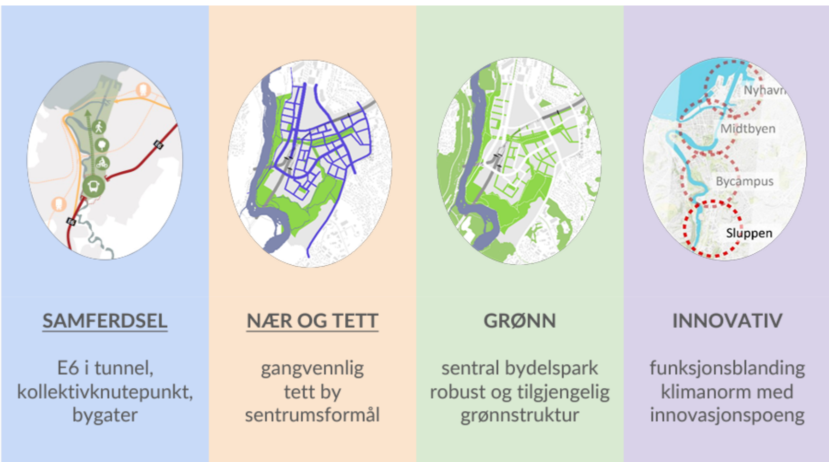

Figure 20: Four Visions for the Sluppen Municipal Subplan (Sandberg 2021)

4.3.3 Positive Energy Districts project by +CityxChange

Trondheim will develop positive energy districts. The procedure and technology that has been developed to achieve precisely this will benefit the rest of the country, and Europe. Sluppen was selected as an experimental area (Bydeler 2022). The +CityxChange is a smart city project granted funding by the European Union's Horizon 2020 research and innovation programme. Norwegian University of Science and Technology (NTNU) is the host and leads the consortium together with the Lighthouse Cities Trondheim and Limerick (*+CityxChange* 2023).

The +CityxChange project will work on the buildings in Sluppen with the aim that Sluppen will become energy positive during 2030 (Bydeler 2022). The project will achieve positive energy goals through relevant interventions in Sluppen; The buildings selected for this project are shown in Figure 21.

Figure 21: Selected Architecture for Intervention (Lauvland et al. 2023)

According to the organization's report, the following measures are planned for Sluppen: Energy efficiency measures, local energy production from PV and heat pumps, large battery storages to buffer surplus PV production and provide temporary energy storage, waste heat utilisation, sector coupling EL-thermal sector, integration of all building and local area assets onto one central management system, and establishment of local energy and flexibility markets for energy coordination, and trade of energy, capacity, and system services. The local markets are based on innovative, project-developed energy trading and flexibility market solutions. Innovative energy solutions, services, and products claim the development of new investment and business models (Lauvland et al. 2023).

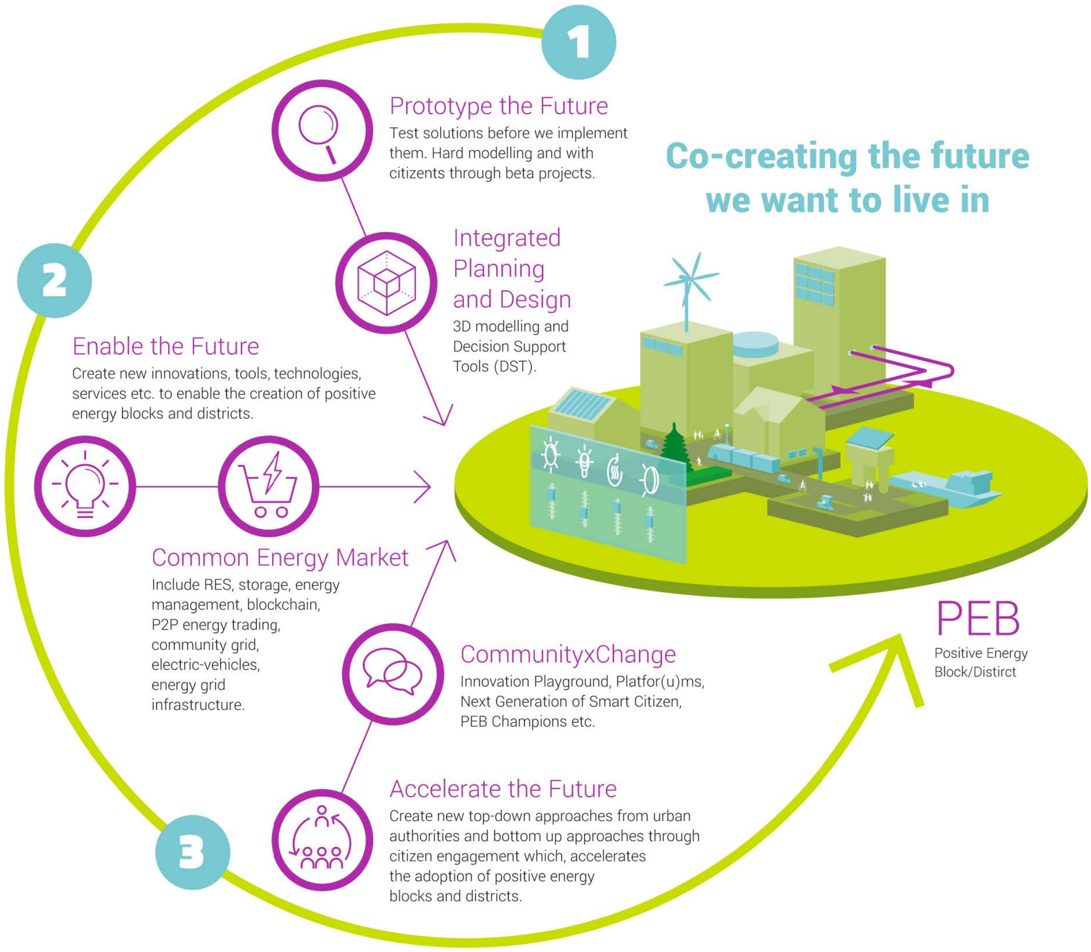

Figure 22: +CityxChange's vision and steps for building PEDs in Sluppen (Ahlers et al. 2019)

4.3.4 Lager 11 Transform and Battery Application Project

Lager11, situated in Sluppen, Trondheim, serves as a vibrant hub for food, culture, and entertainment. Lager11, situated in Sluppen, Trondheim, serves as a vibrant hub for food, culture, and entertainment. It officially opened its doors in June 2020, and real estate developer R. Kjeldsberg led the development and renovation of the building (Bjørseth 2020). The building housing Lager11 has an interesting history, having been originally constructed in 1975/76 by Siemens, a renowned industrial company, on what was then an industrial area. Initially, the building served as a storage facility for panel ovens, driven by the increased demand following the oil crisis of the 1970s. In the 2000s, it was transformed into a sports equipment warehouse for the MX Sport chain. Today, this prominent structure finds itself amidst a landscape of modern office buildings, providing a dynamic setting for hundreds of individuals who work in the vicinity (Aas 2020).

A pilot project with new, Norwegian battery technology can enable storage and usage of locally produced energy. The commercial district Sluppen in Trondheim is undergoing a huge transformation. Warehouses, parking spaces and gas stations are being transformed into a forward-looking, sustainable, zero-emission neighbourhood (Harnes 2023).

According to the data collected by the author on site, Local firm Bryte Batteries installed the 5kW/25kWh system at Lager 11. VRFB firm Pinflow provided the battery itself while Bryte will optimise it with its energy management system (EMS) platform. The project was part-funded by a state-owned company and bank Innovation Norway and the Norwegian University of Science and Technology will assess how it can be used in the flexibility markets (Murray 2023).

New technology can enable positive energy districts in the Nordics. While a lot of progress has been made in demand response and sustainable energy, users still need a cheap, safe and efficient way of storing electrical power. Until now, storage of electrical power in particular has been expensive and inefficient (Lawson 2023). The flow battery, located in the heart of Sluppen, represents an innovative energy storage solution that harnesses the power of redox reactions to store and release electricity. Unlike conventional batteries, flow batteries store energy in separate electrolyte tanks, increased power storage and service life, which allows for scalable and flexible energy storage capacity (Stead 2023). The installation of batteries in buildings makes buildings and grids interactive; buildings no longer consume electricity in one direction but increase the possibility of storing energy and delivering electricity to the grid. The internship project undertaken by the author provided an invaluable opportunity to study the application of battery technology in PEDs.

Figure 23: First flow battery installed in Norway-Lager 11, Sluppen (Author owns)

The flow battery in Lager 11, Sluppen is a cutting-edge technology that offers several advantages. One of the key benefits is its ability to store large amounts of renewable energy generated from intermittent sources such as wind and solar power (Harnes 2023). By storing excess energy during periods of high production and releasing it during times of high demand, the flow battery helps balance the supply and demand dynamics of the local energy grid.

Figure 24: Solar Panels in Sluppen (Haugan et al. 2023)

In addition to its technical capabilities, the flow battery in Sluppen serves as a living laboratory and a showcase of Norway's commitment to sustainable energy solutions. It attracts researchers, industry experts, and policymakers who are eager to explore the potential of flow battery technology and its integration into the broader energy infrastructure.

The installation of the flow battery in Sluppen demonstrates the region's ambition to become a front-runner in renewable energy and smart grid development. Various stakeholders in Sluppen collaborated to explore the impact of new battery technology on PEDs and sustainable development. It not only provides valuable insights into the performance and optimization of flow battery systems but also contributes to the ongoing research and innovation in energy storage technologies.

4.4 Power Market in Sluppen

In 1990, Norway got a new energy law that opened up the power market to competition (Hanssen 2023). This led to Norwegian consumers being among the first in the world to be able to choose their electricity supplier freely. The possibility of choosing a power supplier on the basis of price or other relevant considerations opened up competition between the power suppliers. The Nord Pool Spot power exchange was established in 1996 (Idsø 2021). This was the first power exchange in the world where power could be traded across borders. The power exchange is organized with the aim that the power should at all times go from areas with a low price to areas with a high price (Hanssen 2023; Halsnæs et al. 2021).

Electricity is different from other goods in that it cannot easily be stored. There must therefore always be an exact balance between generation and consumption. In market-based trading, the power exchange sets daily prices that give a planned balance between overall generation and consumption for every hour of the next day (Hanssen 2023).

The market price of power, which is determined each day on the Nord Pool Spot power exchange, is a result of supply and demand (Hanssen 2023). Variations in precipitation and temperature result in considerable fluctuations in power prices, both within 24-hour periods and through seasons and years. The prices also depend on transmission conditions, both between areas and countries within the Nordic region and between the Nordic region and the rest of Europe. Since there are periodic capacity limitations in the grid, power prices may vary from one area to another (Singh and Skjeret 2023).

The Norwegian Energy Act is based on the principle that electricity production and trading should be market-based, while grid operations are strictly regulated. The power market ensures that effective use of resources and reasonable prices on electricity. Electricity transmission and distribution is a natural monopoly, and not subject to competition (Hanssen 2023).

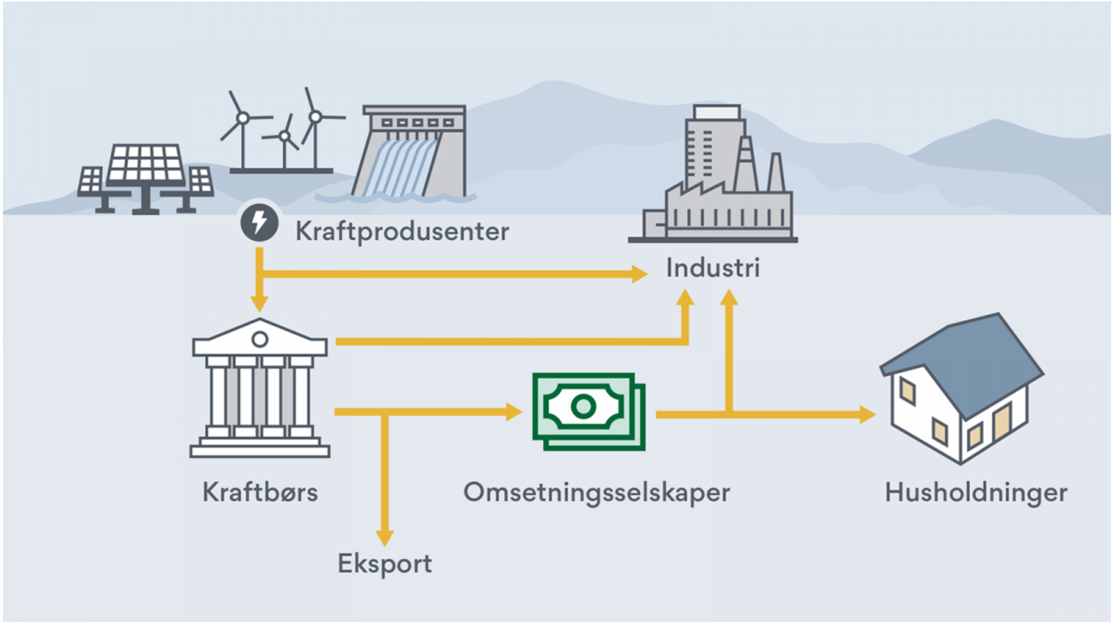

Figure 25: Operation of the Power System in Norway (Ursin 2023)

The electricity bills paid by users in Norway are divided into two parts: electricity costs and grid costs; when users consume more electricity, the pressure on the grid increases, so they have to pay more grid transmission costs (Askeland et al. 2019). Obviously, when battery technology is widely used in cities, it will greatly reduce the pressure on the power grid. The current legal obstacle is that Norwegian law does not allow to sale electricity between buildings (Olje- og energidepartementet 1991).

