Towards a positive energy balance: A comparative analysis of the planning and design of four positive energy districts and neighbourhoods in Norway

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Towards a positive energy balance: A comparative analysis of the planning and design of four positive energy districts and neighbourhoods in Norway and Sweden

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ABSTRACT

Positive energy districts and sustainable plus energy neighbourhoods are developed in the European context to reduce energy use and greenhouse gas emissions from the building sector. The planning and development of positive energy districts and sustainable plus energy neighbourhoods is complex and requires collaboration between stakeholders and new measures to achieve high energy efficiency, local renewable energy generation, energy storage and flexibility, and energy sufficiency. This paper examines the implementation of energy measures in the planning and design of four positive energy district and neighbourhood development projects in Norway and Sweden. The paper compares the two different institutional and energy system contexts and how these affect the development of positive energy districts, focusing on the perspectives of the municipality and developers. Existing academic literature and positive energy district guidelines are used to develop an analytical framework for the planning and design of positive energy districts and sustainable plus energy neighbourhoods. Results highlight an early focus on energy ambitions, wide stakeholder involvement, and the importance of aligning interests between stakeholders and working interdisciplinary in the planning and design phases to find optimal energy measures. Both the building and the neighbourhood/district level are important to increase energy efficiency, energy sufficiency, and energy flexibility, and consequently lower the environmental impact of the whole development project.

1. Introduction

1.1. Context

In 2018, the building sector accounted for 36 % of the final energy use globally and 39 % of the energy and process-related carbon dioxide (CO_2) emissions [36]. The European Green Deal aims to reach net zero greenhouse gas emissions by 2050 [30], and several policies are in place to incentivise the building sector to improve the energy efficiency of buildings. Measures such as nearly zero-energy buildings, zero-emission buildings, and positive-energy buildings are suggested to reduce energy use and greenhouse gas emissions in the building sector [69]. A stock energy analysis of Norway for 2016–2050 shows that widespread implementation of local energy sources, such as heat pumps and photovoltaic installations, provides significantly larger future energy savings in the system than extensive renovation of the building stock [83]. The share of electricity in the total delivered energy is anticipated to rise from 28 % in 2016 to between 37 % and 57 % in 2050 [83]. The shift towards buildings that generate more energy than they use has resulted in the need to look at energy within the neighbourhood context, as opposed to the single building level, introducing energy flexibility, building interactions, load matching and grid interaction [37], to enhance the utilisation of renewable energy sources locally.

The topics of low-carbon communities, zero-emission neighbourhoods (ZEN), sustainable plus energy neighbourhoods (SPEN), and positive energy districts (PED) are widely discussed in the literature, with a large focus on the energy and emission perspective [14,97]. A PED should not be limited to the term district but should be flexible in the scale, if it is in line with the requirements of the PED concept, being it a neighbourhood, a district, or an island [22]. A PED is defined as “a district with annual net zero energy import, and net zero CO_2 emissions working towards an annual local surplus production of renewable

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energy" [48], p. 5 and a collection of other definitions are found in Brozovsky et al. [14]. The energy system in a PED has renewable energy supplies, high energy efficiency, and a substantial degree of flexibility [84]. Krangsås et al. [57] identified only two PEDs in operation in Europe in 2021, while Zhang et al. [97] identified eleven PEDs in operation in 2021. The definition affects how projects are classified and whether they qualify as PEDs. However, PED implementation in Europe is still in the development stage, with most initiatives being pilot projects.

Currently, guidelines for the planning and design of PEDs are under development. However, integrating energy efficiency and zero energy objectives in urban development projects is not new [93]. Urban development projects with high ambitions for energy, including positive energy buildings, can provide wider lessons learned about energy requirement implementation, as shown in a study by Petersen and Heurkens [79]. The literature on PEDs highlights the need to document and disseminate lessons learned and experiences from real demonstration cases of PEDs to enhance knowledge development and dissemination to other contexts [84,94]. There is still little research on the early stages of PED projects and how to include different stakeholders [84]. Collaboration between stakeholders from various fields is necessary to achieve ambitious project results [63]. There has been a strong focus on the technologies needed to achieve PEDs, such as renewable energy systems. However, the knowledge and skills required to plan, implement and monitor PEDs still need further development [66]. Contextual factors are of great importance for the successful implementation of PEDs [6,84]and include both spatial, technical, and social considerations, such as the local climate, existing infrastructure, and district and building functions and use [94]. Straight replication of PED designs is therefore limited since design and performance are strongly context-dependent, thus PED measures need to be adapted to the specific context [94]. To deepen our understanding of PED development, a better overview of the contextual factors is essential for deriving more widely applicable lessons learned.

1.2. Scope and limitations

This paper investigates the planning and design processes of PEDs and SPENs by conducting a comparative case study of four ambitious urban development projects, all of which currently have a PED ambition or a similar goal. Lessons learned from these projects can support the rapid scaling up of PEDs and SPENs in Europe, and contribute to a more energy-sustainable building stock. The research question of this study is "How are positive energy districts and neighbourhoods planned and designed in practice?", and is answered by examining four case studies of PEDs and SPENs: Ydalir in Elverum, Norway, Verksbyen in Fredrikstad, Norway, Vallastaden in Linköping, Sweden and Brunnshög in Lund, Sweden.

1.3. Overview of the paper

The paper is structured as follows, Section 2 describes previous research on the topic to provide a background and presents an analytical framework. Section 3 explains the methodology and materials for the paper. Section 4 provides the results from the case study comparison. In Section 5, the discussion is presented, and in Section 6 the conclusion is given.

2. Background

This section presents a background of energy measures in PEDs, the planning and design of PEDs, and an analytical framework for evaluating the planning and design of PEDs. The background is based on scientific research on PEDs and energy planning, and on five PED guidelines [1,48,80,85,94] which have been published over the last few years and focus on "overall information on and suggestions for the process of planning, implementing monitoring and evaluation of PEDs, and a description of the potential impact of PEDs" (Neumann et al., 2022, p. 516).

2.1. Energy measures in PEDs

As described in the introduction, to develop PEDs, innovative and integrated measures for energy systems that combine renewable energy supplies, a high level of energy efficiency, and a substantial degree of flexibility are needed to reach net zero greenhouse gas emissions and "actively manage an annual local or regional surplus production of renewable energy […] while securing the energy supply and a good life for all in line with social, economic and environmental sustainability" [48], p. 6. Four main elements of a PED energy system have been defined in previous research:

1. **Energy efficiency** is defined in the Energy Efficiency Directive by the European Commission (EU/2023/1791) as "the ratio of output of performance, service, goods or energy to input of energy". Using this definition, energy efficiency in buildings and districts can be described as using less energy for operation in contrast to standard building methods, while maintaining the desired output of performance, i.e. high indoor environmental quality. The energy efficiency of buildings is affected by many factors, including insulation of the building envelope, cooling and ventilation systems, heat recovery systems, and appliances [29,48,55,94].
2. **Renewable energy generation** includes energy generated by technology utilising renewable energy sources. These energy sources, which are continually replenished by nature, include solar, wind, hydropower, geothermal, and biomass, and are used to generate electricity or heat [23]. Examples are building integrated photovoltaics, solar thermal collectors, and stand-alone RES generation facilities [29,48,55,94].
3. **Energy storage and flexibility**. Energy flexibility is defined in IEA EBC Annex 67 Energy Flexible Buildings as "the energy flexibility of a building is the ability to manage its demand and generation according to local climate conditions, user needs, and energy network requirements. Energy flexibility of buildings will thus allow for demand side management/load control and thereby demand response based on the requirements of the surrounding energy networks" [47]. Energy storage consists of generating and collecting energy at one time to use it at another time, allowing for flexibility. The availability of renewable energy fluctuates independently from the demand, and therefore energy storage becomes increasingly more important in the built environment [45]. Examples of energy flexibility and storage systems are smart controls, thermal storage systems, hydroelectric storage and batteries, vehicle batteries, gas storage, connection to other energy networks, and thermal masses of buildings [29,48,55,94].
4. **Energy sufficiency** is defined as: "a state in which people's basic needs for energy services are met equitably and ecological limits are respected" [20]. As energy sufficiency strongly relates to people's experience of buildings, occupant demand and behaviour are at the core of building energy sufficiency. Passive design principles that reduce the need for active energy systems and prolong the periods in which the indoor environmental quality targets can be met with passive strategies, such as natural ventilation, enhance the building energy sufficiency [44]. Other examples of building energy sufficiency are optimised use of buildings, adequate floor space per capita, and line drying clothes.

These four elements are interrelated, but important to distinguish because each factor affects the performance of plus energy buildings and PEDs differently. Energy sufficiency is frequently mistaken for energy efficiency. Energy sufficiency includes the minimum energy necessary to provide a comfortable living environment. Energy efficiency is related to the design and consequently, buildings', districts' and neighbourhoods' potential to use energy optimally and reduce wasted energy. Thus, a building's potential to be energy efficient lies in the design, and is exploited and realised in the operational phase, where energy efficiency in combination with energy sufficiency results in low energy consumption [44]. Interactions between building and district/neighbourhood design for efficiency and sufficiency are necessary for PEDs to reduce the energy need and consumption, e.g., in the orientation of buildings, layout and height of buildings, and the materials and fabric of and between the buildings [29]. Energy flexibility and storage can reduce the temporal mismatch between energy needs and renewable energy generation.

For the implementation of suitable energy measures in a PED, contextual factors play an important role and demand distinct approaches to achieve PED goals [22,80,84,94]. Contextual factors include spatial, technical, and social aspects. Spatial aspects include the location of the area, climate conditions, geographical and urban morphology, building typologies, and the natural resources available, and are defining components in the design of a PED [22,80,84]. The technical factors include the existing energy infrastructure and the available technologies [22,84]. Andresen et al. [2] present designs for SPENs in four different climate zones, illustrating how energy efficiency measures and systems must be tailored to fit each project's spatial characteristics and available technologies. Each project has different design measures to achieve the same goal, a plus energy balance on a neighbourhood level. The technologies for energy efficiency, the integration of renewable energy and energy storage, and energy sufficiency and flexibility are in constant development, which asks for an open approach to innovative energy measures in the planning and design of PEDs [84]. An optimal design of a PED can only be determined based on the local energy context [94]. It is therefore necessary to consider the regional and local energy systems to integrate, scale up and replicate the energy systems in PEDs efficiently. The social aspects include culture, identity, trust, power relations, and the needs of the diverse users [22,84]. Baer et al. [6] describe that it is a challenge for stakeholders involved in urban development to identify and adapt suitable strategies for PEDs to the specific local context, balancing innovation, and technical and social dimensions.