+CityxChange has established a local electricity market in Sluppen within the framework of the Norwegian electricity system. In the demonstration area (Sluppen) where the local energy market solution is deployed, a substantial part of the energy available locally is not utilized, and substantial shares of this energy are available within short time windows only and will be available as a traded product on the local energy market. A scalable and efficient PEDs is thus - as Trondheim sees it - dependent on systems and solutions being able to utilize this flexibility in order to obtain a balance between local production/utilization of renewables and local energy consumption. The solution is deployed and digitally integrated to become the local energy market system as planned (Danielsen et al. 2022).

This process involves the establishment and demonstration of various incentives aimed at determining the market-driven value of flexibility and other local renewable resources, thereby supporting and enhancing this process. The goal is to design, develop, and implement a fully digitalized local market that serves as an arena for showcasing and testing the project's scope and plan. Through this initiative, the Sluppen project aims to showcase the benefits and potential of a localized market environment, where participants can actively engage in trading and optimizing the use of renewable energy resources and flexibility measures (Danielsen et al. 2022).

The deployment of the Local Energy Market in the Trondheim case consists of two separate tasks: (Danielsen et al. 2022).

A. Deployment of the software as a cloud-based solution, including all necessary building blocks.

B. Deployment of the market operation, including onboarding of all the physical energy assets within the PEB, configuration of market participation, and dispatching. The deployment includes that assets are connected physically and digitally to the market.

The value of the Sluppen project lies in its inclusive approach, involving all participants in the market operations to build trust and generate interest. One of the key objectives is to explain the functioning of the market, ensuring transparency and clarity for all stakeholders. Additionally, the project aims to develop comprehensive market reporting mechanisms that provide valuable insights and information to the participants. By fostering open communication and providing relevant data, the project seeks to enhance the participants' understanding of market dynamics, enabling them to make informed decisions and actively participate in market activities.

CHAPTER
FIVE

CASE ANALYSIS AND RESULTS

This chapter analyzes the results and data obtained by the author in the internship work, and clarifies the importance of data. It delves into the role of battery technology in the development of Positive Energy Districts (PEDs) in the Sluppen region. Drawing upon the theoretical framework established in Section 2.2, the authors assess the research subjects, evaluating their effectiveness and implications within the context of PEDs. The findings shed light on the contribution of battery technology to the sustainable and energy-efficient aspects of PED construction, highlighting its potential to enhance energy management, storage, and distribution systems. Through a comprehensive evaluation, this chapter underscores the importance of integrating battery technology into PED projects, emphasizing its role in achieving the envisioned objectives of sustainable urban planning and development.

5.1 Data Visualization for Battery Systems in Sluppen

Lager 11, which used to be an industrial factory and warehouse, is now transformed into a commercial centre and joint workshop. Ample interior space and the power system are relatively chaotic; it has been used as an industrial area for a long time in history and has not been particularly well maintained. There is still a lot of informality in this building, for example, previous users have built many private electricity networks. This leads to difficulties in selecting meters and data.

In this project, the battery was installed in February 2023 by Bryte Batteries. Since the pre-test took two months, the battery did not operate stably in February and March. The battery officially started stable operation in April. There are three rooms with energy systems connected to the battery in Lager11, these three areas have independent electricity meters that can collect data. In the legend of the figure below, Room 1 and Room 2 are two offices inside the Lager11 building, and Room 3 is the food court inside Lager11. Room 1 is the area where the battery gives priority to the power supply. Only when the battery meets the needs of Room 1 will it supply power to Room 2 and 3.

The author collaborates with Bryte Batteries and R. Kjeldsberg AS to monitor and read hourly electricity usage data from electricity meters. Data sampling covers all data from 2020 to April 2023. Electricity consumption data is visualized using Matlab.

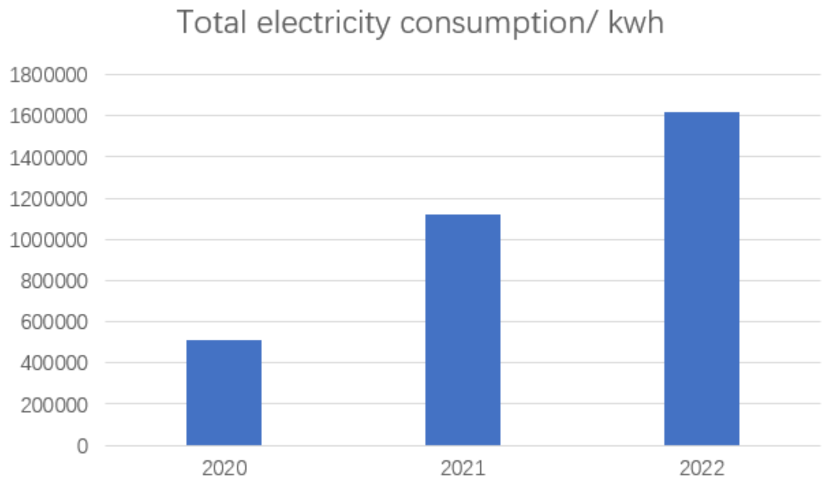

Figure 26: Total electricity consumption data from 2020 to 2022, edited by author

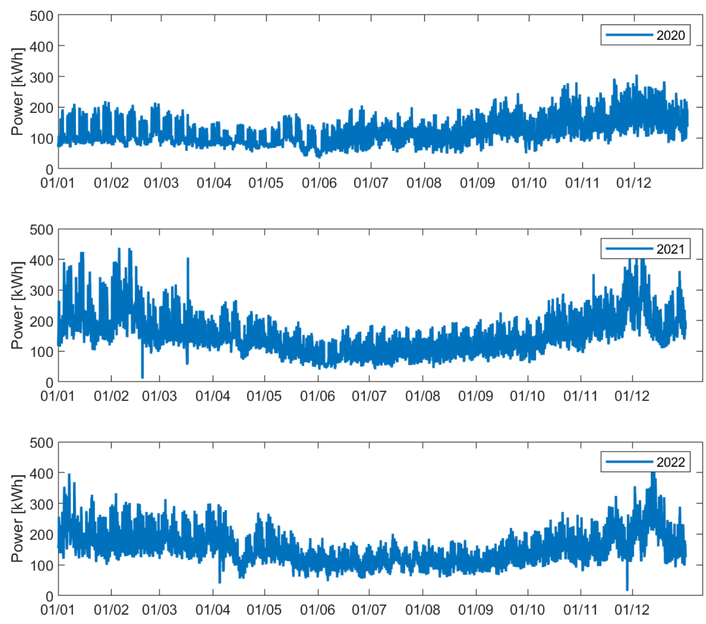

Figure 27: Line chart of power consumption change, edited by author

The electricity consumption data from 2020 to 2022 are shown in the figure above.

Electricity consumption is increasing every year, but the growth rate in 2021 is very large. After investigation, this was caused by the COVID-19 pandemic; many shops were closed during the pandemic, and users decreased. In 2021, Norway gradually opened its borders and lifted the social restriction, so users increased and electricity consumption increased sharply. As Sluppen is a growing area, therefore, the author speculates that the total electricity consumption in 2023 will still increase. Undoubtedly, this will put a lot of pressure on the grid. Since my internship ends in June 2023, I cannot obtain complete data for 2023. Based on the data from January to April 2023, the author made a line chart of the change in electricity consumption according to time.

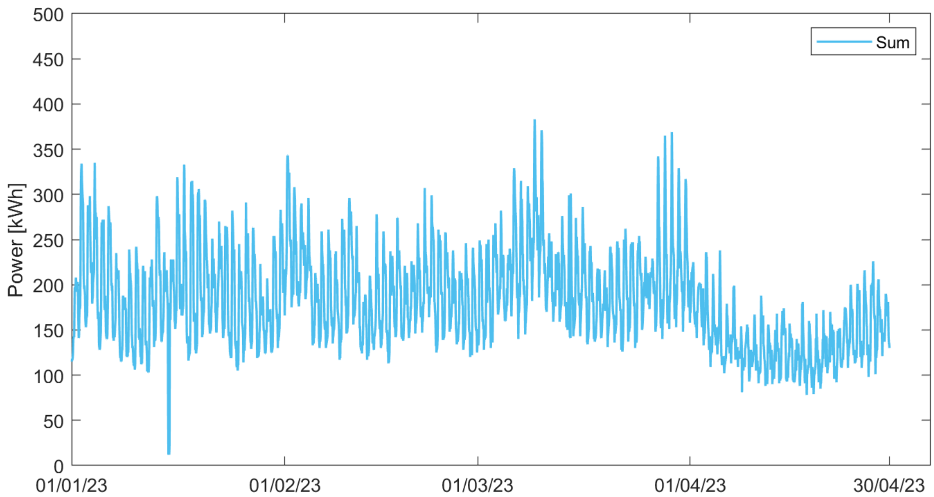

Figure 28: Total electricity consumption data in 2023, January-April, edited by author

It can be seen from the figure 28 that after April, the electricity consumption data is obviously more stable, and the peak was reduced. But at this time, it is impossible to determine which room's peak power consumption decline caused the total power consumption peak decline in April. To delve deeper, the authors visualized electricity usage data for three separate spatial units within the area.

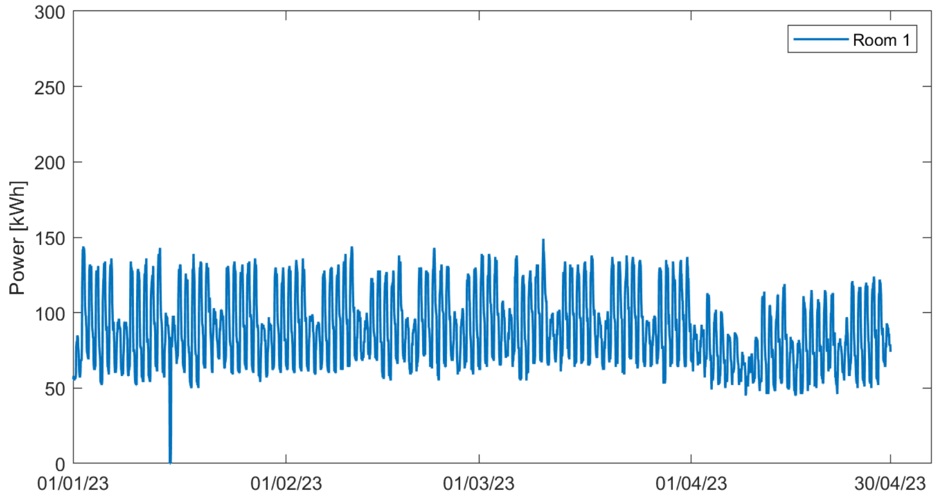

Figure 29: Electricity consumption data of room 1 in 2023, January-April, edited by author

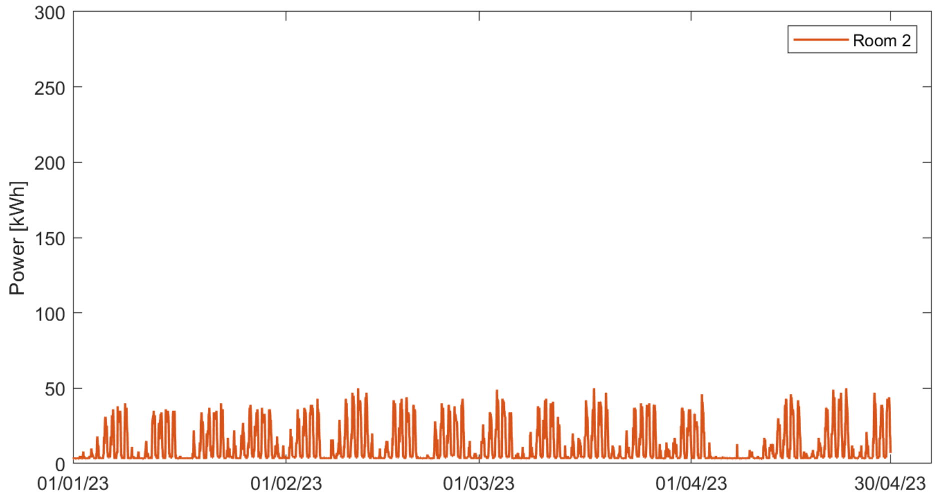

Figure 30: Electricity consumption data of room 2 in 2023, January-April, edited by author

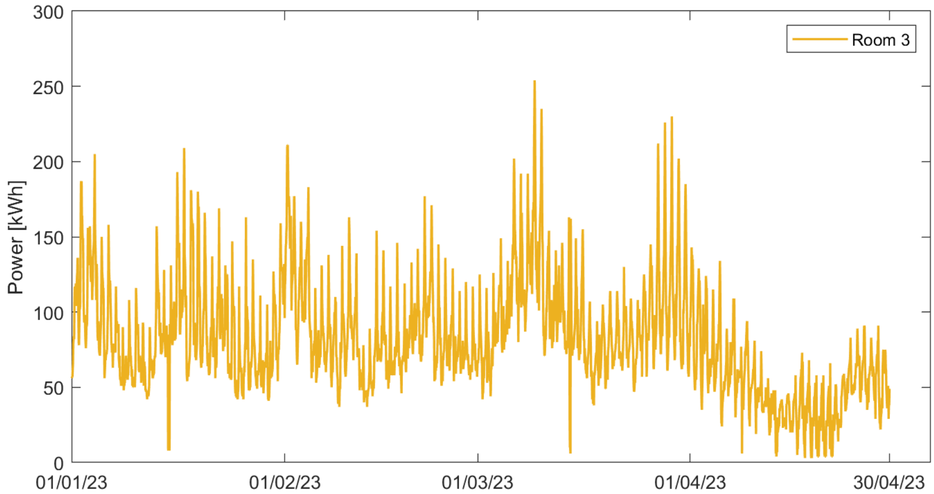

Figure 31: Electricity consumption data of room 3 in 2023, January-April, edited by author

As can be seen from all the figures above, the electricity consumption data of room 1 in April are significantly more stable, with lower peaks. After investigation, room 1 is an office, which is also the area where the flow battery mainly provides services. The synthesis of the above data is shown in the figure below.The peak in room 3 (food court) also dropped significantly in April, but this room is not an area where battery power is prioritized, so it cannot be definitively proved that it is the battery. This article will be discussed in depth in Section 6.2.

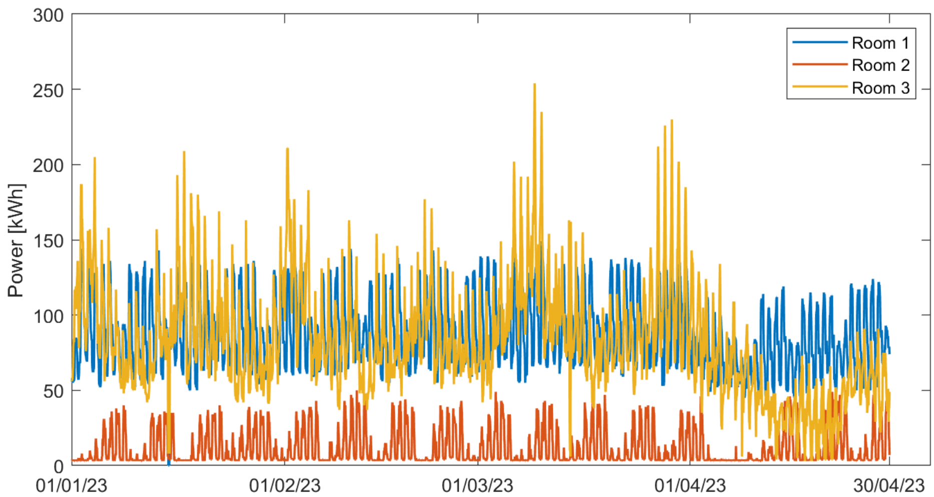

Figure 32: Electricity consumption data of room 1-3 in 2023, January-April, edited by author

In order to verify the year-on-year data, the author visualizes the data from 2020-2022 and selects the total power consumption data from January to April.

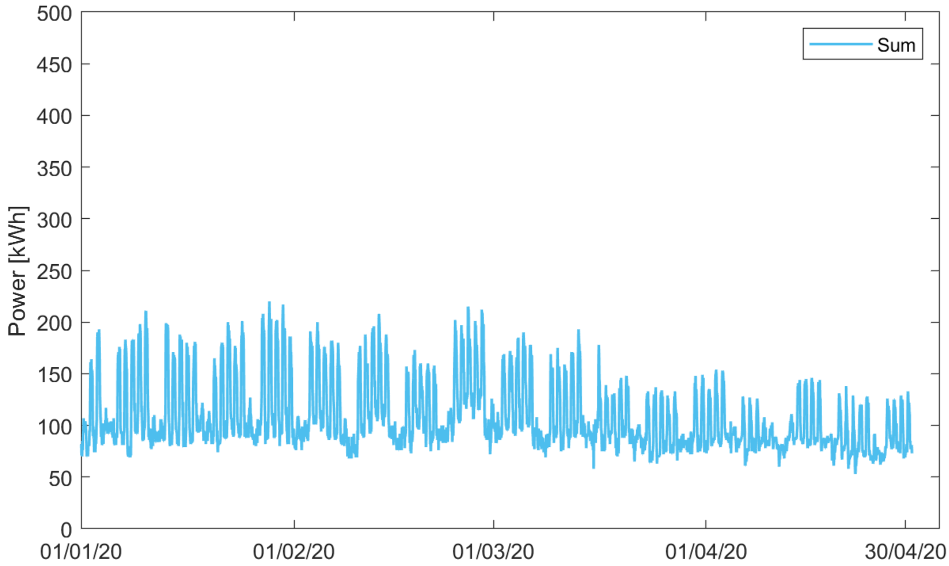

Figure 33: Total electricity consumption data in 2020, January-April, edited by author

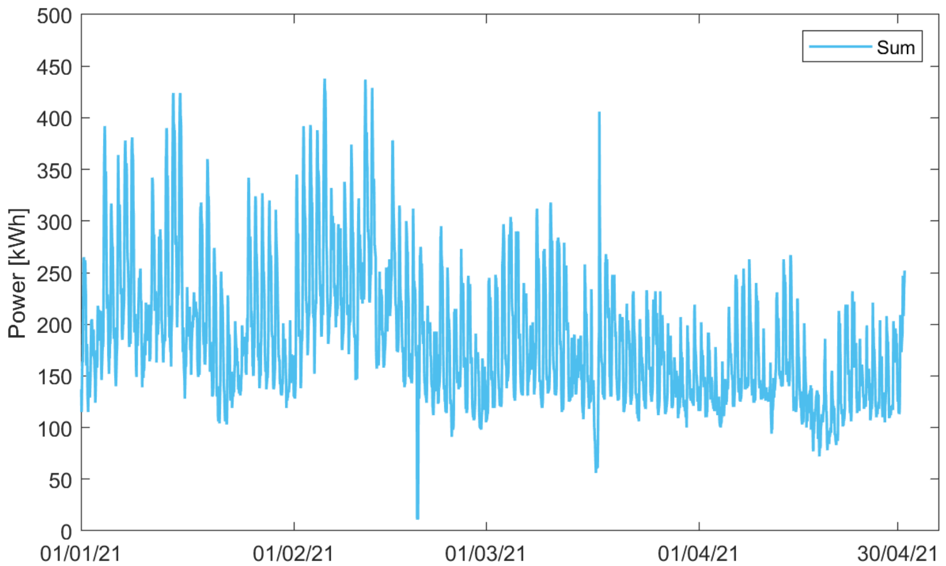

Figure 34: Total electricity consumption data in 2021, January-April, edited by author

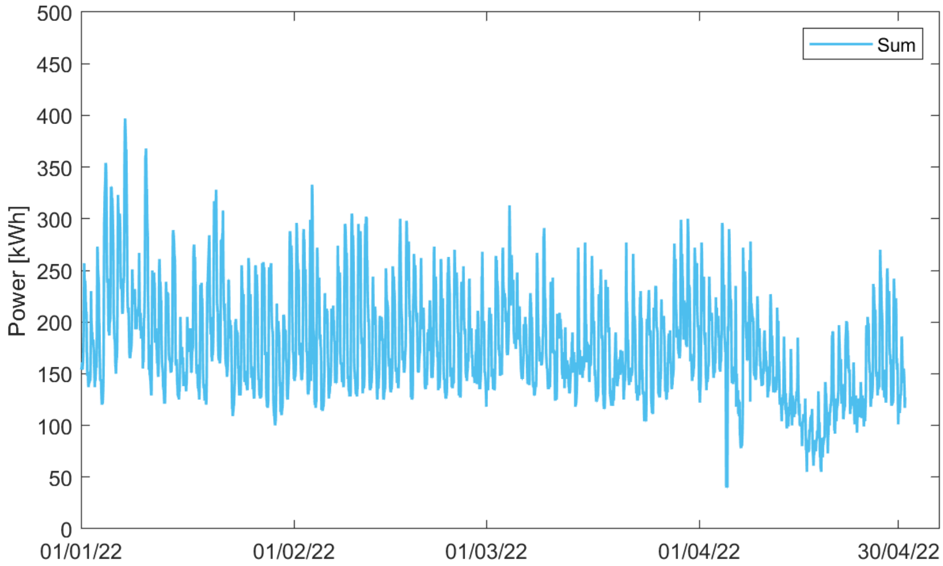

Figure 35: Total electricity consumption data in 2022, January-April, edited by author

The above data results show that after the installation of flow batteries in buildings, peak power consumption can be reduced. But beyond a specific value, the role of the battery is limited; this means that the installed capacity of the battery should match the expected power consumption data. Batteries make it possible for building units to store electricity, so energy sources like solar and wind will have the opportunity to be stored and interact with the grid. Battery technology will become one of the technical cores of building PEDs, because it can technically realize the storage of clean energy and achieve the vision of interaction between energy systems. The above content will help to answer the first research question of this paper.

5.2 Sustainability Analysis- Environmental

5.2.1 Livability

Livability is a measurement of how attractive a neighborhood, city and/or region is for people based on a variety of factors (Musinski and Witkowski 2023). A livable place is safe, clean, beautiful, economically vital, affordable to a diverse population and efficiently administered, with functional infrastructure, interesting cultural activities and institutions, ample parks, effective public transportation and broad opportunities for employment (Balsas 2004). It also connotes a sense of community (Kaal 2011).

One of the primary impacts of using flow battery technology in Sluppen PEDs is the improved reliability and stability of the energy supply. Flow batteries provide a reliable source of energy storage, allowing for efficient management and distribution of electricity within the district. This mitigates the risk of power outages and ensures a continuous and uninterrupted energy supply to residents and businesses. As a result, the daily lives of individuals living in PEDs are less disrupted, and the reliability of essentials is enhanced(Agostino et al. 2015).

This article measures livability by providing a level of quality of life, combined with interviews and reports from various stakeholders. In the interviews for this paper, various stakeholders were satisfied with the project. The owner of the property believes that the use of battery technology reduces operating costs and is conducive to attracting businesses to settle in; the municipality believes that this strategy can improve local energy stability and provide reference value for the establishment of successful PEDs in the future. Sluppen was once an industrial area and a landfill. By using innovative technology and promoting the concept of PEDs, the local area has improved its reputation, improved the environment, and finally achieved improved livability.

5.2.2 Public and Green Space

The integration of flow battery technology in Positive Energy Districts (PEDs) can help renew local landscapes and planning. During the internship work, according to the reports and symposiums of the property owners, the promotion of PEDs technology will help reduce the need for new power grids; more public spaces can be opened to the public. Property owners are willing to invest the saved funds in the construction of public space and green space. During the internship, the author and the company's engineers jointly studied a case in Vienna, where localized PEDs were built relying on geothermal energy, and more green spaces and public spaces were developed in public areas (Hofbauer et al. 2023).

5.2.3 Pollution

The implementation of flow battery technology in Positive Energy Districts (PEDs) can have a significant impact on reducing pollution and improving environmental conditions. By addressing pollution associated with conventional energy sources and optimising the utilisation of renewable energy, flow batteries contribute to a cleaner and more sustainable energy system. Battery energy storage technology can store unstable clean energy such as solar and wind energy, indirectly reducing carbon emissions.

The integration of flow battery technology in PEDs can reduce noise pollution. Flow batteries operate silently, not relying on mechanical moving parts. This absence of noise pollution enhances the overall livability and comfort of the community, particularly in densely populated urban areas where noise can be a significant concern. Since the battery is stored in the basement of Lager11, there is almost no noise and waste heat, so the impact on the environment is minimal and does not affect residents and users living nearby. The municipality is very concerned about pollution in the Sluppen area, regularly checking the soil and water quality in the area, which was once used as a landfill. During the internship, no damage or pollution of the soil and water sources by the flow battery was found.

5.3 Sustainability Analysis- Economical

5.3.1 Local Energy Cost

The implementation of flow battery technology in Positive Energy Districts (PEDs) can have a significant impact on local energy costs, bringing about various improvements and benefits for residents and the community as a whole. This paper will delve into the implications of flow battery technology on local energy costs and explore its potential advantages.

One of the primary impacts of using flow battery technology in PEDs is the potential reduction in energy costs for residents. By incorporating flow batteries into the district's energy infrastructure, excess energy generated from renewable sources during periods of low demand can be stored for later use. This stored energy can then be deployed during peak demand periods, helping to offset the need to purchase electricity from the grid when prices are typically higher. The ability to shift energy consumption to times when electricity rates are lower can lead to cost savings for both individual households and the community at large.

In addition to cost savings, flow battery technology can enhance energy resilience and mitigate the impacts of power outages or disruptions. In PEDs, where the focus is on localized energy production and consumption, having a reliable and continuous energy supply is of utmost importance. Flow batteries can provide backup power during outages, ensuring that critical infrastructure and essential services within the district remain operational. This ability to store and deliver electricity when needed helps to avoid potential financial losses associated with power interruptions and enhances the overall energy reliability for residents.

Moreover, the adoption of flow battery technology can support demand response initiatives in PEDs, further contributing to local energy cost optimization. Demand response programs incentivize consumers to adjust their energy consumption patterns in response to grid conditions or price signals. With the flexibility offered by flow batteries, residents can actively participate in demand response schemes by storing energy during periods of low demand and discharging it during times of high demand. By shifting energy consumption away from peak periods, residents can take advantage of lower energy rates and potentially reduce their overall energy costs.