2.2. Planning and design of PEDs

The development of PEDs requires integrated spatial and energy planning [94], and multiple stakeholders to join forces [84] to implement the energy measures. Energy planning has predominantly centered around either large, centralised power and heat plants, or single buildings. However, for an energy-efficient built environment, innovative solutions on a larger scale than the building scale, such as neighbourhoods, are necessary [17]. Since urban form, energy demand, and renewable energy generation are interrelated, there is a need for urban planning policies and procedures that consider energy planning at the urban scale [15]. Integrated urban and energy planning combines urban planning and energy planning to develop energy transition strategies and improve the climate protection of a neighbourhood, district, or city. Integrated urban and energy planning is characterised by creating future scenarios, goals and objectives for an urban area, and using energy modelling at the city and urban scale to find and implement appropriate climate protection and energy measures [94]. According to JPI Urban Europe / SET-Plan Action 3.2 [48] and Cajot and Schüler [17] energy aspects are traditionally not thoroughly integrated into urban planning processes. Urban planning and energy planning are complex processes, compromising interconnected activities that necessitate integration to develop appropriate solutions [16]. This means integrated and iterative design processes to implement energy efficiency and sufficiency strategies and the development of renewable energy systems that are sound and cost-efficient [80], requiring collaboration between different stakeholders and domains [63,84]. Key stakeholders in PED developments include traditional planning stakeholders, such as the municipality, landowners, urban planners, architects, contractors and property owners and managers. Additionally, energy system stakeholders, such as local energy system operators and energy suppliers for electricity networks and district heating and cooling networks play crucial roles. Lastly, stakeholders who can develop capabilities for energy balancing and aggregation of loads and renewable energy source generators, such as energy community entities, energy service companies (ESCos), and energy storage system operators, have been identified as significant stakeholders [84].

Sareen et al. [84] and Alpagut and Gabaldón [1] stress the need for collaborative governance models to connect different stakeholders and align their interests and priorities during the planning and design of PEDs. Collaborative governance can be defined as "the processes and structures of public policy decision making and management that engage people constructively across the boundaries of public agencies, levels of government, and/or the public, private and civic spheres to carry out a public purpose that could not otherwise be accomplished" [28]. Previous research shows that for the planning and design of PEDs, a common vision and early agreement among the key stakeholders are needed [32,80,84]. Shnapp et al. [85] and Pless et al [80] emphasise the importance of stakeholders collaborating and reaching an agreement on energy targets and overarching energy measures during the design phase. However, achieving consensus among stakeholders is a challenge and could limit the implementation of a PED [85]. Therefore, process management, to steer and guide the project development through the stages from initial idea or concept to implementation and operation, is found to be a key element in the planning and design of PEDs [92]. A third party might be necessary to oversee the overall setup and monitoring of the district [85]. Citizens should be included in the process to align the planning and design of PEDs with their needs as they are the end-users [22,94], achieving democratic governance processes but also increasing transparency in the decision process [41]. Organising citizen participation and collecting knowledge from different stakeholders is part of the process management. Approaches beyond involvement and engagement have also been identified, in which citizens are regarded as participants with ownership of the energy system in a PED, for example through citizen energy communities [55]. In Avedøre, a suburb in Copenhagen, Denmark, the citizens took the initiative to increase the sustainability of their community. As this requires specific energy and building expertise, they created a steering committee with local stakeholders who made a "green city" vision for Avedøre, and a complementary manual with actions and initiatives to reduce the energy need, improve energy efficiency, and incorporate renewable energy supply [85]. Empowering citizens with the knowledge and the right tools can increase the implementation of improved energy measures in the building stock.

The role of occupants and the impact of user behaviour on energy performance are topics of debate in the literature. A review by Mahdavi et al. [70] found little documentation supporting the idea that occupants play a central role in the energy performance gap. Instead, it is argued that energy performance is more of a collective endeavour [70]. However, in residential buildings occupants drive energy use through their control of heating set points, window openings, and the use of appliances, lighting, and domestic hot water. Studies have found that occupants can reduce energy use in residential buildings by 6 % to 25 % through behaviour changes, while in commercial buildings, the reduction ranges from 5 % to 30 % [7,38,98]. A review by Far et al. [31] indicated that half of the energy consumption in residential buildings can be attributed to occupant behaviour, while the other half is attributed to the building's envelope and installed systems [31].

In addition to the importance of early planning and design stages, monitoring and evaluating PEDs during the operational phase is crucial. Evaluation helps to understand how PEDs contribute to energy goals, and how solutions can be scaled up and replicated [84,94].

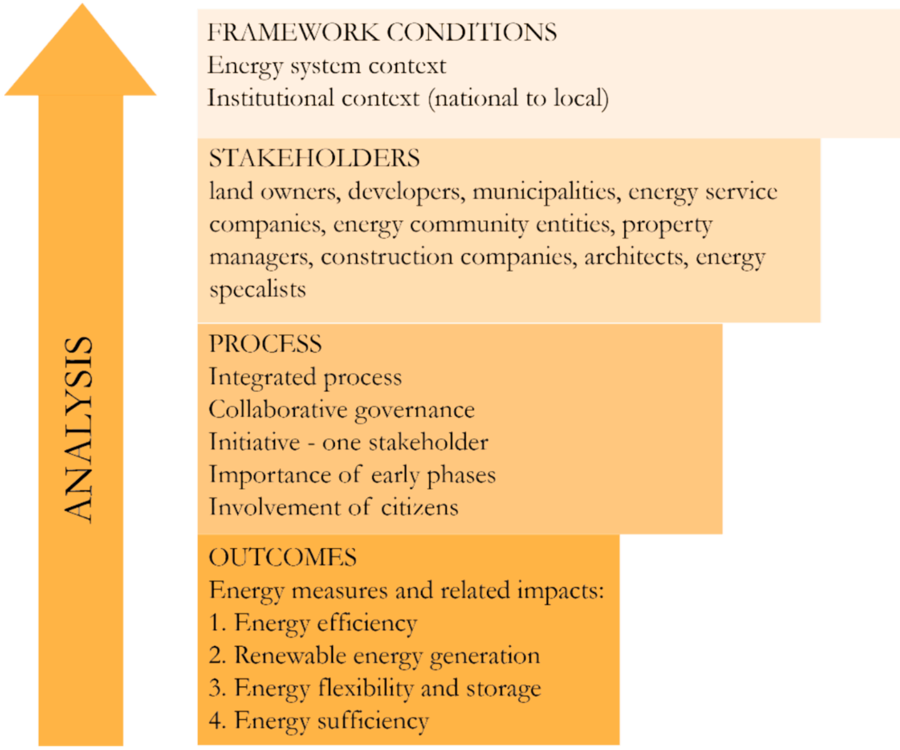

Fig. 1. Analytical framework for the planning and design of PEDs.

2.3. An analytical framework for the planning and design of PEDs

Sareen et al. [84] provide an analytical framework for enabling PEDs, which consists of three parts: framework conditions, prefiguration, and emerging impact. Framework conditions refer to the institutional structures and contexts within which PEDs are implemented. Sareen et al. [84] define prefiguration as the PED process, including multiple stakeholders and collaborative governance. The emerging impact includes both energy-related impacts (such as lower energy use and increased system flexibility/resilience) and non-energy-related impacts (such as improved health and well-being and economic value) [9,84]. The emerging impact can be viewed as the outcomes of the PED process.

To compare different development projects, Squires and Heurkens [86] introduced a conceptual model comprising five levels: the development environments, markets, agencies, processes, and outcomes. These levels are interconnected by institutional rules, market conditions, agency requirements, and actions. The development environments encompass the values, norms, and systems that determine the institutional rules. Markets represent the conditions in which the development takes place. Agencies comprise the organisations, interests, and instruments involved in the project. Processes entail the roles, relations, and events that lead to actions. Outcomes represent the results of the project across different scales. This model is considered comprehensive and generic, making it suitable for comparative studies [86].

Inspired by the literature discussed in Sections 2.1 and 2.2 on energy measures in PEDs and the planning and design of PEDs, the framework of Sareen et al. [84], and the conceptual model of Squires and Heurkens [86], we present an analytical framework for the analysis of the planning and design of PEDs in Fig. 1. This analytical framework shows four levels: framework conditions, stakeholders, process, and outcomes. Framework conditions set the wider context for the PED, including the energy system context and the institutional context. Stakeholders, partially defined by framework conditions, include public, private, and civic organisations with interests in the PED. Throughout the development process of a PED, stakeholders undertake specific roles in coordinating and managing the development process. Successful development of PEDs depends on integrated processes, collaborative governance, and the involvement of citizens. The outcomes of a PED are the implemented energy measures and their related impacts.

Fig. 2. Map of the location of the case studies with the Norwegians marked in red and the Swedish marked in blue. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Project characteristics of the Norwegian and Swedish cases.

Project	Timeframe	Urban development project type	Size	Energy ambition
Ydalir, Elverum (NOR)	2016–2030	Greenfield development, including a kindergarten, a school, and 800 to 1000 dwellings	35 ha	Zero emission neighbourhood
Verksbyen, Fredrikstad (NOR)	2018–2030	Brownfield development (former industrial area), 1500 to 2000 dwellings	20 ha	Plus energy neighbourhood
Vallastaden, Linköping (SWE)	2011–2030	Greenfield development, housing exhibition in 2017, 1800 dwellings with some commercial properties, offices, schools, parking garages, preschools, and nursing homes.	20 ha	Resource-efficient and climate-smart district
Brunnshög, Lund (SWE)	(1998) 2006–2055	Greenfield development, 6000 dwellings, offices, research facilities, commercial properties, schools, services	100 ha	Positive energy district

3. Materials and methods

3.1. Case selection

We conducted a comparative analysis of four urban development projects in Norway and Sweden, see Fig. 2 for the locations of the projects. The number of case studies is based on the balance between the depth of the analysis of each case study and the possibility of making a cross-comparison analysis [58]. An information-oriented case selection was applied, based on the expectation of the information content of the cases [33]. The four cases all have PED, SPEN or similar ambitions, and have been recognised by practitioners and academics as flagship projects for energy [34,60,77]. These urban development projects are distinguished from traditional planning and design processes in their application of various methods and measures to achieve high energy ambitions. The most important characteristics of the cases are given in Table 1.

The four case studies differ in size and scope but the framework conditions for Norway and Sweden are comparable. In both national settings, urban planning is predominantly driven by local government authorities, with comparable ownership structures for housing. In Sweden, urban planning is regulated by the Planning and Building Act [13]. The Act includes regional plans, comprehensive plans, area regulations, and zoning plans [42]. Only the latter two are legally binding plans, the regional and comprehensive plans can be seen as indicative. As a result, Sweden's national and regional planning levels are relatively limited, thereby granting significant authority and accountability to municipalities at the local level [46]. Likewise, in Norway, urban planning predominantly occurs at the municipal level, as it is the primary level of local government and administration. The hierarchical arrangement and objectives of the different plans mirror those found in the Swedish structure [81]. The Norwegian Planning and Building Act requires municipalities to have master plans and zoning plans, which are significant instruments in PED development [81]. In Sweden, 62 % of the dwellings are owner-occupied and 38 % are rented, in Norway 77 % of the dwellings are owner-occupied and 23 % are rented. Of all dwellings, 4 % is social or public housing in Norway, and in Sweden, it is 19 % [49].