5.3.2 Job Creation

The implementation of flow battery technology in Positive Energy Districts (PEDs) not only brings environmental benefits but also has a significant impact on job creation and economic development. By fostering the adoption of renewable energy sources and supporting the growth of the energy storage industry, flow batteries contribute to the expansion of employment opportunities and the stimulation of local economies.

One of the key impacts of using flow battery technology in PEDs is the creation of jobs in the renewable energy sector. The installation, operation, and maintenance of flow battery systems require skilled labor, providing employment opportunities for engineers, technicians, and other professionals specialized in energy storage technologies.(Valstad et al. 2020) Sluppen, as a project participating in the construction of PEDs, has attracted start-up technology companies such as Bryte Batteries to settle in, which is conducive to forming economies of agglomeration economically.To quote a reply from Bryte Batteries: "We have many partners who would like to work jointly at Sluppen in the future. We also plan to hire more engineers and hope to recruit excellent PhD from universities as R&D personnel."

The development of the flow battery industry and the associated renewable energy infrastructure can act as a catalyst for economic revitalization, transforming previously underutilized or economically stagnant areas into vibrant and thriving communities. In an interview, R. Kjeldsberg, owner of Lager 11, believes that battery technology and the concept of PEDs are very helpful for the urban transformation of the Sluppen.To quote one of the interviewees: “Although this battery and PEDs are in the early stages, we can already see the economic potential. This is an industrial area renovation project, and the battery can optimize the grid and infrastructure. We will upgrade and renovate this place in the future, and attract more merchants to settle in.”

5.3.3 Housing Price

The localization of PEDs and the use of new technologies will have many impacts on housing prices.The integration of flow batteries into PEDs introduces several improvements that can influence housing prices and shape the future of real estate.

One of the primary impacts of flow battery technology on housing prices is the potential for reduced energy costs. By efficiently storing and utilizing renewable energy, flow batteries can help balance energy supply and demand within PEDs. This results in lower energy expenses for households, making living in PEDs more affordable. Reduced energy costs can positively impact housing affordability and attract potential homebuyers or tenants to PEDs.

The integration of flow battery technology enhances the overall desirability and market value of properties in PEDs. Flow batteries contribute to the energy efficiency and sustainability of the district, making properties more attractive to homebuyers and tenants. In an era where environmental considerations are paramount, properties equipped with flow battery systems hold an advantage in the real estate market. In R. Kjeldsberg's seminar and interview, the planner revealed that the adoption of new technologies will make the company consider apportioning investment costs and operating costs to the expenses of users and tenants.The potential for lower energy bills and reduced carbon footprint can make these properties more desirable and command higher prices. The demand for sustainable and energy-efficient housing options is on the rise, and PEDs with flow battery technology can fulfill this demand, potentially leading to increased housing prices in the long term.

In addition to the direct impact on housing prices, the construction of PEDs itself can have implications for future housing prices and the real estate market. As PEDs are developed, they often undergo significant transformations that include the construction of sustainable infrastructure, the implementation of renewable energy systems, and the creation of green spaces and amenities. These developments can significantly enhance the appeal and quality of the living environment within PEDs, making them highly desirable places to live.

The amenities and infrastructure built as part of PEDs, such as parks, community centers, and sustainable transportation options, can attract residents and create a sense of place. The overall livability and quality of life within PEDs can be major selling points for potential homebuyers or tenants, and this increased demand can impact housing prices positively.

Additionally, the construction of PEDs can have a spillover effect on the surrounding areas. The development of a sustainable district can spur economic growth, attract businesses, and stimulate job creation. The increased economic activity in the vicinity of PEDs can lead to a higher demand for housing, which may extend beyond the boundaries of the district. As a result, housing prices in the surrounding areas can also experience positive effects.

However, it is important to note that the impact on housing prices and the real estate market will depend on various factors, including location, market conditions, and the overall success of the PEDs. The integration of flow battery technology alone may not be the sole determinant of housing price appreciation. Other factors such as market trends, supply and demand dynamics, and external economic factors will also influence housing prices in PEDs and the broader real estate market.

5.4 Sustainability Analysis- Social

5.4.1 Stakeholder Engagement

The level of stakeholder engagement in Sluppen can be considered relatively high due to the collaborative and participatory approach adopted in the project. Various stakeholders, including academic institutions, energy providers, and public authorities, have been actively involved in the planning and development process.

Stakeholder engagement in Sluppen is characterized by open dialogue, consultation, and participation in decision-making. Regular meetings, workshops, and consultations have been conducted to gather input, share information, and address stakeholders' concerns and interests. This inclusive approach has ensured that stakeholders have a voice in shaping the development of the PED and have the opportunity to contribute their knowledge, expertise, and perspectives.

The real estate developer has demonstrated a high level of engagement in the project. They have actively participated in stakeholder meetings, provided input on design choices, and collaborated with other stakeholders to align interests and ensure the project's success. Their financial and operational involvement further emphasizes their commitment to the project's outcomes and the importance they place on stakeholder engagement.

Local residents and community groups have also shown a high level of engagement in Sluppen. Their participation in workshops, consultations, and public meetings has allowed them to express their views, raise concerns, and contribute to decision-making processes. The project has made efforts to ensure that the perspectives and needs of the local community are considered in the planning and development of the PED. This level of engagement fosters a sense of ownership and empowerment among residents, promoting a more inclusive and sustainable development process.

Academic institutions have also been actively engaged in the project, providing research, expertise, and knowledge sharing. Their involvement has enriched the stakeholder engagement process by bringing evidence-based approaches, best practices, and innovative ideas to the table. The collaboration between academic institutions and other stakeholders has contributed to a higher level of engagement, ensuring that the project benefits from a multidisciplinary perspective and the latest advancements in urban planning and sustainable development.

Energy providers, as critical stakeholders, have demonstrated a high level of engagement in Sluppen. Their expertise and experience in energy systems have been instrumental in developing and implementing the necessary infrastructure for the PED. The collaboration between energy providers and other stakeholders has facilitated the integration of renewable energy sources, including the utilization of battery technology, to ensure a sustainable and reliable energy supply in the district.

Public authorities have also shown a strong level of engagement in Sluppen, providing the necessary regulatory frameworks, permits, and policies to support the project. Their involvement has ensured compliance with legal requirements, alignment with regional development plans, and the consideration of public interest in the decision-making processes. The engagement of public authorities enhances the legitimacy and credibility of the stakeholder engagement process.

5.4.2 Gentrification

The utilization of flow battery technology in Positive Energy Districts (PEDs) can have complex and multifaceted impacts on gentrification, housing prices, and the real estate market. Gentrification is a process characterized by the influx of more affluent residents, the displacement of existing communities, and changes in the socioeconomic fabric of an area (Atkinson and Bridge 2008). Technology clusters drive innovation and economic growth, but also cause income segregation (Gaetani 2023). The introduction of new technologies often attracts investment and development, leading to increased property values and changes in the socio-economic composition of neighborhoods (Carolan 2019). The construction of PEDs and the integration of flow battery technology can potentially contribute to gentrification dynamics, but their specific impact depends on various factors and how they are managed.

One potential impact of PEDs and flow battery technology on gentrification is the transformation of neighborhoods into attractive and desirable places to live. The implementation of sustainable infrastructure, renewable energy systems, and improved amenities can enhance the overall quality of life within PEDs. These improvements may attract wealthier individuals or households looking for sustainable and energy-efficient housing options. As a result, the demand for housing within PEDs could increase, potentially leading to rising housing prices and the displacement of lower-income residents.

The construction of PEDs and the presence of flow battery technology can also stimulate economic growth and create job opportunities. The development and operation of sustainable energy projects and the associated industries can generate employment and attract businesses to the area. In the interview and practical work, the interviewee of R. Kjeldsberg AS said that the company has taken various measures to attract capital investment.This economic growth may lead to increased property values and potentially accelerate gentrification processes. As property values rise, existing residents, particularly those with lower incomes, may face challenges in affording housing and may be forced to relocate.

In interviews, though, the municipality and R. Kjeldsberg AS denied the possibility of gentrifying effects of building PEDs and using new technologies. But because their strategic goals are largely to pursue profit and ensure that their own property increases in value, the result of a series of moves is likely to cause local rents to increase and users to move out.

One example is Nedre Elvehavn's renewal project. The renovation of the area is led by R. Kjeldsberg AS (Bjørseth 2018). At present, the area has become a recognized gentrification area, and most of the original community residents have moved out. The construction of the commercial center has made Nearby land prices rose (Sager 2014). It makes a stretch of the wharfside very narrow and uninviting, and until 2013, it excluded the general public even from the ground floor (Lundemo 2023). Sluppen, as similar to Nedre Elvehavn, also has industrial heritage and urban in Transformation areas, it is very necessary to consider the risk of gentrification after the adoption of new technologies and concepts.

5.5 Interview results

5.5.1 Interview with R. Kjeldsberg AS

R. Kjeldsberg AS, as a local real estate developer, plays a significant role in the development and transformation of Sluppen. Their ownership of numerous properties in the area positions them as key stakeholders with a vested interest in the success of Sluppen as a positive energy district (PED).

The role of R. Kjeldsberg AS in Sluppen revolves around their involvement in the redevelopment and revitalization of properties in the district. Interviewees felt that, with their expertise in real estate development, they had the potential to shape Sluppen's built environment, incorporating innovative technologies and design principles that support the goals of the PED.

Interviewees from R. Kjeldsberg AS's hope and achievements for Sluppen are multifaceted. Firstly, they aim to create a vibrant and attractive urban environment that meets the needs and aspirations of residents, businesses, and visitors. By incorporating energy-efficient features and sustainable practices in their property developments, they seek to enhance the overall livability and quality of life in Sluppen. They have carried out many effective urban transformation projects in Sluppen, such as transforming Lager11 from a warehouse to a commercial centre. From an energy perspective, R. Kjeldsberg AS likely aspires to contribute to the establishment of a self-sufficient and environmentally friendly energy system in Sluppen. By integrating renewable energy sources and energy storage solutions, such as batteries, into their properties, they can support the PED's goal of producing more energy than it consumes. This achievement would position R. Kjeldsberg AS as a leader in sustainable real estate development and demonstrate their commitment to reducing carbon emissions and mitigating the impact of climate change.

The interviewees stated that they want to find solutions based on profitability and market orientation. They hope to increase the value of the property they own, and hope to make all the projects they renovate more upscale and attract merchants to settle in. Profit is the most important goal of their daily work. The energy designer said that because his company is a company with very strong financial resources, it did not pay special attention to energy saving when formulating development plans. For the promotion of battery technology and PEDs, the stakeholder's most important expectation is to enhance his own reputation and the value of the corresponding property. Quoting an original sentence in the interview: *"We have not deliberately reduced energy consumption, and our main purpose of using new technologies is also for profit. We hope to use batteries and PEDs to increase our reputation and enhance our contribution to sustainable development, and We have the opportunity to cooperate with other partners to increase our business opportunities. To be honest, we really don't pay much attention to the local residents and their opinions."*

In terms of ambitions for the future, R. Kjeldsberg AS may envision expanding their portfolio of sustainable properties in Sluppen and further contributing to its growth as a thriving PED. They may seek opportunities to collaborate with other stakeholders, including local authorities, energy providers, research institutions, and community organizations, to collectively drive the development and success of Sluppen.

5.5.2 Interview with Bryte Batteries

Bryte Batteries is a startup company in Sluppen. Its role in Sluppen revolves around providing and maintaining batteries, particularly flow batteries, which have been installed at Lager11, making it the first of its kind in Norway. This installation represents a major milestone in the integration of sustainable energy solutions in the district.

The interviewees stated that the company's primary objective and hope for Sluppen is to support its transition towards a sustainable and energy-efficient community. By providing high-quality batteries and reliable maintenance services, Bryte Batteries aim to facilitate the optimal utilization of renewable energy sources and enhance the energy resilience of the district. To quote the original text of the interview: *"Through our innovative battery technologies, we aspire to contribute to the achievement of Sluppen's positive energy goals, where the community generates more energy than it consumes."*

According to the marketing executives interviewed, the company's most important goal at present is profit. Companies are very keen to sell more batteries, and they hope to get financial support from banks or social institutions. Quoting the subjective words of market sales: *"As a start-up company, we hope to contribute to the transformation and sustainable development of Sluppen. However, since the initial investment of liquid flow batteries is relatively large, we hope that in the future, we can obtain funds from banks, etc. Loans or grants from institutions. Our business strategy is unquestionably market-oriented."*Bryte Batteries may face challenges in demonstrating the financial viability and return on investment for their battery solutions, particularly in the context of Sluppen. They need to work closely with stakeholders, such as local governments and investors, to develop innovative financing models and secure funding for their projects.

Their ambitions for the future extend beyond the borders of Sluppen. The envision expanding their operations and installations to other positive energy districts and sustainable urban developments. To quote the original text of the interview: *"We aim to be a leading provider of battery solutions not only in Norway but also internationally, contributing to the global transition towards a clean and sustainable energy future."* Bryte Batteries held many exchange meetings and creative workshops in 2023, and they invited many local residents and businesses to participate in the discussions. The main purpose of this purpose is advertising, which is used to promote products to potential customers and increase the company's popularity.But in terms of stakeholder management, Bryte Batteries expressed its own limitations. They don't have a lot of assets locally, and the company has a lot of ongoing projects elsewhere, the company need to coordinate their own resources into different projects. Therefore, they do not have particularly great influence and authority over the planning and development of Sluppen.

5.5.3 Interview with NTNU

NTNU is the host and leads for the +CityxChange project. As an academic institution, NTNU can contribute their research capabilities, technical expertise, and knowledge to support sustainable urban planning and the integration of innovative technologies. They may collaborate with stakeholders such as the municipality, real estate developers, and energy companies to provide scientific insights, data analysis, and modelling expertise that can inform decision-making processes in Sluppen.

The author selected researchers of NTNU related to the +CityxChange project and PEDs as interviewees. According to the interview results, NTNU has carried out many scientific research projects in Sluppen, especially the exploration of the localization path of PEDs.In terms of hopes and achievements for Sluppen, the interviewee want to aspire to create a living laboratory where research, innovation, and sustainable practices converge. To quote the original text of the interview: *"We aim to demonstrate the feasibility and effectiveness of various technologies, strategies, and policies in achieving positive energy outcomes, urban resilience, and environmental sustainability. By actively participating in Sluppen's development, NTNU can showcase the practical applications of our research findings and contribute to the advancement of sustainable urban planning practices."*

Interviewees of NTNU are not very utilitarian and market-oriented about Sluppen's projects and development. So far they are not under pressure from academic budgets. NTNU is not a decision-making body and has no power to intervene directly in urban planning policies. Quoting the interviewee's original text: *"We cannot directly influence policy decisions; we only provide academic support for various stakeholders, such as providing analysis reports. Profitability and market* *orientation are only part of our analysis, and we will also Combine some values and theories."*

Looking towards the future, NTNU's ambitions include expanding their research endeavors in Sluppen and exploring new areas of collaboration. They may seek to develop interdisciplinary research projects, involving multiple faculties and departments, to address complex challenges in energy, environment, and urban development. Furthermore, based on the interview result, the researchers aim to foster stronger connections with other stakeholders, such as industry partners, government agencies, and community organizations, to create a collaborative system that promotes knowledge exchange, innovation, and sustainable development.

5.5.4 Interview with Trondheim kommune

Trondheim Kommune, as the municipality responsible for the city of Trondheim, plays a pivotal role in the development and implementation of projects in Sluppen. The role of Trondheim Kommune in Sluppen is multifaceted. They act as the regulatory and governing body, responsible for creating and implementing policies, regulations, and plans that guide the development of the district. They collaborate with various stakeholders, including real estate developers, energy companies, research institutions, and community organizations, to ensure that Sluppen aligns with the municipality's vision for sustainable and livable urban environments.

Trondheim Kommune's hopes and achievements for Sluppen revolve around creating a model for sustainable urban development, energy efficiency, and innovation. They aim to transform Sluppen into a vibrant, low-carbon district that prioritizes renewable energy, resource efficiency, and green infrastructure. Their achievements in Sluppen may include the successful implementation of sustainable urban design principles, the integration of renewable energy technologies, the creation of green spaces, and the improvement of residents' quality of life.

The Trondheim Kommune has led to much of the regional transformation in the Sluppen area, and this is where the municipality is focusing. A designer interviewed said: *"We want to build PEDs in Sluppen and use new technologies, such as batteries. We want this place to be a place to experiment with PEDs and provide experience for future generations. But the use of new technologies also gives us a lot from regulations. Provides challenges and we need to find solutions."*

In terms of ambitions for the future, Trondheim Kommune seeks to expand the sustainability initiatives in Sluppen and set new benchmarks for urban development. They may aim to achieve carbon neutrality or net-zero energy targets, enhance the district's resilience to climate change, and promote social inclusivity and well-being. Their long-term vision could involve the integration of innovative technologies, the development of smart city solutions, and the establishment of a circular economy in Sluppen.To quote the interviewee: *"We want Sluppen to go from a dump to a star of the future. We are committed to transforming the area* *here."*

Due to Norway's democratic system and liberalized economic system, municipalities are not the only authority in formulating policy. Quoting the respondent: *"As an urban planner, I consult more with stakeholders. We cannot enforce the decisions of property owners, but we usually make decisions through consultation. Of course, economic benefits will be our One of the priorities. We don't usually think about energy budgets when we make decisions, but since the Russo-Ukrainian war last year, people complained about high energy prices and inflation, now we have to think about energy security and prices gone."*

Trondheim Kommune's relationships with other stakeholders in Sluppen are characterized by collaboration, consultation, and partnership. They actively engage with real estate developers, energy companies, research institutions, and community representatives to ensure a holistic and participatory approach to decision-making and project implementation. By fostering these relationships, the municipality can leverage the expertise, knowledge, and resources of different stakeholders, creating a shared vision and collective action towards sustainable urban development.

5.6 SWOT analysis

SWOT analysis is a strategic planning and strategic management technique used to help a person or organization identify Strengths(S), Weaknesses(W), Opportunities(O), and Threats(T) related to business competition or project planning (Weihrich 1982). This technique is designed for use in the preliminary stages of decision-making processes and can be used as a tool for evaluation of the strategic position of organizations of many kinds (for-profit enterprises, local and national governments, NGOs, etc.) (Caves 2004). In this section, a SWOT approach based on the characteristics of the Sluppen case is provided.

Figure 36: SWOT analysis result, edited by author

CHAPTER

SIX

CONCLUSIONS AND RECOMMENDATIONS

Based on the previous analysis of analyzing the application of battery technologies and strategies in PEDs, implications and recommendations are summarized from the analysis of results, case studies and literature review. These recommendations encompass various aspects, such as governance, policy formulation, and the integration of innovative technologies. The author strives to offer valuable insights and guidance to stakeholders, empowering them to make informed decisions and take necessary actions to ensure the sustainable and prosperous development of Sluppen.

6.1 Discussion of the relationship between positive energy districts, battery technology and urban planning, based on the case of Sluppen.

The Positive Energy Districts (PED) aims to optimise the local energy system through energy efficiency, flexibility and local energy generation from renewables in actions towards the (urban) energy transition and climate-neutrality and mainstreaming these actions in urban planning processes (Gollner 2023). When developing PEDs locally, a clear goal and process are needed.

Battery technology plays a vital role in enabling the efficient storage and utilization of renewable energy in PEDs.The application of battery technology makes building units no longer just consumers of energy, but also have the opportunity to become a "storage warehouse" of energy, realizing the two-way interaction between users and the grid. In the case of Sluppen, with the batteries installed at Lager11, buildings can choose to store electricity during low periods and release it during peak periods. The battery will also store this electricity if renewable energy sources such as solar power are installed later. The model of PEDs shows a decentralized energy system and localized energy production. Batteries technically ensure that localized energy production such as solar wind energy can be stored, thereby helping to realize the vision and goals of PEDs.

Urban planning plays a pivotal role in shaping the development and implementation of PEDs and the integration of battery technology. It provides a framework for strategic decision-making, policy formulation, and coordination among various stakeholders. Urban planning strategies need to encompass the spatial, economic, social, and environmental dimensions of PEDs, taking into account factors such as land use, building design, transportation infrastructure, and community engagement. Effective urban planning ensures the optimal allocation of resources, the integration of PEDs within the existing urban fabric, and the creation of livable and inclusive neighbourhoods.

In conclusion, the relationship between positive energy districts, battery technology, and urban planning is intricately intertwined, with each component influencing and shaping the others. The case of Sluppen in Trondheim exemplifies the potential and challenges of integrating battery technology in urban planning strategies to create a sustainable city. The successful integration of battery technology in PEDs requires comprehensive urban planning, stakeholder engagement, supportive regulatory frameworks, and collaboration among various actors. The ongoing development of Sluppen and other similar projects provides valuable insights and lessons learned that can guide future urban planning endeavors and foster the transition towards sustainable and energy-efficient cities.

6.2 Discussion of the performance and data of the battery

According to the data and pictures in 5.1, it can be seen that electricity consumption has increased enormously from 2020 to 2021. This is mainly due to the reopening policy after pandemic. The research report pointed out that rapid growth in electricity demand can lead to grid congestion and overload. When the demand for electricity surpasses the capacity of the transmission and distribution infrastructure, it can strain the grid, leading to voltage fluctuations, power outages, and reduced system stability and also driving up the price of electricity (Jack 2023; Nadel 2023). Therefore, for such emergencies, as well as cases of population increase (such as industrial area renovation, area densification, new construction areas, etc.), it is possible to invest in the installation of a certain number of batteries. This measure can relieve the pressure on the grid and regulate peak power consumption. Urban planners can consider it from this perspective and use it in future projects.

In the analysis of electricity consumption data in 2023, a noticeable decrease in electricity consumption can be observed in April. Several factors contribute to this decline. One of the main factors is the influence of temperatures and seasons on electricity usage. In Norway, the winter season is relatively long, spanning from January to March, during which there is a high demand for heating. As Lager11 utilizes heat pump heating, the energy consumption for heating during the first quarter of each year significantly contributes to the overall energy consumption. However, as April arrives, temperatures start to rise, leading to a decrease in energy consumption for heating.

Another factor impacting electricity consumption is social activities. April coincides with the Easter holiday, during which buildings experience a reduction in energy consumption. This is a significant contributor to the decline in energy consumption observed in April.

Comparing the data for the same period from 2020 to 2022, before the implementation of batteries, a pattern emerges. During the Easter holiday, electricity consumption decreases rapidly but rebounds just as rapidly after the holiday. There is no substantial difference in the peak consumption between the periods before and after the holiday.In Figures 37 and 38, the red line represents the Peak Maximum/Minimum in April.

However, examining the data for 2023 reveals a significant decrease in the peak consumption after the conclusion of the Easter holiday in April. The data indicates a more stable and consistent pattern. Notably, when analyzing the data for Room1 in 2023, it can be determined that the overall peak value in April has decreased by approximately 10%. After field confirmation, the heating consumption of the room did not drop significantly in April, so it was also confirmed that it was not due to seasonal changes in heating consumption. This area corresponds to the main service area of the battery, suggesting that the battery technology implementation has had a positive impact on reducing peak electricity consumption. The power consumption of Room 3 dropped significantly in April 2023, but this area is not the priority service area of the battery. After investigation, since room 3 is the meeting place and commercial area of Lager 11, the user's electricity consumption changed greatly in April, so this study excludes the data of room 3 as a reference.

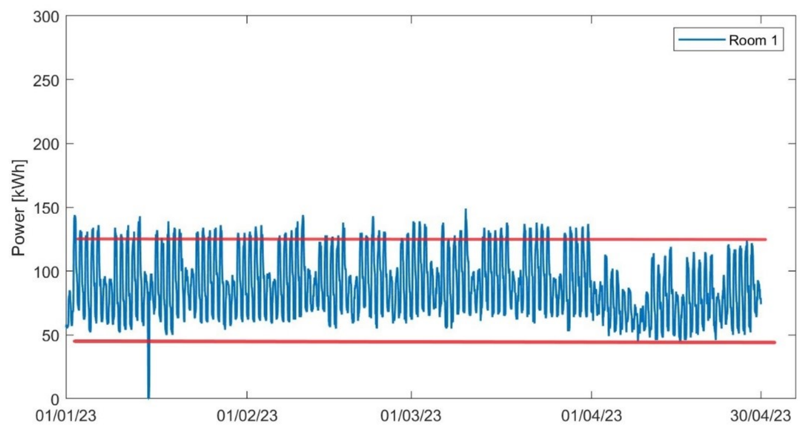

Figure 37: Comparison of peaks and troughs in April with previous months in 2023, edited by author

In order to prove the argument, the author once again generated the data of room1 from 2020 to 2022 and drew the data from January to April each year, and the results are shown in figure 38. This data proves that in years when battery technology is not used (2020-2022), electricity consumption and peaks in April have not decreased compared with January to March, and the peaks around Easter have not decreased. In 2023, after using battery technology, the peak value in April will be significantly lower than the previous data.

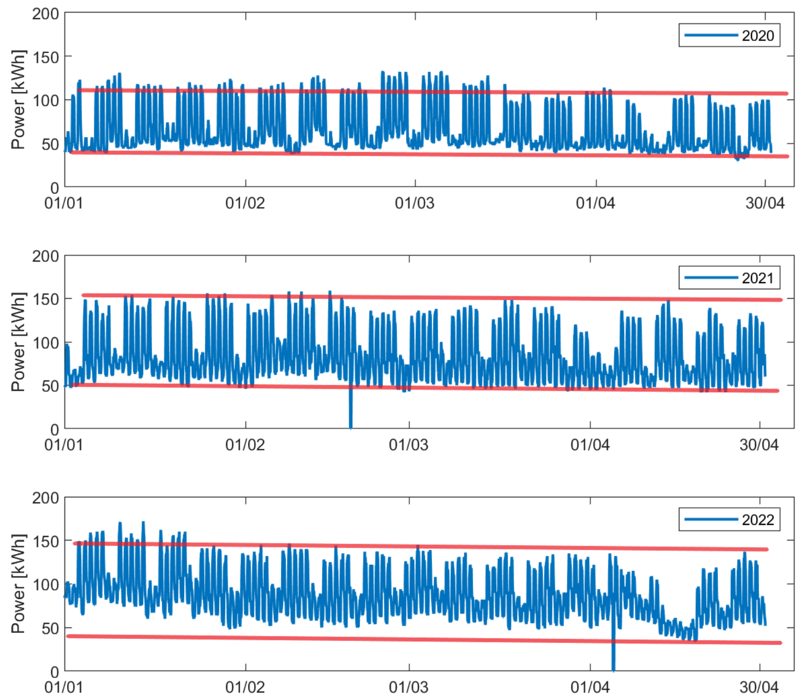

Figure 38: Electricity consumption data of room1 from 2020 to 2022 (January to April), edited by author

Based on all the data in this study, this paper draws a conclusion on the efficacy of the battery: after the battery ran stably in April, it effectively reduced the peak value of Room1 in Lager11. Before using the battery, there was no significant drop in Room 1 from the peak in April (see Figures 37 and 38). The peak value of Room 2 did not change significantly. Although Room 3 has a significant decline in April 2023, after investigation, it was found that it was caused by fluctuations in the usage of the food centre; and this room is not an area where batteries can be powered first, so Room 3 is excluded. Overall, the analysis demonstrates that the use of battery technology in energy consumption has contributed to a noticeable decrease in peak electricity consumption, particularly in the service area of the battery. This indicates the effectiveness of the battery system in smoothing out electricity demand and optimizing energy usage, leading to more sustainable and efficient energy management.