Table 2
Primary energy factors (PEF) for Sweden and Norway.

Energy carrier	Primary energy factor/weighted factor (PEF), Sweden before 01.09.2020[1]	Primary energy factor (PEF), Sweden after 01.09.2020[2]	Primary energy factor (PEF), Norway[3]
Electricity	1.6	1.8	1
District heating	1	0.7	1
District cooling	1	0.6	1
Biofuel	1	0.6	1
Oil	1	1.8	1
Gas	1	1.8	1

[1] BBR25 (Boverket's Building Regulations).
[2] BBR29 (Boverket's Building Regulations).
[3] [54].

3.2. Data collection and analysis

Document analysis of planning documents and relevant literature for each case was performed. For a detailed overview of the empirical material used in the case study analysis, see Appendix. The case studies have used various building energy performance tools to calculate the energy consumption for the buildings and districts. In addition, energy performance is reported in different metrics, such as energy use, delivered energy, primary energy, and greenhouse gas emissions. The energy data for Ydalir is calculated with the energy simulation tool SIMIEN and based on the Norwegian standard for passive houses for residential buildings, NS 3700:2013. The Norwegian standard is based on the passive house requirements by the Passive House Institute and adapted to the Norwegian climate and building practices [87]. For Verksbyen, the energy data is calculated with the "ZEN predictor", a tool developed within the FME Research Center on Zero Emission Neighbourhoods and Smart Cities. For Vallastaden and Brunnshög, energy performance data used in this paper is based on the energy performance calculations available in the municipal archive (for calculated energy demand), where energy performance in Vallastaden is calculated with *Energihuskalkyl*, a Swedish calculation tool for energy performance calculations, with standard figures provided by the municipality of Linköping. For Brunnshög, developers are free to choose which tool to use, and consequently, the data is calculated with different calculation tools (e.g., IDA ICE). For actual energy use (delivered energy and primary energy use) in Vallastaden and Brunnshög, the energy performance certificates available in a database managed by the Swedish National Board of Housing, Building and Planning are used, where the data is based on measurements by an independent certified energy expert. In Table 2, the primary energy factors (PEF) used in Sweden and Norway are given.

Moreover, seven semi-structured interviews were carried out during 2022 and 2023 to obtain further information about the planning processes and the tools used. These interviews were with different people from the municipality, energy companies, architects, and developers. A thematic interview guide was used, focusing on the energy goals and requirements for the district, the planning process and the implementation of energy measures, and the involved stakeholders. The interviews lasted approximately one hour each, and five out of seven were audio-recorded, transcribed, and coded, while the data from the other two was collected through notetaking.

4. Results and analysis

4.1. Presentation of the cases

4.1.1. Ydalir (NOR)

In a former sand pit in Elverum, a new development of approximately thirty-five hectares, called Ydalir (see Fig. 3), will include a kindergarten, a school, and 800 to 1000 housing units. The largest landowner in the area, a combination of a public (municipality) and a private organisation, drives the development. Ydalir is a ZEN (zero emission neighbourhood) pilot project in the FME ZEN research centre

[24]. A ZEN "aims to reduce its direct and indirect greenhouse gas (GHG) emissions towards net zero over the analysis period, in line with a chosen ambition level", where the focus is on energy efficiency, renewable energy generation, energy flexibility, sustainable mobility, economic sustainability through minimising total life cycle costs, spatial qualities and sustainable behaviour, and lastly incorporating innovative solutions [51], p. 5. The development of the neighbourhood is planned for more than ten years ahead, with a 2030 vision for the neighbourhood identity; to create a zero-emission neighbourhood with a sustainably built environment, which also promotes social connectivity [24,27]. The initial energy concept is based on a ZEB – O (Zero Emission Building – Operation) level for the area, which means that renewable energy generation compensates for the greenhouse gas emissions from the operations of the buildings in the neighbourhood. It is suggested to increase the ambition level to ZEB – COM (Zero-Emission Building – Construction, Operation and Production of building Materials) towards the last development period, which means that renewable energy onsite will compensate for greenhouse gas emissions from construction, operation, and production of materials [60].

4.1.2. Verksbyen (NOR)

Verksbyen (see Fig. 4) is a new neighbourhood, 4.5 km from the city centre of Fredrikstad in Norway. It is developed by a private developer who owns the whole area, and has a project timeframe of ten to fifteen years. The neighbourhood is a former industrial area, and the site used to be excavated for clay for the brick industry, which has resulted in a small lake on site. The lake is now protected due to bird migration. The area consists of roughly twenty hectares, and the neighbourhood includes single-family housing, row houses, and apartment buildings, and will have between 1500 and 2000 housing units when finalised [64]. The project is called "Future Living" with the strategy to supply the buildings with renewable energy, and together with energy-efficient buildings, aims to be a plus energy neighbourhood [3]. A section of the neighbourhood is part of the European research project syn.ikia, funded by Horizon 2020. Syn.ikia aims to develop and demonstrate sustainable plus energy neighbourhoods (SPEN) in four different climate zones in Europe [91]. A SPEN is "a group of interconnected buildings, with associated infrastructure, located within both a confined geographical area and a virtual boundary. A SPEN aims to reduce its direct and indirect energy use towards zero over adopted complete year and an increased use and production of renewable energy according to a normalisation factor" [82]. A SPEN focuses on energy efficiency, renewable energy generation, energy flexibility, sustainable mobility, and well-being for the inhabitants, and has a social perspective for the neighbourhood.

4.1.3. Vallastaden (SWE)

Vallastaden (see Fig. 5) is an urban development project, located 3.5 km from the city centre of Linköping in Sweden. The planning of Vallastaden started in 2011, and the first phase of the district was shown in an urban planning and housing exhibition in September 2017 [35,39]. The goal for Vallastaden, formulated in the Idea program of the municipality (2012), was to become a leader in realising the latest innovations in energy, environmental technology, and sustainable urban development, and to develop an energy- and resource-efficient district that contributes to the municipal goal of being CO_2 neutral in 2025. Currently, Vallastaden consists of 1400 dwellings (apartments, detached houses, and single-family houses), and 400 more will be developed in the coming years. A total of forty different developers were contracted to develop the buildings in the first phase in Vallastaden [35]. An infrastructure culvert is an important innovation in the district, consisting of a 1.8 km major underground pipe-bound construction, holding pipes and cables for district heating, electricity, telecommunications, water, waste, and sewage. The electricity grid is designed to manage a surplus of electricity, and the buildings in Vallastaden are developed with stricter energy performance requirements than the national building code prescribes, and some have been developed as passive houses.

4.1.4. Brunnshög (SWE)

Brunnshög (see Fig. 6) is an urban development project in the northeast of the city of Lund in Sweden, connecting the existing city with two new research facilities. The initial planning of Brunnshög started in the late 1990 s in the comprehensive plan of Lund, the first specific plans were developed from 2006 onwards, and the first buildings in the district were completed in 2015. Brunnshög will be further developed until 2055, on a total area of one hundred hectares. The first part (South Brunnshög) is almost completed, and the second part consisting of Central Brunnshög and the Science Village is currently under development. The vison for Brunnshög is that it will be a showcase for sustainable urban development, generating more energy than what is used in the district, referred to as a PED. The sustainability goals for Brunnshög are based on the principles: minimise – balance – maximise. The minimise goal includes the energy goal: minimising the climate impact is about generating sustainable energy, reducing energy use, and climate-adapting the urban environment to face the effects of a changing climate. A central part of the energy system is a low-temperature district heating network that uses excess heat from two large-scale research facilities in the area. Energy-efficient buildings and PV systems in the buildings are energy measures implemented in the district. The urban development project was part of Trans-PED, an international research project resulting in tools for co-creating sustainable and inclusive urban energy systems.

4.2. Cross-case comparison

Comparing the cases with the analytical framework from Section 2.3

Fig. 3. To the right: An aerial view of Ydalir's development. To the left: A photo of the new school in Ydalir ().
Source: FME ZEN, https://fmezen.no/ydalir-elverum/?lang=no

Fig. 4. A photo of Verksbyen development in Fredrikstad, Norway ().
Source: ArcaNova, https://www.synikia.eu/neighbourhoods/demo-neighbourhood-norway/

Fig. 5. Two photos of Vallastaden in Linköping, Sweden (photos taken by the authors).

provides insight into the empirical understanding of the planning and design of PEDs. Table 3 provides an overview of the outcomes, the main elements of the process, the stakeholders, and the framework conditions in Ydalir, Verksbyen, Vallastaden, and Brunnshög.

4.2.1. Outcomes

All case studies implemented energy-efficient buildings, often more energy-efficient than the national building code prescribes. The Nordic climate is heating-dominated and requires a well-insulated building

Fig. 6. Two photos of Brunnshög in Lund, Sweden (photos taken by the authors).

envelope. Ydalir and Verksbyen follow the Norwegian passive house standard (NS 3700:2013). This standard requires an energy-efficient and airtight envelope, ventilation with heat recovery, and efficient heating systems For Vallastaden, the buildings are designed to reduce energy demand by 25 % compared to the national building code, and some buildings also meet the passive house standard. In Brunnshög, there are currently no overarching quantifiable requirements for the energy performance of the buildings. However, the different land allocation competitions have criteria for building certification system levels (including heat load, solar heat gain, and energy performance) and the installation of photovoltaics. The energy performance calculations and certificates of the buildings in Brunnshög show low primary energy use, see Table 4. The lower primary energy use number in comparison to delivered energy is due to the applied PEF, as shown in Table 2. The cases also demonstrate the importance of PV systems in PEDs. All four cases have local renewable electricity generation through building integrated photovoltaic panels (BIPV). Verksbyen used an iterative process to orient the building to increase solar access and PV generation [92]. Three of the case studies utilise (low-temperature) district heating as the main source of thermal supply, while Verksbyen uses ground-source heat pumps. Table 4 provides a more detailed comparison of the energy systems.