6.3 Answer research questions

6.3.1 What is the role of batteries in advancing PEDs?

following sub-questions were formulated:

A. How can batteries be integrated into the energy systems of PEDs?

Batteries can be effectively integrated into the energy systems of Positive Energy Districts (PEDs) to support their sustainable and efficient operation. Sluppen serves as a valuable example that showcases the potential of integrating battery technology into positive energy districts (PEDs) and sustainable urban planning. It highlights the importance of addressing energy challenges and leveraging innovative solutions to create more resilient, efficient, and environmentally friendly communities. Sluppen's case inspires a deeper understanding of the practical implementation of battery integration in PEDs. It demonstrates the positive impacts of such integration, including grid independence, renewable energy optimization, demand management, and enhanced resilience. The case also underscores the importance of stakeholder engagement, collaboration, and forward-thinking urban planning in realizing sustainable energy systems.Based on the research results and conclusions of this paper, the author answers this research question from four aspects:

Building-Level Integration:

- On-Site Energy Optimization: Battery systems can be integrated with building energy management systems to optimize on-site energy consumption. The batteries can store excess energy from renewable sources during periods of high generation and discharge it when demand exceeds supply. This helps reduce reliance on the grid and promotes self-consumption of clean energy. Taking the case of Sluppen as an example, the internal energy system of Lager 11 is relatively chaotic; the use of battery technology can optimize and integrate the energy of the building, so that the fragmented internal energy system can be integrated into a whole, which is convenient for management.
- Peak Demand Management: Batteries can be used to manage peak electricity demand within individual buildings. During periods of high demand, the batteries can discharge stored energy to supplement the grid supply, reducing peak demand charges and easing the strain on the electricity infrastructure.
- Backup Power Supply: Batteries can provide backup power during grid outages, ensuring continuity of critical operations in PED buildings. This is particularly important for essential services such as hospitals, schools, emergency response centers, and communication facilities.

District-Level Integration:

- Energy Sharing and Optimization: Battery systems installed in multiple buildings within the PED can be interconnected to create a district-level energy storage system. This allows for the sharing and distribution of excess energy between buildings, promoting energy optimization across the district. For example, buildings with surplus solar energy can supply it to neighboring buildings with higher energy demands.
- Microgrid Implementation: Batteries can be an integral part of microgrid systems within the PED. By combining renewable energy generation, battery storage, and local energy management, the microgrid can operate independently or in coordination with the main grid. This enhances energy resilience, reduces reliance on the grid, and enables localized energy sharing and optimization.

Grid Interaction:

- Grid Stabilization and Balancing: Batteries can contribute to grid stability by providing ancillary services such as frequency regulation and voltage control. They can respond quickly to grid fluctuations, absorbing or injecting power as needed, thus supporting the integration of intermittent renewable energy sources and enhancing grid reliability.
- Demand Response Programs: Batteries in PEDs can participate in demand response programs, where energy consumption is adjusted based on grid conditions. During periods of high electricity demand or grid constraints, the batteries can reduce their discharge or temporarily shift energy usage, helping to manage peak loads and avoid grid stress.

Collaborative Business Models:

- Shared Ownership: Stakeholders within the PED can jointly invest in battery systems and share ownership, costs, and benefits. This collaborative approach spreads the financial burden and ensures equitable distribution of advantages among participants. The first flow battery installed at Lager11 was co-funded by organizations such as NTNU, easing the pressure on startups like Bryte Batteries. The successful integration of battery technology into the energy system of PEDs is inseparable from the economic collaboration of various stakeholders.
- Leasing and Energy Service Agreements: Organizations specializing in battery storage, such as Bryte Batteries, can lease or provide energy services using batteries to PED stakeholders. This allows stakeholders to access the benefits of battery integration without the upfront costs of purchasing and maintaining the systems.
- Community-scale local energy markets: It enable the aggregation of multiple battery systems across different buildings or properties. These aggregated

systems can be controlled and optimized as a single entity, allowing for collective participation in energy markets, grid services, and revenue generation.

B. What is the impact of using battery technology?

The use of battery technology has a significant impact across various aspects of energy systems and beyond. Based on the analytical framework built in the theoretical part and the collected data, this paper can answer this question. Here are some key impacts of using battery technology:

Energy Storage and Flexibility: Battery technology enables efficient energy storage, allowing excess energy to be stored when demand is low and released when demand is high. This improves the flexibility and reliability of energy systems by bridging the gap between energy generation and consumption. Batteries provide a means to store and utilize intermittent renewable energy sources, such as solar and wind, thereby facilitating their integration into the grid and reducing dependence on fossil fuel-based power generation.

Grid Stability and Resilience: Batteries play a crucial role in enhancing grid stability and resilience. They provide rapid response capabilities to balance the supply and demand of electricity, helping to mitigate fluctuations in power generation and consumption. Batteries can also act as backup power sources during grid outages or emergencies, ensuring continuity of critical services and improving the resilience of the energy infrastructure.

Renewable Energy Integration: Battery technology facilitates the integration of renewable energy sources into the grid. By storing surplus energy during periods of high renewable generation and releasing it during times of low generation, batteries help to overcome the intermittent nature of renewable sources. This promotes higher utilization of renewable energy and reduces curtailment, allowing for a greater share of clean energy in the overall energy mix.

Decentralized and Distributed Energy Systems: Batteries support the development of decentralized and distributed energy systems. They enable localized energy generation, storage, and distribution, reducing the reliance on centralized power plants and transmission infrastructure. This leads to greater energy autonomy, reduced transmission losses, and improved energy efficiency.

Demand Response and Load Management: Batteries support demand response programs and load management strategies. They can be charged during periods of low demand and discharged during peak demand, helping to reduce stress on the grid and avoid the need for additional infrastructure investments. This contributes to more efficient energy use, lower energy costs, and improved grid reliability.

Environmental Benefits: The use of battery technology in energy systems has significant environmental benefits. It reduces reliance on fossil fuel-based power generation, leading to decreased greenhouse gas emissions and air pollution. By enabling the integration of renewable energy sources, batteries contribute to the transition to a cleaner and more sustainable energy future.

Economic Opportunities: The adoption of battery technology creates economic opportunities, such as job creation and innovation in the manufacturing and deployment of battery systems. The growing demand for batteries in various sectors, including energy storage and transportation, drives investments and stimulates economic growth.

C. How can battery storage help to mitigate the intermittency of renewable energy sources in PEDs?

Battery storage enables the time shifting of renewable energy, allowing excess energy to be stored during off-peak periods and utilized during peak demand times. This not only addresses intermittency but also reduces reliance on non-renewable energy sources during high-demand periods, promoting overall energy efficiency and sustainability in the PED while also taking advantage of market opportunities.

Furthermore, battery storage systems contribute to grid stabilization by providing voltage and frequency regulation. They can quickly respond to fluctuations in renewable energy generation, maintaining a stable and reliable electrical grid. By injecting or absorbing power as needed, batteries support grid stability and enhance the quality of the energy supply.

In conclusion, battery storage technology provides a flexible and scalable solution to address the intermittency challenges associated with renewable energy sources in PEDs. By smoothing out energy supply, enabling time shifting, supporting grid stabilization, providing ancillary services, and integrating with advanced energy management systems, batteries play a pivotal role in ensuring a sustainable and reliable energy system within Positive Energy Districts.

D. What types of batteries are best suited for use in PEDs and sustainable urban planning?

Flow batteries are considered a highly suitable technology for Positive Energy Districts (PEDs) due to their unique characteristics and advantages. They offer several benefits that make them advantageous compared to other battery technologies in the context of PEDs. Here, we will explore the advantages and disadvantages of flow batteries and discuss why they are currently the most suitable choice for PEDs.

Advantages of Flow Batteries:

Scalability: Flow batteries are highly scalable, allowing for flexible adjustment of energy capacity and power output. This scalability is particularly valuable in PEDs where the energy demand may vary over time. By easily adding or removing electrolyte solutions, flow batteries can adapt to the changing needs of the PED, making them suitable for both small and large-scale energy storage applications.

Long Duration Discharge: Flow batteries can provide long-duration energy discharge, ranging from hours to even days. This extended discharge capability is crucial for PEDs as it enables the storage of excess energy during periods of high generation and its release during periods of high demand. Flow batteries help mitigate the intermittency of renewable energy sources by providing a reliable and continuous supply of electricity.

High Energy Efficiency: Flow batteries offer high energy efficiency, typically ranging from 70% to 90%. This means that a significant portion of the stored energy can be efficiently utilized without substantial losses. The high efficiency contributes to the overall sustainability of the PED, maximizing the utilization of renewable energy and reducing reliance on the grid.

Safety: Flow batteries have inherent safety advantages compared to other battery technologies. Since they store energy in liquid electrolytes contained in separate tanks, the risk of thermal runaway and fire is reduced. This makes flow batteries a reliable and safe option for PEDs, where safety is a critical consideration.

Long Cycle Life: Flow batteries can endure a large number of charge-discharge cycles without significant degradation. With proper maintenance and operation, flow batteries can last for several thousand cycles. This longevity ensures their suitability for long-term use in PEDs, contributing to their economic viability and sustainability.

Disadvantages of Flow Batteries:

Lower Energy Density: Flow batteries typically have lower energy density compared to some other battery technologies like lithium-ion batteries. This means they require larger physical space to store the same amount of energy. However, the scalability of flow batteries compensates for this drawback, allowing for the adjustment of the system size to meet the energy storage needs of the PED.

Higher Initial Cost: Flow batteries, particularly certain chemistries like vanadium redox flow batteries, have higher upfront costs compared to traditional battery technologies. The cost of the electrolyte solutions and the infrastructure required for the flow battery system contribute to this higher initial investment. However, as flow battery technology advances and economies of scale are realized, the cost is expected to decrease, making it more economically viable for PEDs.

Why Flow Batteries are Currently the Most Suitable for PEDs:

Flow batteries are currently the most suitable battery technology for PEDs due to their unique combination of advantages. The scalability of flow batteries aligns well with the varying energy demands of PEDs, allowing for efficient adjustment of energy capacity as the district evolves. The long-duration discharge capability of flow batteries enables reliable and continuous power supply, mitigating the intermittency of renewable energy sources and enhancing the stability of the PED's energy system.

Additionally, the high energy efficiency of flow batteries ensures optimal utilization of stored energy, reducing waste and maximizing the PED's sustainability. The inherent safety features of flow batteries provide peace of mind in terms of operational reliability and mitigate potential risks associated with battery systems.

Furthermore, the long cycle life of flow batteries ensures their durability and longevity, making them suitable for long-term use in PEDs. This aligns with the goals of sustainable urban planning, which emphasizes the long-term viability and resilience of the energy systems.

While flow batteries have some disadvantages such as lower energy density and higher initial costs, ongoing research and development efforts in flow battery technology are addressing these challenges. Advancements in electrolyte chemistries, system designs, and manufacturing processes are driving cost reductions and improving energy density, making flow batteries even more advantageous for PEDs.

In conclusion, flow batteries offer a unique set of advantages that make them the most suitable battery technology for PEDs. Their scalability, long-duration discharge, high energy efficiency, safety features, and long cycle life contribute to the resilience, stability, and sustainability of PEDs. With ongoing advancements in flow battery technology, they continue to be an attractive choice for integrating energy storage in PEDs, supporting the transition to renewable energy sources and promoting sustainable urban planning.

6.3.2 What are the roles and interests of stakeholders in developing the PED?

The development vision of the Trondheim municipality for Sluppen is: *To develop Sluppen into a sustainable district that underpins the zero-growth target, through coordinated housing, area and transport planning. Sluppen's goal is to become a zero-emission district and in that way become a role model for energy- and climate-friendly urban development.* (Stenstad 2022a) During the construction process, various stakeholders have adopted the form of cooperation to develop Sluppen jointly.

R. Kjeldsberg AS is the largest local real estate developer, owns many real estate properties, and develops plans and solutions for many local clients, belonging to "high interest, high power". According to the data and content collected in the interview, R. Kjeldsberg AS almost dominated the development of Sluppen, especially for PEDs. Their cooperation is very much needed if the concept of PEDs is to be localized in Sluppen. Enterprises are profit-seeking, and take profit as the primary task; when a certain enterprise monopolizes decision-making power, it may have adverse effects on other stakeholders. In the interviews, companies promote their real estate development projects and enhance brand value by promoting the concept of PDEs; companies also lack the adoption of residents' opinions. Users and residents are still in the status of "customers", and have not really participated in the development of PEDs and building their own communities.