The four case studies illustrate energy efficiency measures and renewable energy generation solutions primarily focused on the building level. Energy flexibility and energy sufficiency measures within the developments remain insufficient, as do measures on larger scales than individual buildings, such as enhancing energy flexibility through interconnectedness among buildings in the district. This could be explained by limiting barriers in the Energy Act in Norway, and legal barriers for sharing of power between buildings in Sweden [71]. Verksbyen has previously gotten time-limited dispensations from the Energy Act to share energy between apartments [10]. Energy sufficiency is incorporated in passive design principles by reducing the energy needs of buildings and users and is strongly linked to energy efficiency. In Verksbyen, neighbourhood-level energy measures were considered during the detailed planning of the district, e.g., by considering the orientation of the buildings concerning solar energy [92]. In Brunnshög, researchers participated in the early stages of the project investigating the solar potential of the neighbourhood [34]. Energy sufficiency related to adequate floor space per capita transcends the scale of the building and needs to be considered on a larger scale. For example, Ydalir will have a platform for sharing common spaces and activities [59]. The concept of sharing spaces and goods for Ydalir was developed within the FME ZEN research centre, to reduce greenhouse gas emissions by lowering the total neighbourhood resource consumption. Also, Vallastaden has shared common spaces in each building group, which often include a guest apartment, a play area for children and teenagers, and a shared kitchen that can be used for larger gatherings or parties. These shared spaces reduce the floor space needs per person and consequently lower energy use per person while satisfying the occupants' needs.

4.2.2. Process

PEDs can be developed through different management structures, and Verksbyen falls in the category where the whole area is developed by one privately owned company, which makes the ownership structure [19], the implementation, and the business models for energy measures more straightforward. In Ydalir, Vallastaden, and Brunnshög, the initial planning phase is overseen by the municipality, consistent with the decentralised planning systems in both Norway and Sweden.

A master plan or overarching program for the district or

Table 3
Significant elements of the planning and design of the case studies.

	Ydalir (NOR)	Verksbyen (NOR)	Vallastaden (SWE)	Brunnshög (SWE)
Outcomes: Energy measures for Energy efficiency, Renewable energy generation, Energy storage and flexibility, Energy sufficiency	• Passive houses • PV panels on roofs • CHP • District heating based on biofuels	• Passive houses • PV panels on roofs and facades • Hybrid-Solar-System on facades (on selected buildings) • Ground-source heat pump • EV charging • Dispensation for energy sharing between apartments • Solar energy studies • Instruction videos for energy-conscious user behaviour	• Energy-efficient buildings (some passive houses) • Energy-efficient lighting and appliances in buildings • PV on buildings • District heating and cooling (infra culvert) • Electricity grid designed to manage surplus electricity • Common spaces in each block	• Energy efficient buildings (some plus energy buildings) • Low-temperature district heating and cooling, supplied with excess heat from two research facilities • Low-temperature district heating and cooling, supplied with excess heat from two research facilities • Building-integrated photovoltaics • Battery storage in some buildings • Solar energy studies • Smart building technology in some buildings (remote control)
Process	• Workshops to develop the Master plan • Master plan as part of a contract with developers • LCA Calculation tool to evaluate GHG emissions[1]	• Workshops to develop the energy concept • Close collaboration between developer, architect, and PV specialists.	• Overarching programs for the district • Point system for the land allocation competitions for the developers • Software prescribed for energy calculations[2]	• Overarching program for the district • Land allocation competitions • Sustainability contracts with developers • Collaboration contract with energy company
Main stakeholders	Municipality (initiative), developers, research center	Developer (initiative), architect, PV specialist, energy consultant	Municipality (initiative), developers, energy company	Municipality (initiative), developers, energy company
Citizen involvement	Workshops and interviews with the local community through Ydalir Living lab	"Verksbyen Day", a social gathering where current and new residents meet	Citizen dialogues, an online platform to collect ideas and exhibitions of the plans	Resident meetings, city walks, newsletters, an outdoor exhibition, and several events
Framework conditions	The site is owned by the municipality, but a small private section of the area is privately owned.	Privately owned site by one developer.	The municipality owns most of the land, and Linköping has a district heating network in place.	The municipality owns most of the land, and Lund has a district heating network in place.

[1] Life Cycle Assessment calculation tool developed by FME ZEN Research Center.
[2] *Energihuskalkyl*, a Swedish calculation tool for energy performance calculations, with standard figures provided by the municipality of Linköping.

Table 4
Energy system comparison of the case studies.

	Net calculated delivered energy and generated energy	Net calculated specific delivered energy and generated energy per area	Actual energy use per area
Project: Ydalir (NOR)			
Electrical energy system	PV panels CHP Electricity grid		
Thermal energy system	CHP District heating		
Electrical energy (fans and pumps, cooling, lighting, technical equipment)	3.9 GWh/year	36 kWh/m^2-year	Not available
Thermal energy (space heating + DHW)	4.8 GWh/year	63 kWh/m^2-year	Not available
Electricity generation	**PV panels:** 1.0 GWh/year (6000 m^2) **CHP:** 2.5 GWh/year	**PV panels:** 10 kWh/m^2 for residential buildings (6 m^2/ residential building)	Not available
Thermal generation	**CHP (9 machines):** 6.3 GWh/year **District heating**: 5.5 GWh/year		Not available
Project: Verksbyen (NOR)			
Electrical energy system	PV panels Electricity grid		
Thermal energy system	GSHP/HYSS District heating for auxiliary heat		
Electrical energy (fans and pumps, cooling, lighting, technical equipment)	5.4 GWh/year	37 kWh/m^2-year	Not available
Thermal energy (space heating + DHW)	1,9 GWh/year	13 kWh/m^2-year	Not available
Electricity generation	**PV panels:** 7,3 GWh/year	**PV panels:** 50 kWh/m^2-year	Not available
Thermal generation	GSHP/HYSS District heating	Not available	Not available
Project: Vallastaden (SWE)			
Electrical energy system	PV panels Electricity grid		
Thermal energy system	District heating and cooling		
Thermal and electrical energy	Not available	**Delivered energy:** between 25 kWh/m^2-year and 73 kWh/m^2-year **Primary energy use (delivered energy * PEF):** between 36 kWh/m^2-year and 83 kWh/m^2-year	**Delivered energy:** between 48 kWh/m^2-year and 121 kWh/m^2-year **Primary energy use (delivered energy * PEF):** between 41 kWh/m^2-year and 154 kWh/m^2-year
Electricity generation	Not available	Not available	1611 m^2 PV panels
Project: Brunnshög (SWE)			
Electrical energy system	PV panels Electricity grid		
Thermal energy system	Low-temperature district heating and cooling		
Thermal energy	23 GWh/year (prognosis for 2030)	Not available	Not available
Thermal and electrical energy	Not available	**Delivered energy:** between 29 kWh/m^2-year and 68 kWh/m^2-year **Primary energy use (delivered energy * PEF):** between 38 kWh/m^2-year and 89 kWh/m^2-year	**Delivered energy:** between 22 kWh/m^2-year and 88 kWh/m^2-year **Primary energy use (delivered energy * PEF):** between 36 kWh/m^2-year and 74 kWh/m^2-year
Electricity generation	Not available	Not available	2139 m^2 PV panels
Thermal generation	250 GWh/year in 2050, 28 GWh/year from MaxIV (one of the two research facilities) in 2030	Not available	Not available

Note. The data for Ydalir are from Wiik et al. [51] and Lausselet et al. [62]. The energy demand per floor area is based on the design of two houses that are a part of the first construction step in Ydalir, and the results are scaled up for the whole neighbourhood. The data for Verksbyen are from Lindberg et al. [64]. The data for Vallastaden are from the energy performance calculations available in the municipal archive and from the available energy performance certificates in June 2023. The district data for Brunnshög are from Moallemi et al. [72] and Kraftringen [56], and the building data are from the energy performance calculations available in the municipal archive and available energy performance certificates in June 2023 from Boverket.

neighbourhood with energy ambitions is part of all case studies. In Ydalir, the formulation of the project ambition and the development of the implementation strategy within the master plan fostered a shared understanding among all stakeholders of the challenges and complexity of a ZEN area [24]. The process of developing the master plan improved the stakeholder commitment and reduced uncertainty at the beginning of the planning phase [40]. The master plan functions as a framework for detailed zoning plan development for Ydalir and is a part of the contract between the landowner and the developers. Both Verksbyen and Ydalir received external funding from a Norwegian state enterprise to perform an initial planning study for the energy concept of the neighbourhood, which allowed for an early assessment of low-emission measures with different neighbourhood scenarios and strengthened the energy concept for Verksbyen and master plan for Ydalir [26,92]. Interdisciplinary collaborations are necessary to find optimal energy measures for neighbourhoods, from building specific energy efficiency measures to district energy supply systems, connecting demand and supply. In Verksbyen, energy specialists developed the concept and strategies for a plus energy neighbourhood [64], which functioned as the main tool for implementing energy efficiency measures. In Vallastaden, an overarching plan for the district was developed in 2012 and included the vision for Vallastaden with eleven principles, one of which concerned energy. In 2013, a more detailed program was published and formed the basis for the further development of the district. This program included an overall description of the goals and specific requirements for the public spaces and the buildings, of which six requirements and three recommendations were related to energy. These requirements and recommendations connect to the responsibilities of the municipality, the energy company, and the developers. All buildings in Vallastaden were required to exceed the national building code's energy performance standards by 25 %. Additionally, the developers were required to utilise the municipality's designated software for energy calculations, as different software programs can produce significantly different results. In Brunnshög, the vision for the district is published in an overarching plan for Brunnshög, first developed in 2006, and then redeveloped in 2012. This document outlines the vision of a PED and three goals for the development, one of which is related to energy efficiency, "Minimize climate impact". There is a larger focus on energy concepts at the district level in the Norwegian case studies. However, the Swedish case studies have energy plans on the municipal level. Furthermore, local energy companies play a significant role in the developments, overseeing the district heating network, and entering collaboration agreements with the municipality for the projects.

In Ydalir, Vallastaden and Brunnshög, a key factor is that most of the land is owned by the municipality. For Ydalir, the Norwegian planning and building legislation limits the authority of the municipality to enforce energy efficiency requirements beyond the building code for privately owned land [10]. As previously mentioned, the master plan is a part of the contract between the landowner and developer, applying the ambition and requirements of the master plan to the developer's design and construction. In general, municipalities and urban planners encounter constraints when utilising regulatory planning instruments. A building permit must be approved if it complies with relevant legislation, regulations, and plans, and the room for applying additional energy efficiency measures is limited. In the development of Ydalir issues with managing the entire process emerged because of the necessity for a wide range of expert skills and knowledge. The PED development process involves innovation, is challenging, and is not yet established. For the Swedish case studies, municipal land ownership makes it possible to include energy requirements in the land allocation competition for the developers. Thus, the land allocation competition is an important planning tool in Swedish projects to ensure that the buildings and neighbourhoods perform better than the national building code prescribes for energy efficiency. However, in Vallastaden, energy was not the primary focus of the land allocation competition. Developers had the opportunity to strategise with the point system for land allocation competitions, bypassing the development of passive or plus-energy houses. As a result of the point system used in the land allocation competition, only nine buildings were designed as passive houses. In Brunnshög, the municipality works with land allocation competitions to select developers, including proposals for sustainability measures. Each time, the land allocation competitions have a distinct focus, enabling adaptation over time. There is no prescribed method or predefined list of energy measures mandated to achieve the energy goals in Brunnshög. However, the municipality suggests designing low-energy buildings with low heat losses, low cooling demand, efficient heating and cooling, and efficient electricity use and in the more recent land allocation competitions the installation of photovoltaics is required. Upon being awarded a land allocation contract, a sustainability agreement is established between the municipality and the developer. In this agreement, the three overarching goals for Brunnshög have different subgoals and the document provides information about the actions the municipality and the energy and utility companies of Lund take to reach the goals, and what the developer contributes with, based on their proposal from the land allocation competition. For the buildings commissioned by the municipality of Lund, a sustainability certification system (*Miljöbyggnad* level silver or *Svanen*) must be used, including energy performance requirements that are stricter than the national building code prescribes.