The Trondheim Kommune also has high local interests and power. Municipalities have the power to formulate master plans for land use and to issue permits for related works. But Trondheim Kommune cannot directly intervene in the strategy of the enterprise, and the decision-making power is in the hands of property owners. This leads to Trondheim Kommune in most cases grand planning and indirect influence. And for the municipal sector, economic prosperity will be one of the cores of their work, which has led to Trondheim Kommune still being largely a market-oriented decision-maker. And for Sluppen, an area with a unique industrial heritage and rapid immigration growth, there is a great need to listen to local residents in the future of work.

As a university and research institution, NTNU plays a role of decision-making support in the local area. NTNU, as the host of the +cityxchange project, will improve the concept of PEDs on the basis of theory and theory, and provide interest support for various stakeholders. NTNU does not have particularly strong market-oriented characteristics, and will not aim at profit. It also cannot directly affect decision-making, and it does not have particularly strong local interests. It is a medium-level interest and medium-power. NTNU's values and academic philosophy will complement other stakeholders.

Bryte Batteries, a start-up in Sluppen, does not currently manufacture batteries but sells and maintains them. The company installed Norway's first flow battery at Lager11 and is responsible for subsequent maintenance and data analysis. The enterprise has close cooperation with other stakeholders. As a start-up, they need the support of other stakeholders, especially the assistance of funds. According to the results of the interview, Bryte Batteries' strategy is also for profit. The company wants to sell as many batteries as possible everywhere, where its local interests are relatively low and power is relatively low. For the content mentioned above, the author created a power interest matrix.

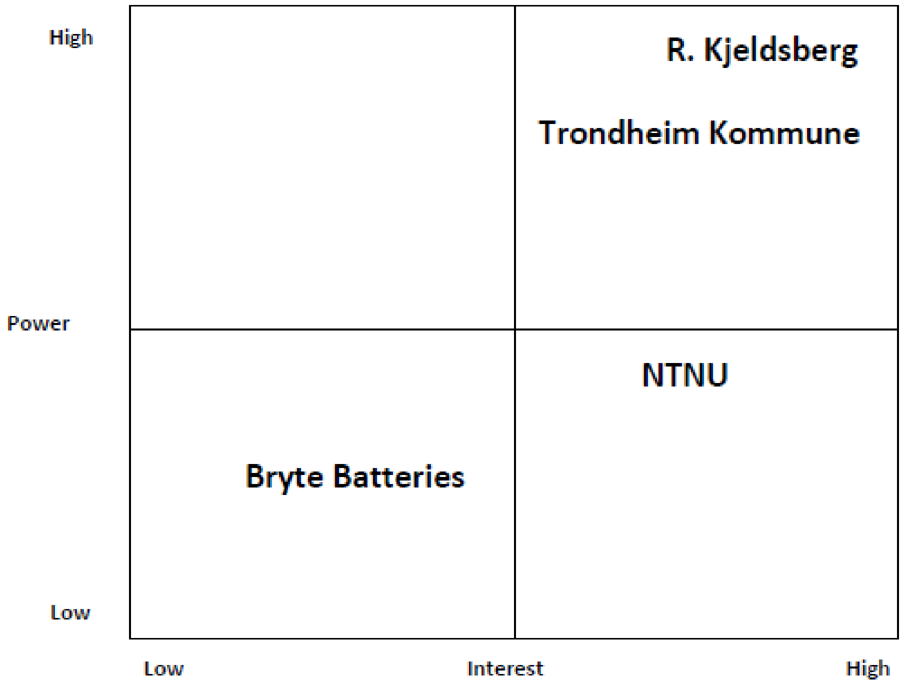

Figure 39: Power interest matrix in Sluppen, edited by author)

6.4 Recommendations for Sluppen

Based on the analysis and findings from the Sluppen case, several recommendations can be proposed to further enhance the positive energy district (PED) and battery technology integration in the area. These recommendations aim to optimize energy efficiency, sustainability, and stakeholder engagement.

6.4.1 Using Batteries as a Bridge—Integrating Energy Systems and Energy Markets

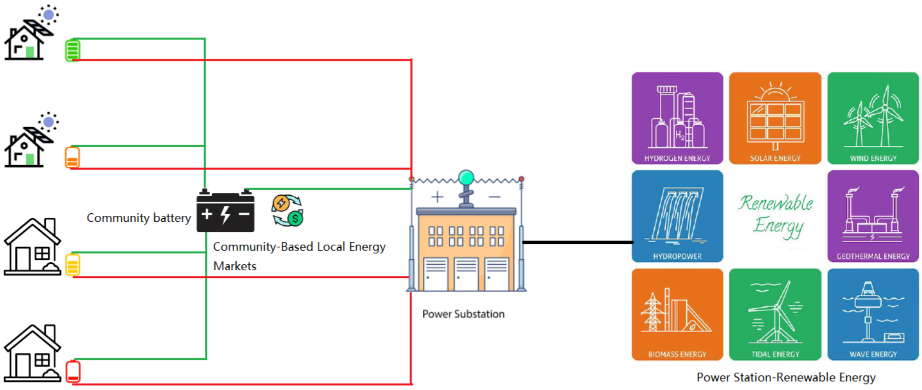

Figure 40: Recommended PEDs Energy and Market Mode, edited by author

Based on the findings of this paper, the authors propose a model for PEDs that integrates energy systems and local energy markets. The model is based on the scale of the community, and the authors recommend that each user and individual building systems have batteries installed. This article has demonstrated the efficacy of batteries in the context of PEDs. Currently, the total installed battery capacity in Sluppen is still small, and the total installed capacity should be increased in the future.

The green line in the figure represents the localized energy system. Residential users use batteries to store clean energy such as solar energy, or use batteries for peak regulation. And establish a battery system within the community to connect users and settle electricity. The red lines represent the parts of the community that are directly connected to the grid.

Given that Norwegian law currently prohibits the transfer of electricity between different building units, it also prohibits users from transferring surplus energy generated by their own buildings (such as solar energy) directly to other users. Therefore, the author proposes to set up a battery system within the community to collect and distribute the electricity of all users, which solves the legal obstacles. And establish a community-based local energy market.

Users in PEDs can use batteries to integrate their own energy systems, put the excess electricity generated in the community in the electricity futures market, so that PEDs can economically adjust the electricity price; or distribute electricity within the community, and transport the surplus output to Building units that need electricity, and complete the settlement of electricity bills within the community. This is a market-oriented solution while balancing the values behind PEDs.

6.4.2 Positive energy district-based local energy market

The integration of battery technology transforms building units from passive energy consumers to active participants that can store electricity and interact with the grid. Additionally, the use of renewable energy technology opens up the possibility for each positive energy district to establish its own energy market. In the Case study section, the paper discussed the liberalized and market-oriented nature of the Norwegian electricity energy market. Building upon the model presented in section 6.4.1 and taking into account the Norwegian market and policy framework, the author propose a local market model tailored to the scale of positive energy districts in section 6.4.2. The model is depicted in the figure below:

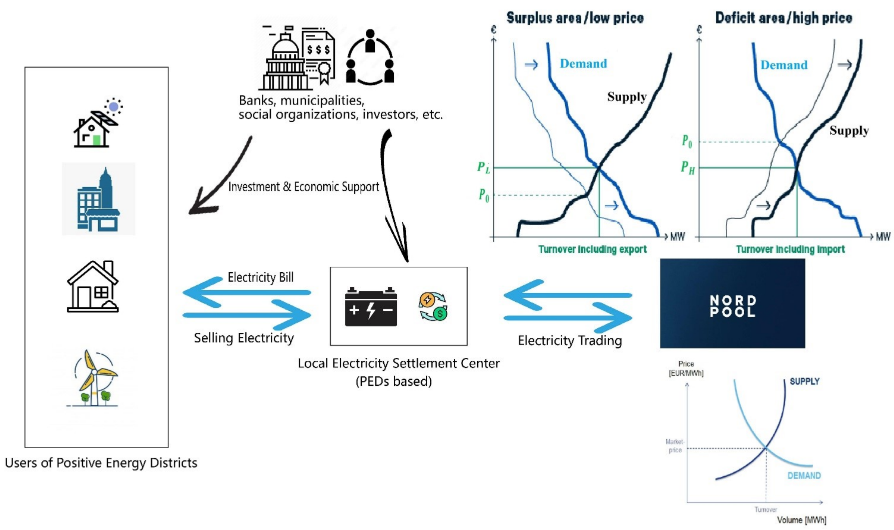

Figure 41: Model of local energy market-PED based, Source: (Idsø 2021), integrated and edited by the author

The model is derived based on a supply and demand curve and it works as follows:

- Each power supply area is set to three states - power balance, deficiency or excess;
- The market is profit-driven, and the distribution of electricity will flow from areas with lower quotations to areas with high demand and higher quotations;

In the supply and demand part of the model, P_L and P_H represent the price in each area when the transaction capacity is fully utilized; P_0 represents the Price in each area when no transition capacity is available.

When a PED has surplus electricity and the electricity price is low, the PED sells electricity to the outside world, which means that the PED's demand for electricity increases (It means some users temporarily connected to the PED, and these users do not actually exist in this PED), so the demand curve shifts to the right, resulting in a new Equilibrium-P_L.

When the electricity price of the PED is at a high level, the PED imports electricity, the electricity supply of the PED increases, the supply curve moves to the left, and a new Equilibrium is obtained-P_H.

Therefore, the local energy market based on the PED increases the size of the energy market in Norway as a whole (Nord Pool). As a result, when PED exports electricity, $P_0 \rightarrow P_L$,the electricity price rises, and users can make profits by selling electricity; when PED imports electricity, $P_0 \rightarrow P_H$, electricity prices fall, and users' electricity costs decrease.

The stakeholders and framework of the model are as follows:

1. Participants:
   - Prosumers: Building owners or residents who generate their own renewable energy and have the capability to sell excess energy back to the grid.
   - Consumers: Building owners or residents who primarily consume energy and may purchase energy from prosumers or the grid.
   - Aggregators: Entities that aggregate and manage energy resources on behalf of multiple participants, optimizing energy usage and facilitating energy transactions.
   - Distribution System Operator: The entity responsible for managing the distribution grid and ensuring the reliable supply of electricity to the PED.
2. Market Mechanisms:
   - Energy Trading Platform: A digital platform that connects prosumers, consumers, and aggregators, facilitating energy transactions and providing real-time information on prices, availability, and demand.
   - Dynamic Pricing: Prices fluctuate based on real-time supply and demand conditions, encouraging participants to adjust their consumption patterns and optimize energy usage.
   - Contracts and Agreements: Participants can enter into bilateral contracts for energy supply or participate in spot market trading through the trading platform.
   - Demand Response Programs: Incentives are provided to participants who adjust their energy consumption in response to signals from the market or the DSO to balance supply and demand.
   - Net Metering: Prosumers are credited for the excess energy they feed back into the grid and can utilize those credits when their own generation is insufficient.

3. Energy Generation and Storage:

    - Renewable Energy Sources: Promote the installation of solar panels, wind turbines, and other renewable energy technologies in buildings within the PED.
    - Energy Storage Systems: Encourage the deployment of battery storage systems to store excess energy generated from renewables and balance supply during peak demand periods.

4. Metering and Monitoring:

    - Smart Meters: Install smart meters at individual buildings to monitor energy consumption and production in real-time, enabling accurate billing and transaction settlement.
    - Advanced Monitoring Systems: Implement monitoring systems to track the performance of renewable energy generation, energy storage systems, and overall grid operations.

5. Regulatory Framework and Policy Support:

    - Establish clear regulations and policies that support the operation of the local energy market, including guidelines for energy transactions, market operation, and participant rights.
    - Collaborate with regulatory bodies to streamline processes, ensure compliance, and promote the growth of PEDs and the local energy market.
    - Provide financial incentives, tax benefits, or subsidies to encourage participation and investment in renewable energy generation and storage.

6. Stakeholder Engagement and Education:

    - Conduct outreach programs to educate participants about the benefits of the local energy market, energy conservation, and renewable energy adoption.
    - Foster collaboration and engagement among building owners, residents, utilities, and local authorities to ensure active participation and support for the local energy market.

7. Monitoring and Evaluation:

    - Implement a monitoring and evaluation framework to assess the performance of the local energy market, including factors such as energy transactions, system reliability, environmental impact, and cost savings.
    - Use the collected data to identify areas for improvement, make informed decisions for policy adjustments, and optimize the operation of the local energy market.

In summary, the proposed model is market-oriented and establishes a localized energy market based on positive energy districts (PEDs). It facilitates profitable and efficient supply and demand adjustments within the district. A key feature of the model is the active participation of ordinary users in the energy market, with battery technology playing a crucial role. The model encourages broad societal involvement, including the investment and support of stakeholders such as banks. It is important to note that the model is developed within the context of Norway's highly liberalized electricity market. For other countries, decision-makers can adapt and apply the model to their local context, leveraging their own experiences and market conditions.