In Ydalir, the municipality is no longer a part of the process once the infrastructure is in place and the plots are sold [5]. An Excel sheet serves as a quality assurance tool and check-list to ensure that the objectives from the master plan are being implemented in four different phases in Ydalir; before the zoning plan/concept phase, before the building permit/design phase, during construction, and when construction is finished [25]. There is no dedicated plan for operational performance. The operational phase in Ydalir will require more management than traditional residential neighbourhoods due to the sharing of services and possibly energy. As part of the syn.ikia research project, Verksbyen has a project evaluation of the energy and indoor environment after one year of monitoring [82]. In Vallastaden, the municipality underestimated the workload of following up on the operational performance of the buildings. The municipality finds it difficult to assess the energy performance of buildings in use (overall set up of monitoring, how to measure performance, when to measure it), and there are difficulties with the legal process if the energy requirements are not met. Data from energy performance certificates were used for performance follow-up on the buildings. Assigning the performance gap to the developers because the energy use measurements are partly dependent on user factors, which developers proved challenging due to the dependency of energy use measurements on user factors, which developers have limited control over. Nevertheless, it is crucial to evaluate the effectiveness of designs in real life, to commission buildings and systems thoroughly, to refine and enhance the operational performance of the neighbourhoods, and to learn and gather insights for the planning and design of future projects. The land allocation competition documents of Brunnshög include three official meetings between the developer and the municipality; first to discuss the ambitions and decide on the following actions, then before the building permit to ensure the ambitions are met, and a final meeting to reflect on the collaboration, process, and results. So far, most developers have delivered what was defined in the sustainability contract. Thus far, developers who have not delivered the requirements outlined in the sustainability contract have not faced any consequences. According to the municipality, a possible consequence could be that the developers are excluded from future projects in Brunnshög. An evaluation of demonstrations and installations of the low-temperature district heating in Brunnshög indicates that the system operates in a techno-economically viable manner. However, the system needs improvement to fulfil the needs of the end-users. The thermal comfort during the first winter was unsatisfying and the users would like more information about the heating system and more frequent feedback on their energy use [72].

4.2.3. Stakeholders

In both Ydalir and Verksbyen, a wide range of stakeholders participated in the initial phases of the project through workshops focused on crafting the vision, energy, and climate-related goals, resulting in the master plan for Ydalir and energy concept for Verksbyen. Key stakeholders were involved in the process of developing the energy concept in Verksbyen, including energy consultants, the developer, an architecture company, a company that develops hybrid solar systems, a smart house solutions provider, a power company, and a photovoltaic panels supplier [92]. Through this process, they experienced an increased understanding of each other's expertise and viewpoint. In contrast, Brunnshög and Vallastaden did not engage such a wide range of experts initially, instead, the concept was developed by the municipality in collaboration with local energy and utility companies. The community engagement process in Ydalir, through the LivingLab, did not start from the beginning of the project and was more oriented towards understanding the community's way of living rather than asking for project input and feedback to consider in the planning and design process [96]. Both perspectives are valuable, but only including one form or perspective of community engagement and consultation can limit the impact on the project outcome. Citizen involvement was less prominent in Brunnshög, Vallastaden, and Verksbyen. An annual social gathering day in Verksbyen was organised for the last two years for existing and future neighbourhood residents to meet and socialise [68]. The aim of the development of Vallastaden was to engage citizens in the planning process. The municipality created different platforms for citizens to participate through; three citizen dialogues and one online platform at the beginning of the process to collect ideas, and exhibitions of the plans for the district in various locations in the city [77]. However, participation methods did not focus on energy specifically [35,77]. In Brunnshög, citizens are involved through resident meetings, city walks, newsletters, an outdoor exhibition (showroom Brunnshög), and events for kids, families, and other target groups. Similar to Vallastaden, citizen involvement is primarily informational and not specifically targeted at energy-related aspects. To conclude, all case studies lack a process for community engagement concerning the energy ambitions of the neighbourhoods.

4.2.4. Framework conditions

The framework conditions of the energy systems for Sweden and Norway are different, where Sweden has a larger share of district heating, while electric heating is the main heating source in Norway. As of 2021, 91.5 % of the power production was from hydro in Norway, 7,5 % was from wind and only 1 % was thermal energy production [88]. In Sweden, 39 % comes from hydropower, 39 % from nuclear, and the rest of the electricity comes from combined heat and power plants (10 %), wind energy (12 %), and solar (0.4 %), where the latter two are increasing [89]. Sweden has one of the highest implementation rates of district heating in Europe, and the implementation rate is on the rise in Norway, driven by the establishment of new waste-to-energy plants. A high implementation rate affects the heating measures implemented in new urban districts, where (low-temperature) district heating networks are more common for the Swedish PEDs, as seen in Vallastaden and Brunnshög.

The framework conditions concerning (national) planning regulations also affect the development of PEDs. The follow-up of the energy performance of new buildings two years after the building is in use is regulated in the national building regulations of Sweden. However, the Swedish case studies show that municipalities are not using energy performance certificates to follow up on the energy requirements, and there are currently no consequences for exceeding the energy consumption stipulated by building codes. In Norway, municipalities lack the authority to reject a building permit application based on requirements beyond the regulations. Landowners and developers are not required to follow the municipal area plan but are required to base their applications on the plans [11]. This implies limitations for ambitious planning projects that move beyond the legislation. For Ydalir, it might lead to lower energy efficiency than the initial goals in the master plan due to resistance from developers and contractors regarding the costs of building to the passive house standard, resulting in lower efficiency and higher greenhouse gas emissions for the whole neighbourhood [52]. At present, there are no dedicated regulations specifically addressing PEDs in Norway [81]. However, a new addition to the Energy Act in Norway allows energy sharing between units/apartments on the same property, with a limit for power generation of 100 kW [76].

5. Discussion

This paper aims to understand how PEDs are planned and designed in practice and contributes to the dissemination, adaptation, and large-scale implementation of energy measures for PEDs, ZENs, SPENs, and similar energy-ambitious district or neighbourhood concepts. As the nature of the planning and design of districts and neighbourhoods are highly context-specific, general recommendations for every PED development are challenging. The energy measures in PEDs must be tailored to suit the local climate, existing infrastructure, available renewable energy sources, and the functions and use of the buildings and district. However, the case studies show that there are several significant factors common for PED projects despite different contexts: early focus on energy efficiency, coupling energy efficiency with energy sufficiency, assessing options for renewable energy generation, developing measures for energy flexibility, aligning interests between stakeholders and sharing a common vision for the development, wide stakeholder involvement, and working interdisciplinary in the planning and design to find optimal energy measures.

The cross-case analysis of the four cases revealed that integrated energy and urban planning is still limited. This is in line with the conclusion of previous studies that found that energy and urban planning are often unintegrated, which decreases the capacity to meet energy targets [15,17,21]. De Pascali and Bagaini [21], conclude that a more strategic approach in urban planning is needed to move beyond short-term actions, policies, and building-scale focused measures to achieve more structural impacts and improved integration. The specific contextual factors of the climate and locally available renewable resources are important in the urban planning and design of the energy systems in PEDs [80,94]. Solar energy in cold climates, such as the Nordic climate, has a large potential for both passive heating and renewable energy supply [73]. Thus, urban planning should account for solar accessibility [65], but municipalities often lack the tools for solar energy integration [34]. Kanters and Wall [50] found that the detailed development plan or zoning plan is an often-overlooked instrument influencing solar energy in buildings [50]. The case studies in this paper included solar studies and solar energy systems. However, the focus has been on the building level rather than on the interaction between buildings and the neighbourhood or district level, which could limit the efficacy of the solutions [21]. Even though the buildings in the case studies are highly energy efficient, increasing the size of housing does not follow the principle of sufficiency, and Lorek and Spangenberg [67] argue that it is necessary to implement policies that target energy sufficiency, by adapting to smaller living spaces with more shared facilities [67]. None of the projects incorporated specific strategies for reducing the living space per person in the design. However, in Ydalir, the aim is to include the sharing of communal spaces, while in Vallastaden community spaces have been developed for shared use. For buildings with different user profiles, coordinating the energy loads through energy balancing can reduce the costs of the power system [4], and improve the energy sufficiency of the neighbourhood by reducing wasted energy. While energy flexibility offers incentives for both energy and utility providers as well as occupants, none of the case studies incorporates explicit measures to enhance energy flexibility at the neighbourhood or district scale. Only in Vallastaden, the electricity grid is designed to manage surplus electricity.

The case studies report energy consumption in different metrics and have used different software and methods to predict energy use and delivered energy to the projects. This challenges comparing the case studies, as the energy data might not be based on the same assumptions. In addition, the use of primary energy factors differs between Norway and Sweden. In Norway, the use of primary energy has been close to nonexistent. However, as of 2023 official primary energy coefficients for the Norwegian energy sources were provided, but they are all equal to 1, assuming fully renewable energy for all sources [54]. Thus, the conversion from delivered and generated energy to primary energy does not affect the energy numbers. Primary energy is more widely used in Sweden. The Swedish case studies report energy performance in primary energy use and have different factors for the different energy sources, as shown in Table 2. There have been debates about the primary energy factors being affected by the allocation, the calculation method, and the value of different energy sources [90]. Bilardo et al. [8] suggest adopting shared primary energy factors to facilitate an adequate comparison between buildings in different geographical contexts. Furthermore, they describe that “the use of current PEFs depends on political choices that do not reflect the actual condition of energy generation and production of European countries” [8].

In the four case studies, the alignment of goals and interests at the beginning of the projects proved crucial, either set by the municipality and communicated to the other stakeholders, or created in collaboration with developers, energy specialists, energy and utility companies, or other involved stakeholders. This confirms previous research indicating the importance of the planning and design phase for energy-efficient technology implementation [18] when the project framework is set. The guidelines for PEDs describe that the development of an energy master plan is significant for high-performance districts [80], arguably the most crucial factor in achieving PEDs. Each of the case studies established a vision and energy goals at the project’s start, providing a clear direction and necessary focus for the development [32]. More specific energy measures, such as passive house requirements, were explicitly stated in the master plans or overarching program or were part of the land allocation process. This is in line with Shnapp et al. [85], showing that building code requirements for energy efficiency on the building scale are still significant to achieve PEDs and SPENs, following the energy efficiency first principle, where highly energy-efficient individual buildings are the precursor, and local RES to cover the low energy demand [85]. A master plan incorporating an integrated energy concept, with active involvement from local energy and utility companies, merges urban planning with energy planning and results in more suitable measures [17]. Innovative measures increase project risks, but national funding schemes could provide support in the pilot stages, where measures are not yet robust, as shown in the Norwegian cases. A sustainability framework or energy measures, together with community engagement and consultation, strengthens the project outcomes in the design and improves the planning and design process. Therefore it should be introduced as early as possible in urban development projects [75].

Several PED studies and guidelines recognise the value of citizen involvement as a key factor for PED implementation [12,55]. Citizens are expected to become more important actors in their role as prosumers or in citizen’s communities [53,55], which requires more citizen involvement in the development of new neighbourhoods and energy systems. The four cases show varying levels of citizen involvement in the development processes, but overall, the engagement of citizens is low. The cases show an initial ambition to include citizens in the process but seem to have difficulties reaching further than workshops or information provision. This is in line with the conclusion of Neij and Heiskanen [74] who show that there is a lack of municipal strategies for citizen participation, that the citizens’ abilities to contribute are disregarded, and that diverging views about the role of citizen contributions exist [74]. Pissourios (2014) argue that bottom-up approaches with citizen participation are more time-consuming when the size of the community increases, require a high level of coordination and planning and must relate to the local interests and consequences (Pissourios, 2014). Citizen involvement should be designed to work efficiently, targeted at factors that affect the citizens directly or indirectly. Koutra et al. [55] demonstrated that in PED research technological innovation has taken precedence over citizen engagement, a trend mirrored in practice shown in the case study of these four cases. Koutra et al. [55] emphasise future research on “how bottom-up initiatives will be incorporated for the co-creation of PED designs” [55] to which we would like to add future research on the capabilities and the role and responsibility of the initiating stakeholder in collaborative governance and citizen involvement.

As described in the background, process management of a PED is important to facilitate and coordinate the development and management of the district [48,85,94]. The four cases differ in the roles and responsibilities of the stakeholders involved. In both the Swedish cases and one Norwegian case, municipalities took the lead and were responsible for the overall management of the planning process, aligning with the recommendations of Vandevyvere et al. [94]. The other Norwegian case is initiated and managed by the developer, fostering long-term involvement and responsibility. The involvement of municipality-owned energy companies plays an increasingly significant role in the Swedish cases, with their responsibilities formalised through collaboration contracts and designated roles. In the Norwegian cases, the energy consultants play an important role and are included from the beginning of the process. In the cases initiated by the municipality, after the land allocation competition, the developers are the main stakeholders in the design and construction phase of the buildings, and the role of the municipality becomes less clear. This is in line with previous studies, highlighting the dependence on the participation of the private sector in the implementation of plans [74,79]. However, only limited practices of follow-up and evaluation of energy requirements are found in the case studies. As discovered in previous studies, there are no consequences for exceeding energy use stipulated by building codes [43,61,78,95]. Sareen et al. [84] and Vandevyvere et al. [94] highlighted the importance of (adaptive) monitoring for impact assessment, but also for the scaling up and replication of measures for PEDs.

6. Conclusion

This paper shows that planning and development of positive energy districts and sustainable plus energy neighbourhoods is complex and requires diverse expertise within energy and urban planning, from the building level to the urban scale and new measures to achieve high energy efficiency, local renewable energy generation, energy storage and flexibility, and energy sufficiency. This paper develops and uses a new analytical framework for the planning and design of PEDs to examine the implementation of energy measures in four positive energy district and neighbourhood development projects in Norway and Sweden. The development and implementation of a master plan including PED ambitions and goals is arguably the most important factor in achieving PEDs and SPENs, fostering alignment of interests among stakeholders in an early phase. Land allocation competitions function as an important tool for the implementation of energy measures in cases of municipal landownership. Pilot projects and innovations incur risk, and external funding for the initial planning stages can provide support when PED and SPEN measures are not yet robust. However, the cases show a lack of follow-up procedures for the implementation of energy measures by the developers, and there are no consequences for failing to meet them. Lastly, the study highlights that it is necessary to focus on both the building and the neighbourhood/district level to increase energy efficiency, energy sufficiency, and energy flexibility. This requires interdisciplinary cooperation in the planning and design to find optimal energy measures, and consequently lower the environmental impact of the whole development project.

We recommend further research to focus on the operational phase of PEDs and SPENs to provide a deeper understanding of the actual outcome of the planning and design processes of PEDs and SPENs, and to improve the understanding of how to operate such districts and neighbourhoods to achieve low energy consumption and environmental impact. Furthermore, future research on the capabilities, roles and responsibilities of initiating stakeholders in collaborative governance and citizen involvement and engagement is crucial.

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CRediT authorship contribution statement

Tonje Healey Trulsrud: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Janneke van der Leer:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix. Overview of the empirical material used for the case study analysis

Interviews

Role	Organisation	Duration
Project manager	Municipality of Linköping	1 h
Project manager	Municipality of Linköping	1 h
Technical manager	An energy company in Linköping	1 h
Quality manager	Consulting company (Vallastaden)	1 h
Project manager	Municipality of Lund	1 h
Urban planner	Municipality of Lund	1 h
Developer and Architect	Verksbyen	1 h
Developer	Verksbyen	1 h

Documents

Name of the document	Author
Idea program (Idéprogram)	Municipality of Linköping (2012)
Quality program (Kvalitetsprogram)	Municipality of Linköping (2013)
What have we learned so far? (Vad har vi lärt oss hittils?)	Municipality of Linköping (2018)
Brunnshög contract 2013 (Brunnshögskontraktet 2013)	Municipality of Lund, Lunds Energi, VASyd, Lunds Renhållningsverk (2013)
Lund NE/Brunnshög – Vision and goals (Lund NE/Brunnshög – Vision och mål)	Municipality of Lund (2012)
Sustainability PM Brunnshög: Action program for future societal challenges, Version 2 (Hållbarhets-PM Brunnshög: Åtgärdsprogram för framtidens samhällsutmaningar, Version 2)	Municipality of Lund (2018)
Sustainability in Brunnshög: how the district reaches Lund municipality's goals (Hållbarhet i Brunnshög: hur stadsdelen når Lunds Kommuns mål)	Municipality of Lund (2022)
Ydalir Master plan Part 1 (Ydalir Masterplan Del 1)	Elverum Tomteselskap, Tegn_3, Asplan Viak
Ydalir Master plan Part 2 (Ydalir Masterplan Del 2)	Elverum Tomteselskap, Tegn_3, Asplan Viak
Planning description for the detailed zoning plan for Ydalir B4 (Planbeskrivelse til Detaljregulering for Ydalir B4)	Plan 1, Elverum Tomteselskap
Zoning regulations for the detailed zoning plan for Ydalir B7 (Reguleringsbestemmelser til Detaljregulaering for Ydalir B7)	Municipality of Elverum
Status report 2022 Ydalir (Statusrapport 2022 Ydalir)	FME ZEN
Theory meets practice – is environmentally firendly buildings economically viable?) (Teori møter praksis – er miljøriktige bygg økonomisk gjennomførbare?)	FME ZEN
Climate and Energy in Elverum 2020–2024 (Klima og Energi i Elvrum 2020–2024)	Municipality of Elverum
Concept study energy system Verksbyen (Konseptutredning energy system Verksbyen)	Multiconsult, Arca Nova

References

[1] B. Alpagut, A. Gabaldón, Guidelines for Positive Energy District Design: How to Transform a district into a PED, 2020.

[2] I. Andresen, T. Healey Trulsrud, L. Finocchiaro, A. Nocente, M. Tamm, J. Ortiz, J. Salom, A. Magyari, L. Hoes-van Oeffelen, W. Borsboom, W. Kornaat, N. Gaitani, Design and performance predictions of plus energy neighbourhoods – Case studies of demonstration projects in four different European climates, Energ. Buildings 274 (2022) 112447. https://doi.org/10.1016/j.enbuild.2022.112447.

[3] Arca Nova. (n.d.). Verksbyen Future Living. Retrieved June 28, 2023, from https://www.arcanova.no/verksbyen/future_living.

[4] M. Askeland, S. Backe, K.B. Lindberg, Zero energy at the neighbourhood scale: Regulatory challenges regarding billing practices in Norway, IOP Conference Series: Earth and Environmental Science 352 (1) (2019) 012006, https://doi.org/10.1088/1755-1315/352/1/012006.

[5] D. Baer, M. Haase, Energy Master Planning on neighbourhood level: learnings on stakeholders and constraints from the Norwegian case of Ydalir, IOP Conf. Ser.: Earth Environ. Sci 588 (2) (2020) 22001, https://doi.org/10.1088/1755-1315/588/2/022001.

[6] D. Baer, B. Loewen, C. Cheng, J. Thomsen, A. Wyckmans, A. Temeljotov-salaj, D. Ahlers, Approaches to social innovation in positive energy districts (Peds)—a comparison of norwegian projects, Sustainability (Basel, Switzerland) 13 (13) (2021) 7362, https://doi.org/10.3390/su13137362.

[7] V.M. Barthelmes, C. Becchio, S.P. Corgnati, Occupant behavior lifestyles in a residential nearly zero energy building: Effect on energy use and thermal comfort, Sci. Technol. Built Environ. 22 (7) (2016) 960–975, https://doi.org/10.1080/23744731.2016.1197758.

[8] M. Bilardo, S. Galatà, E. Fabrizio, The role of Primary Energy Factors (PEF) for electricity in the evaluation and comparison of building energy performance: An investigation on European nZEBs according to EN 17423:2020, Sustain. Cities Soc. 87 (2022), https://doi.org/10.1016/j.scs.2022.104189.