6.4.3 Human-centred Governance Model in PEDs

According to the results of the interview, the current development of PEDs in Sluppen is obviously a market-oriented development model, which lacks attention to the interests of residents and the public. Based on this, this paper proposes a human-centered governance model.

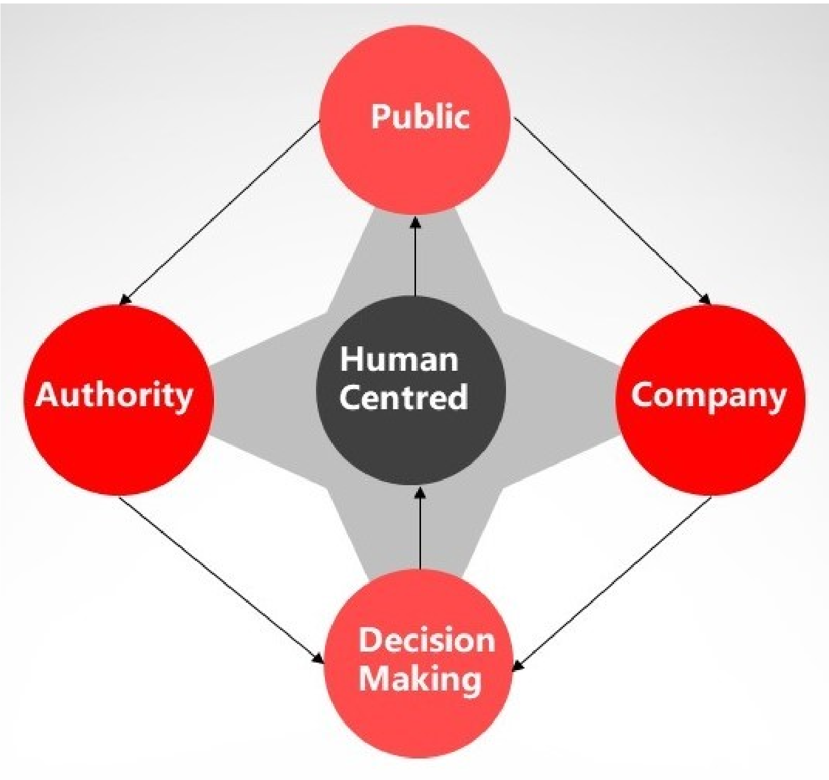

Figure 42: Human-centred Governance Model in PEDs, edited by author

This model is a closed-loop model, starting from the interests of the public, constructing effective communication channels, and conveying the will of the public to the companies and authorities with relevant interests. They combine their own interests and seek the optimal solution. Make decisions based on human-centred values. Ultimately, any decision must be implemented in the interests of the public. This model can be used for the future construction of Sluppen, and can also be used as a reference for the construction of PEDs. The author believes that a good governance framework should not only be dominated by economic benefits; more importantly, it should pay attention to the feelings of the public with relevant interests. The core of PEDs is sustainable development, and the well-being and feelings of the people should be the core, which is also the value of PEDs.

6.5 Research Limitations

6.5.1 Literature review limitations

There are several limitations that researchers may encounter when conducting a literature review on PEDs. One of the main limitations is the availability and quality of the literature itself. The concept of PEDs is very new, and from the data of search engines, the number of available and valuable literature is very small.

Another limitation is that literature reviews are inherently limited by the research questions and search terms used. If the research questions are too broad or the search terms are too narrow, important literature may be missed, leading to incomplete or biased results.

Additionally, literature reviews are typically based on published literature, which may not fully capture the experiences and perspectives of practitioners or stakeholders involved in the development and implementation of PEDs. This can limit the ability of researchers to fully understand the complexities and nuances of the topic.

Finally, literature reviews are typically static and may not capture the most up-to-date research and developments in the field. As new studies are published and new technologies emerge, the conclusions and recommendations of a literature review may become outdated quickly.

Overall, while literature reviews are an important tool for synthesizing existing knowledge and identifying gaps in research, they are not without limitations and should be complemented with other research methods and sources of data.

6.5.2 Case study limitations

Like any research method, case studies have their limitations. One of the main limitations is that the findings may not be generalizable beyond the specific context of the case study. In the case of studying PEDs, this means that the findings of a case study in one particular city or region may not be applicable to other cities or regions. Case studies in Sluppen are time-consuming and require significant resources, which may limit the number of cases that can be studied and the depth of analysis that can be conducted. Additionally, case studies may be influenced by researcher bias, particularly if the researcher has a pre-existing relationship with the case study site or stakeholders.

6.6 Next investigation

Since this paper is in the early development stage of the PEDs project in the Sluppen area, especially in the early stage of battery technology application, there will be limitations in the data and conclusions. The following are topics worthy of future research and investigation:

Performance Monitoring and Optimization: Continued monitoring and analysis of the energy systems in Sluppen is crucial to assess their performance, identify areas for improvement, and optimize energy generation, distribution, and consumption. This includes evaluating the effectiveness of battery storage integration, assessing the balance between renewable energy generation and demand, and optimizing energy management strategies.

Economic Viability and Financial Models: Investigating the economic viability of the PED concept in Sluppen is crucial. This includes assessing the financial models for implementing and operating the energy systems, estimating the return on investment, and exploring potential funding mechanisms or incentives to encourage stakeholders' participation and support.

Social and Community Engagement: Understanding the social dynamics and community engagement within Sluppen is essential for the successful implementation and long-term sustainability of the PED. Further investigation can focus on assessing residents' perceptions, behavior changes, and acceptance of new energy technologies, as well as identifying effective strategies for community engagement, education, and participation in energy management initiatives.And as the project progresses, it is necessary to dynamically monitor the development of stakeholders.

Life cycle assessment: conduct LCA assessment on battery technology and PEDs, obtain full life cycle data in a qualitative way, and use this to judge the success of PEDs.

Policy and Regulatory Framework: Investigating the policy and regulatory framework surrounding PEDs in Sluppen is vital. This includes assessing the existing policies, regulations, and incentives related to renewable energy integration, energy storage, and sustainable urban development. Research can focus on identifying any barriers or gaps in the current framework and proposing policy recommendations to facilitate the widespread adoption of PEDs.

Scalability and Replicability: Sluppen can serve as a model for future PEDs and sustainable urban developments. Further investigation can explore the scalability and replicability of the Sluppen model in other regions, assessing the transferability of the technological, social, and regulatory aspects of the project to different contexts.

By addressing these areas of investigation, Sluppen can further advance as a leading example of sustainable urban development and serve as a catalyst for future PED projects. The findings and insights gained from continued research will contribute to the ongoing optimization and improvement of the energy systems in Sluppen and provide valuable knowledge for the broader transition towards sustainable and energy-efficient cities.

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APPENDICES

Figure 43: Interviews and Workshop

Figure 44: Site visits

	A	B	C	D
1				
2	Time	EL1	EL2	EL3
3	**01.01.23 00:00**	56	3	56
4	**01.01.23 01:00**	58	3	57
5	**01.01.23 02:00**	56	4	57
6	**01.01.23 03:00**	55	3	62
7	**01.01.23 04:00**	56	4	66
8	**01.01.23 05:00**	57	3	79
9	**01.01.23 06:00**	56	4	82
10	**01.01.23 07:00**	56	3	84
11	**01.01.23 08:00**	57	3	82
12	**01.01.23 09:00**	59	4	108
13	**01.01.23 10:00**	77	3	117
14	**01.01.23 11:00**	79	3	113
15	**01.01.23 12:00**	81	4	113
16	**01.01.23 13:00**	80	3	115
17	**01.01.23 14:00**	85	4	119
18	**01.01.23 15:00**	84	3	115
19	**01.01.23 16:00**	84	4	104
20	**01.01.23 17:00**	77	3	118
21	**01.01.23 18:00**	76	3	124
22	**01.01.23 19:00**	72	4	126
23	**01.01.23 20:00**	64	3	136
24	**01.01.23 21:00**	60	3	135
25	**01.01.23 22:00**	58	4	104
26	**01.01.23 23:00**	57	5	92
27	**02.01.23 00:00**	58	4	79
28	**02.01.23 01:00**	61	4	78

Figure 45: Raw data of electricity consumption (partial)

Listing 1: Matlab Code for Plotting

```
file2020 = append("data"+"2020"+".csv");
file2021 = append("data"+"2021"+".csv");
file2022 = append("data"+"2022"+".csv");
data2020 = readmatrix(file2020);
data2021 = readmatrix(file2021);
data2022 = readmatrix(file2022);

r1_2020 = data2020(: , 2);
r2_2021 = data2021(: , 2);
r3_2022 = data2022(: , 2);
t2020 = linspace(1,size(r1_2020,1),size(r1_2020,1));
t2021 = linspace(1,size(r2_2021,1),size(r2_2021,1));
t2022 = linspace(1,size(r3_2022,1),size(r3_2022,1));
% r1_2020 = data2020(1:2904 , 2);
% r2_2021 = data2021(1:2880 , 2);
% r3_2022 = data2022(1:2880, 2);
% t2020 = linspace(1,2904,2904);
% t2021 = linspace(1,2880,2880);
% t2022 = t2021;

days1 = [31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30,
   31];
days2 = [31, 29, 31, 30, 31, 30, 31, 31, 30, 31, 30,
   31];
hours1 = 24*days1;
hours2 = 24*days2;
ticks1 = ones(1,4);
ticks2 = ones(1,4);
for i = 1:11
       ticks1(i+1) = ticks1(i)+hours1(i);
       ticks2(i+1) = ticks2(i)+hours2(i);
end

f1 = figure(1);
f1.Position = [100 100 700 600];
set(gcf,'color','w');

subplot(3,1,1);
plot(t2020,r1_2020,'Linewidth',1.5,'DisplayName', '2020'
   );
xticks(ticks2);
xticklabels({'01/01','01/02','01/03','01/04','30/04', '
   01/05','01/06','01/07','01/08','01/09','01/10','01/11
   ','01/12'});
ylabel('Power [kWh]');ylim([0,200]);
legend show
```

```
subplot(3,1,2);
plot(t2021,r2_2021,'Linewidth',1.5,'DisplayName', '2021'
   );
xticks(ticks1);
xticklabels({'01/01','01/02','01/03','01/04','30/04', '
   01/05','01/06','01/07','01/08','01/09','01/10','01/11
   ','01/12'});
ylabel('Power [kWh]');ylim([0,200]);
legend show

subplot(3,1,3);
plot(t2022,r3_2022,'Linewidth',1.5,'DisplayName', '2022'
   );
xticks(ticks1);
xticklabels({'01/01','01/02','01/03','01/04','30/04', '
   01/05','01/06','01/07','01/08','01/09','01/10','01/11
   ','01/12'});
ylabel('Power [kWh]');ylim([0,200]);
legend show

%
% f2 = figure(2);
% f2.Position = [100 100 700 400];
% set(gcf,'color','w');
% plot(time,room1,'Linewidth',1.25);
% legend('Room 1');
% ylabel('Power [kWh]');
% ylim([0,300]);
% xticks([1,745,1418,2160,2856]);
% xticklabels
   ({'01/01/23','01/02/23','01/03/23','01/04/23',
   '30/04/23'});
%
% f3 = figure(3);
% f3.Position = [100 100 700 400];
% set(gcf,'color','w');
% plot(time,room2,'Linewidth',1.25,'color',[0.8500
   0.3250 0.0980]);
% legend('Room 2');
% ylabel('Power [kWh]');
% ylim([0,300]);
% xticks([1,745,1418,2160,2856]);
% xticklabels
   ({'01/01/23','01/02/23','01/03/23','01/04/23',
   '30/04/23'});
%
% f4 = figure(4);
% f4.Position = [100 100 700 400];
```

```
% set(gcf,'color','w');
% plot(time,room3,'Linewidth',1.25,'color',[0.9290
  0.6940 0.1250]);
% legend('Room 3');
% ylabel('Power [kWh]');
% ylim([0,300]);
% xticks([1,745,1418,2160,2856]);
% xticklabels
  ({'01/01/23','01/02/23','01/03/23','01/04/23',
  '30/04/23'});

% f5 = figure(5);
% f5.Position = [100 100 700 400];
% set(gcf,'color','w');
% plot(time,sum,'Linewidth',1.25,'color',[0.3010 0.7450
  0.9330]);
% legend('Sum');
% ylabel('Power [kWh]');
% ylim([0,500]);
% xticks([1,745,1417,2160,2856]);
% xticklabels
  ({'01/01/21','01/02/21','01/03/21','01/04/21',
  '30/04/21'});
```

Internship certificate

Ming Yang

June 12, 2023

Ming Yang has completed an internship from February 2023 - June 2023 on the role of batteries in city planning, using Positive Energy Districts as a starting point.

He has looked at the Sluppen area in Trondheim, and studied the first flow battery in Norway that was installed in the beginning of January 2023 by Bryte Batteries. Bryte has helped Ming to get in touch with decision makers and key stakeholders at the real estate company R. Kjeldsberg, who own most of Sluppen, Trondheim Municipality and at City Exchange.

Ming has had a desk at our office space, and has contributed to the team both socially and intellectually while he has been with Bryte. He has worked independently and has produced a master thesis of value. His findings of how the battery at Sluppen has shaved off energy peaks, while also pointing out the future potential of batteries in local energy systems similar to the City Exchange Project has been an important contribution to prove the business case for flow batteries in Norway.

Working with Ming has been a pleasure, and he has delivered both valuable and insightful work through his time at Bryte.

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