[9] A. Bisello, G. Grilli, J. Balest, G. Stellin, M. Ciolli, Co-benefits of Smart and Sustainable Energy District Projects: An Overview of Economic Assessment Methodologies, Smart and Sustainable Planning for Cities and Regions (2016).
[10] Bø, L. A., Askeland, M. (2020). ZEN and the legislations.
[11] Bø, L. A., Junker, E., Askeland, M. (2020). ZEN og lovverket: Muligheter og begrensninger i dagens lovverk ved utvikling av et ZEN område.
[12] S. Bossi, C. Gollner, S. Theierling, Towards 100 positive energy districts in europe: Preliminary data analysis of 61 European cases, Energies 13 (22) (2020), https://doi.org/10.3390/en13226083.
[13] Boverket. (2021). Planning process. https://www.boverket.se/en/start/building-in-sweden/developer/planning-process/.
[14] J. Brozovsky, A. Gustavsen, N. Gaitani, Zero emission neighbourhoods and positive energy districts – A state-of-the-art review, Sustain. Cities Soc. 72 (2021), https://doi.org/10.1016/j.scs.2021.103013.
[15] S. Cajot, M. Peter, J.M. Bahu, F. Guignet, A. Koch, F. Maréchal, Obstacles in energy planning at the urban scale, Sustain. Cities Soc. 30 (2017) 223–236, https://doi.org/10.1016/j.scs.2017.02.003.
[16] S. Cajot, M. Peter, J.-M. Bahu, A. Koch, F. Maréchal, Energy Planning in the Urban Context: Challenges and Perspectives, Energy Procedia 78 (2015) 3366–3371. https://doi.org/10.1016/j.egypro.2015.11.752.
[17] Cajot, S., Schüler, N. (2019). Urban energy system planning: Overview and main challenges. In Urban Energy Systems for Low-Carbon Cities (Issue March, pp. 1–463). Elsevier. https://doi.org/10.1016/C2016-0-00821-5.
[18] J. Carlander, P. Thollander, Barriers to implementation of energy-efficient technologies in building construction projects — Results from a Swedish case study, Resources, Environ. Sustain. 11 (2023) 100097. https://doi.org/10.1016/j.resenv.2022.100097.
[19] Cities4PEDs. (2021). PED Atlas: From 7 case interviews to recurring strategies and PED relevant.
[20] Darby, S., Fawcett, T. (2018). Energy sufficiency: an introduction. Concept Paper. European Council for an Energy Efficient Economy, Stockholm.
[21] P. De Pascali, A. Bagaini, Energy transition and urban planning for local development. A critical review of the evolution of integrated spatial and energy planning, Energies 12 (1) (2019) 1–21, https://doi.org/10.3390/en12010035.
[22] Derkenbaeva, E., Halleck Vega, S., Hofstede, G. J., van Leeuwen, E. (2022). Positive energy districts: Mainstreaming energy transition in urban areas. In Renewable and Sustainable Energy Reviews (Vol. 153). Elsevier Ltd. https://doi.org/10.1016/j.rser.2021.111782.
[23] O. Ellabban, H. Abu-Rub, F. Blaabjerg, Renewable energy resources: Current status, future prospects and their enabling technology, Renew. Sustain. Energy Rev. 39 (2014) 748–764. https://doi.org/10.1016/j.rser.2014.07.113.
[24] Elverum Kommune, Asplan Viak, TEGN_3. (2017). Ydalir Masterplan Del 1. In Versjon 2 (2nd ed.). Elverum kommune.
[25] Elverum Tomteselskap, FME ZEN. (2021). Sjekkliste-Masterplan-krav-gjeldende.
[26] Elverum Vekst, TEGN_3, Asplan Viak. (2017). Ydalir Masterplan Del 1. In Versjon 2 (2nd ed.). Elverum kommune.
[27] Elverum Vekst, Tegn_3, Asplan Viak. (2019). Ydalir Masterplan Del 2 - Ambisjoner og Krav. In Versjon 4 (4th ed.). Elverum kommune.
[28] K. Emerson, T. Nabatchi, S. Balogh, An integrative framework for collaborative governance, J. Public Adm. Res. Theory 22 (1) (2012) 1–29, https://doi.org/10.1093/jopart/mur011.
[29] S. Erba, L. Pagliano, Combining sufficiency, efficiency and flexibility to achieve positive energy districts targets, Energies 14 (15) (2021), https://doi.org/10.3390/en14154697.
[30] European Commission. (2019). A European Green Deal. https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.
[31] C. Far, I. Ahmed, J. Mackee, Significance of occupant behaviour on the energy performance gap in residential buildings, Architecture 2 (2) (2022) 424–433, https://doi.org/10.3390/architecture2020023.
[32] J. Fischer, D. Alimi, J. Knieling, C. Camara, Stakeholder collaboration in energy transition: Experiences from urban testbeds in the baltic sea region, Sustainability (Switzerland) 12 (22) (2020) 1–12, https://doi.org/10.3390/su12229645.
[33] B. Flyvbjerg, Five misunderstandings about case-study research, Qual. Inq. 12 (2) (2006) 219–245, https://doi.org/10.1177/1077800405284363.
[34] M. Formolli, G. Lobaccaro, J. Kanters, Solar energy in the nordic built environment: challenges, opportunities and barriers, Energies 14 (24) (2021), https://doi.org/10.3390/en14248410.
[35] Glad, W., Gramfält, M. (2019). The vallastaden model - Alternative urban governance and energy system designs. Eceee Summer Study Proceedings, 2019-June, 805–815.
[36] Global Alliance for Buildings and Construction, International Energy Agency, & United Nations Environment Programme. (2019). 2019 Global Status Report for Buildings and Construction: Towards a zero-emissions, efficient and resilient buildings and construction sector. International Energy Agency.
[37] F. Guarino, R. Rincione, C. Mateu, M. Teixidó, L.F. Cabeza, M. Cellura, Renovation assessment of building districts: Case studies and implications to the positive energy districts definition, Energ. Buildings 296 (2023), https://doi.org/10.1016/j.enbuild.2023.113414.
[38] O. Guerra-Santin, L. Itard, Occupants' behaviour: determinants and effects on residential heating consumption, Build. Res. Inf. 38 (3) (2010) 318–338, https://doi.org/10.1080/09613211003661074.
[39] Gustafsson, S., Andréen, V. (2018). Local Spatial Planning Processes and Integration of Sustainability Perspective Through a Broad Systems Perspective and Systematic Approach. In Handbook of Sustainability Science and Research (Issue November, pp. 567–580). https://doi.org/10.1007/978-3-319-63007-6.
[40] Haase, M., Baer, D. (2021). Constraints, Stakeholders, and Framing Goals in Energy Master Planning Between Neighborhood and District. 3–13. https://doi.org/10.1007/978-3-030-57764-3_1.
[41] Halachmi, A., Holzer, M. (2010). Citizen participation and performance measurement: operationalizing democracy through better accountability. 34(3), 378–399. https://www.jstor.org/stable/41288353.
[42] Hedström, R.T., Lundström, M. J. (2013). Swedish Land-use Planning Legislation. In Planning and Sustainable Urban Development in Sweden (pp. 69–82).
[43] C. Hjortling, F. Björk, M. Berg, T.A.F. Klintberg, Energy mapping of existing building stock in Sweden – Analysis of data from Energy Performance Certificates, Energ. Buildings 153 (2017) 341–355, https://doi.org/10.1016/j.enbuild.2017.06.073.
[44] S. Hu, X. Zhou, D. Yan, F. Guo, T. Hong, Y. Jiang, A systematic review of building energy sufficiency towards energy and climate targets, Renew. Sustain. Energy Rev. 181 (2023) 113316. https://doi.org/10.1016/j.rser.2023.113316.
[45] H. Ibrahim, A. Ilinca, J. Perron, Energy storage systems—Characteristics and comparisons, Renew. Sustain. Energy Rev. 12 (5) (2008) 1221–1250. https://doi.org/10.1016/j.rser.2007.01.023.
[46] K. Isaksson, S. Heikkinen, Sustainability transitions at the frontline. Lock-in and potential for change in the local planning arena, Sustainability (Switzerland) 10 (3) (2018), https://doi.org/10.3390/su10030840.
[47] S.Ø. Jensen, A. Marszal-Pomianowska, R. Lollini, W. Pasut, A. Knotzer, P. Engelmann, A. Stafford, G. Reynders, IEA EBC Annex 67 energy flexible buildings, Energ. Buildings 155 (2017) 25–34. https://doi.org/10.1016/j.enbuild.2017.08.044.
[48] JPI Urban Europe / SET-Plan Action 3.2. (2020). White Paper on Reference Framework for Positive Energy Districts and Neighbourhoods. https://jpi-urbaneurope.eu/ped/.
[49] K. Aarland, J. Sørvoll, O. Met, Norsk boligpolitikk i internasjonalt perspektiv, NOVA (2021).
[50] J. Kanters, M. Wall, Experiences from the urban planning process of a solar neighbourhood in Malmö, Sweden, Urban, Plann. Transp. Res. 6 (1) (2018) 54–80, https://doi.org/10.1080/21650020.2018.1478323.
[51] Kjendseth Wiik, M., Fjellheim, K., Vandervaeren, Krekling Lien, S., Meland, S., Nordström, T., Baer, D., Cheng, C., Truloff, S., Brattebø, H., Gustavsen, A. (2022). Zero emission neighbourhoods in smart cities definition, assessment criteria and key performance indicators: Version 3.0.
[52] Kjendseth Wiik, M., Schneider-Marin, P., González Fernández, I., Winsvold, J., Rosochacki, L., Nøstebøen, S., Tonjer, A.-T., Erikstad, H. (2022). TEORI MØTER PRAKSIS – ER MILJØRIKTIGE BYGG ØKONOMISK GJENNOMFØRBARE? Scenarioanalyse av konstruksjonsvalg på Ydalir.
[53] Kojonsaari, A.-R., Palm, J. (2021). Distributed Energy Systems and Energy Communities Under Negotiation. 9, 1–21.
[54] Kommunal- og distriktsdepartementet. (2023). Veiledning om beregning av primærenergibehov i bygninger og energirammer for nesten nullenergibygninger .
[55] Koutra, S., Terés-Zubiaga, J., Bouillard, P., Becue, V. (2023). 'Decarbonizing Europe' A critical review on positive energy districts approaches. In Sustainable Cities and Society (Vol. 89). Elsevier Ltd. https://doi.org/10.1016/j.scs.2022.104356.
[56] Kraftringen. (2022). Hållbarhetsrapport för verksamhetsåret 2021.
[57] S.G. Krangsås, K. Steemers, T. Konstantinou, S. Soutullo, M. Liu, E. Giancola, B. Prebreza, T. Ashrafian, L. Murauskaitė, N. Maas, Positive energy districts: Identifying challenges and interdependencies, Sustainability (Switzerland) 13 (19) (2021), https://doi.org/10.3390/su131910551.
[58] A. Krehl, S. Weck, Doing comparative case study research in urban and regional studies: what can be learnt from practice? Eur. Plan. Stud. 28 (9) (2020) 1858–1876, https://doi.org/10.1080/09654313.2019.1699909.
[59] Krekling Lien, S., Tonjer, A.-T., Kjendseth Wiik, M., Bergsdal, H. (2022). Statusrapportering for pilotprosjekt Ydalir i Elverum kommune 2022.
[60] Kristjansdottir, T., Fjeldheim, H., Selvig, E., Risholt, B., Time, B., Georges, L., Dokka, T. H., Bourelle, J., Bohne, R., Cervenka, Z. (2014). A Norwegian ZEB-definition embodied emission.
[61] A.L. Lane, M. Cehlin, T. Gustavsson, Byggae - Method for quality assurance of energy efficient buildings, Int. J. Energy Prod. Manage. 2 (2) (2017) 133–139, https://doi.org/10.2495/EQ-V2-N2-133-139.
[62] C. Lausselet, K.M. Lund, H. Brattebø, LCA and scenario analysis of a Norwegian net-zero GHG emission neighbourhood: The importance of mobility and surplus energy from PV technologies, Build. Environ. 189 (2021) 107528. https://doi.org/10.1016/j.buildenv.2020.107528.
[63] Y. Li, J. O'Donnell, R. García-Castro, S. Vega-Sánchez, Identifying stakeholders and key performance indicators for district and building energy performance analysis, Energ. Buildings 155 (2017) 1–15, https://doi.org/10.1016/j.enbuild.2017.09.003.
[64] Lindberg, P. F., Selstrøm, A., Marte, M., Carl, M., Kaas, G., Jarstein, S., Winther, R., Petersen, A. K., Kap, Godager Kaas, C. (2019). Konseptutredning energisystem Verksbyen-Sluttrapport til Enova.
[65] G. Lobaccaro, S. Carlucci, S. Croce, R. Paparella, L. Finocchiaro, Boosting solar accessibility and potential of urban districts in the Nordic climate: A case study in Trondheim, Sol. Energy 149 (2017) 347–369. https://doi.org/10.1016/j.solener.2017.04.015.
[66] D. Longo, S.O.M. Boulanger, M. Massari, G. Turci, Energy citizenship. tools and technologies to enable transition in districts, Techne. J. Technol. Architect. Environ. (2022). https://doi.org/10.36253/techne-13721.
[67] S. Lorek, J.H. Spangenberg, Energy sufficiency through social innovation in housing, Energy Policy 126 (2019) 287–294. https://doi.org/10.1016/j.enpol.2018.11.026.

[68] Mafé Cortés, C., Utaker, O.-E., van den Oord, T., Mair ma Tinkhof, O., Megías Lupiañez, P., Barret, M. (2022). D7.22 Report on stakeholder and user engagement activities.
[69] A. Magrini, G. Lentini, S. Cuman, A. Bodrato, L. Marenco, From nearly zero energy buildings (NZEB) to positive energy buildings (PEB): The next challenge - The most recent European trends with some notes on the energy analysis of a forerunner PEB example, Dev. Built Environ. 3 (2020) 100019, https://doi.org/10.1016/j.dibe.2020.100019.
[70] A. Mahdavi, C. Berger, H. Amin, E. Ampatzi, R.K. Andersen, E. Azar, V. M. Barthelmes, M. Favero, J. Hahn, D. Khovalyg, H.N. Knudsen, A. Luna-Navarro, A. Roetzel, F.C. Sangogboye, M. Schweiker, M. Taheri, D. Teli, M. Touchie, S. Verbruggen, The role of occupants in buildings' energy performance gap: myth or reality? *Sustainability* 13 (6) (2021) https://doi.org/10.3390/su13063146.
[71] Mattsson, M., Nair, G., Olofsson, T., Lundberg, L., Kordas, O. (2022). Challenges and drivers for Positive Energy Districts in a Swedish context. Summer Study Proceedings of the European Council for an Energy Efficient Economy, September, 1–14. https://www.eceee.org/library/conference_proceedings/eceee_Summer_Studies/2022/5-towards-sustainable-and-resilient-communities/challenges-and-drivers-for-positive-energy-districts-in-a-swedish-context/.
[72] Moallemi, A., Gadd, H., Sernhed, K. (2023). Cool ways of using low grade Heat Sources from Cooling and Surplus Heat for heating of Energy Efficient Buildings with new Low Temperature District Heating (LTDH) Solutions.
[73] M. Mussard, Solar energy under cold climatic conditions: A review, Renew. Sustain. Energy Rev. 74 (2017) 733–745. https://doi.org/10.1016/j.rser.2017.03.009.
[74] Neij, L., Heiskanen, E. (2021). Municipal climate mitigation policy and policy learning - A review. In Journal of Cleaner Production (Vol. 317). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2021.128348.
[75] A. Oliver, D.S. Pearl, Rethinking sustainability frameworks in neighbourhood projects: a process-based approach, Build. Res. Inf. 46 (5) (2018) 513–527, https://doi.org/10.1080/09613218.2017.1358569.
[76] Olje- og energidepartementet. (2023). Forskrift om endringer i forskrift om økonomisk og teknisk rapportering, inntektsramme for nettvirksomheten og tariffer (forskrift om kontroll av nettvirksomhet) og i forskrift om måling, avregning, fakturering av nettjenester og elektrisk energi, nettselskapets nøytralitet mv. (forskrift om kraftomsetning og nettjenester). In Energiloven (§3-12).
[77] Palm, J., Wihlborg, E. (2013). Vallastaden växer fram - Policy och Planering för en ny stadsdel.
[78] D. Parks, Energy efficiency left behind? Policy assemblages in Sweden's most climate-smart city, Eur. Plan. Stud. 27 (2) (2019) 318–335, https://doi.org/10.1080/09654313.2018.1455807.
[79] J.P. Petersen, E. Heurkens, Implementing energy policies in urban development projects: The role of public planning authorities in Denmark, Germany and the Netherlands, Land Use Policy 76 (May) (2018) 275–289, https://doi.org/10.1016/j.landusepol.2018.05.004.
[80] Pless, S., Polly, B., Houssainy, S., Torcellini, P., Livingood, W., Zaleski, S., Jungclaus, M., Hootman, T., Craig, M. (2020). A guide to energy master planning of high-performance districts and communities.
[81] Rieke Boll, J., Doriaz, V., Broer, R., Toth, Z. (2021). Policy mapping and analysis of plus-energy buildings and neighbourhoods.
[82] Salom, J., Tamm, M., Pascual, J., Civiero, P., Andresen, I., Gaitani, N., Crespo del Granado, P., Doriaz, V., Toth, Z., Zuhaib, S., Magyari, Á., Bukocszki, V., Reith, A., Cali, D., Junker, R. G., Cheng, C., Kvellheim, A. K., Mafe, C. (2020). D3.1 Methodology framework for plus energy buildings and neighbourhoods. syn.ikia. https://www.synikia.eu/wp-content/uploads/2020/12/D3.1_Methodology-framework-for-Plus-Energy-Buildings-and-Neighbourhoods.pdf.
[83] N.H. Sandberg, I. Sartori, M.I. Vestrum, H. Brattebø, Using a segmented dynamic dwelling stock model for scenario analysis of future energy demand: The dwelling stock of Norway 2016–2050, Energ. Buildings 146 (2017) 220–232. https://doi.org/10.1016/j.enbuild.2017.04.016.
[84] S. Sareen, V. Albert-Seifried, L. Aelenei, F. Reda, G. Etminan, M.-B. Andreucci, M. Kuzmic, N. Maas, O. Seco, P. Civiero, S. Gohari, M. Hukkalainen, H.-M. Neumann, Ten questions concerning positive energy districts, Build. Environ. 216 (2022) 109017. https://doi.org/10.1016/j.buildenv.2022.109017.
[85] Shnapp, S., Paci, D., Bertoldi, P. (2020). Enabling Positive Energy Districts across Europe: energy efficiency couples renewable energy. https://doi.org/10.2760/452028.
[86] G. Squires, E. Heurkens, Methods and models for international comparative approaches to real estate development, Land Use Policy 50 (2016) 573–581, https://doi.org/10.1016/j.landusepol.2015.10.005.
[87] Standard Norge. (2013). NS 3700:2013 Kriterier for passivhus og lavenergibygninger Boligbygninger.
[88] Statistisk sentralbyrå. (2023, May 15). Elektrisitet: Elektrisitetsbalanse (GWh). https://www.ssb.no/energi-og-industri/energi/statistikk/elektrisitet.
[89] Swedish Energy Agency. (2022). Energy in Sweden 2022 – An overview.
[90] M. Swing Gustafsson, M. Gustafsson, J.A. Myhren, E. Dotzauer, Primary energy use in buildings in a Swedish perspective, Energ. Buildings 130 (2016) 202–209, https://doi.org/10.1016/j.enbuild.2016.08.026.
[91] syn.ikia. (2020). https://www.synikia.eu.
[92] Trulsrud, T. H., Andresen, I., van den Oord, T., Estrada Aliberas, J., Strassl, I., Mair am Tinkhof, O., Gaitani, N. (2023). D2.9 integrated energy design guidelines for sustainable plus energy neigbhourhoods.
[93] van der Leer, J., Calvén, A., Glad, W., Femenías, P., Sernhed, K. (2023). Energy systems in sustainability-profiled districts in Sweden: A literature review and a socio-technical ecology approach for future research. In Energy Research and Social Science (Vol. 101). Elsevier Ltd. https://doi.org/10.1016/j.erss.2023.103118.
[94] Vandevyvere, H., Ahlers, D., Alpagut, B., Cerna, V., Cimini, V., Haxhija, S., Hukkalainen, M., Kuzmic, M., Livik, K., Padilla, M., Poel, M., Montalvillo, C. S., Schouten, S., Myrstad, T., Van Wees, M., Williams, K., Wyckmans, A., Gabaldon, A., Fernandez Perez, N., … Smok, A. (2020). Positive Energy Districts Solution Booklet.
[95] J.A. Vogel, P. Lundqvist, P. Blomkvist, J. Arias, Problem areas related to energy efficiency implementation in Swedish multifamily buildings, Energ. Effi. 9 (1) (2016) 109–127, https://doi.org/10.1007/s12053-015-9352-4.
[96] R. Woods, T. Berker, Homelife in a Norwegian forest: a rural approach to the sustainable transition, Sustainability: Science, Practice and Policy 18 (1) (2022) 636–650, https://doi.org/10.1080/15487733.2022.2108254.
[97] X. Zhang, S.R. Penaka, S. Giriraj, M.N. Sánchez, P. Civiero, H. Vandevyvere, Characterizing positive energy district (Ped) through a preliminary review of 60 existing projects in Europe, Buildings 11 (8) (2021) 318, https://doi.org/10.3390/buildings11080318.
[98] Y. Zhang, X. Bai, F.P. Mills, J.C.V. Pezzey, Rethinking the role of occupant behavior in building energy performance: A review, Energ. Buildings 172 (2018) 279–294, https://doi.org/10.1016/j.enbuild.2018.05.017.