FLEXPOSTS

FLEXIBLE ENERGY POSITIVITY DISTRICTS

Report:

Developing Methodologies for Implementing PEDs

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Table of Contents

1 Introduction

Positive Energy Districts (PEDs) can play an important role in the energy transition for urban areas. Implementation of PEDs require integration of energy planning in urban planning processes, as well as a committed network of stakeholders from the public and private sector. The aim of FLEXPOSTS (FLEXible energy POSitivity districTS) is to develop effective and replicable strategies to enhance the process of establishing PEDs. A major emphasis is placed on engaging stakeholders and developing innovative business models for flexible energy systems. FLEXPOSTS will apply an interdisciplinary approach for integrating energy and urban planning. This approach is demonstrated in two demo sites, Zwette VI (Leeuwarden, the Netherlands), and Aalborg East (Aalborg, Denmark). In these demos, the lessons learnt and new insights from research will be translated to practice and vice versa. More specifically, Zwette VI focusses on energy system planning issues hindering further urban development and application of flexibility. Aalborg East focusses on a mixed-use neighbourhood with established partnerships between local stakeholders, seeking to implement solutions with the ambition of moving towards net-zero emissions. The project results will facilitate the emergence of PEDs as green energy solutions for urban areas, but also the enabling of PEDs as a solution for energy system planning issues, such as electricity grid congestion.

This report outlines the methodological approach that will guide the analysis of how to implement PEDs in the two demo sites. The targeted audience of the report is the FLEXPOSTS consortium for internal knowledge sharing as well as the expert facility group of the JPI Urban Europe PED research program.

1.1 The societal challenges and PEDs

For urban areas to become energy positive, many challenges exist. For example, building design, development of renewable energy sources, energy system planning, and stakeholder engagement should be aligned with other urban planning and sustainable development needs. These requirements go beyond the challenges faced in the energy transition, also including aspects such as economic development, facilitating business and job opportunities, social inclusion, environmental quality, air quality, affordable housing, welfare standards, digitalization, etc. As such, inclusive and sustainable designs for future urban areas are being developed. FLEXPOSTS combines the multiple challenges of sustainable, affordable, and accessible urban areas. In search of such designs, sustainable energy system planning should be embraced to facilitate these options. To do so, an interdisciplinary approach should be applied, combining multiple challenges in search for sustainable, affordable, and accessible urban areas.

The specific challenges for sustainable energy systems are especially in energy intensive and densely populated areas, as the integration of renewable energy is challenging. Renewable energy production requires development of new production (re)sources, and because of the intermittent character of e.g. solar and wind energy, also comes with several operational challenges. One of the challenges is the balancing of electricity systems, and steeply increasing demands for peak transport capacity in the electricity distribution and transport systems. For urban areas to become energy positive, these challenges need to be rapidly addressed.

In each of the two case study countries, the challenge is different. In the Netherlands, the increasing demand for sustainable electricity and the growing supply of fluctuating renewable electricity, is causing the electricity system to become congested. Currently, the existing methods to solve these congestions do not include flexibility (by applying congestion management) but only focus on increasing grid capacity. This problem presently occurs in the Netherlands and is expected to occur in many urban areas across the EU. Congestion not only puts a hold on the further development of renewable energy sources, as they cannot be integrated in the electricity system, but also hinders urban planning processes and regulations. All businesses, houses and public buildings need connections to the electricity system. Waiting for grid expansions is very time consuming, as it can take up to five or more years. This is a significant hurdle for further urban development. Another challenge is replacing fossil-based heat sources with sustainable alternatives. One of the solutions would be to use residual heat from industry. This requires coordination and planning of both the spatial planning and the energy system. At present, such coordination is not common practice.

The situation in Denmark is different. Whilst in the Netherlands district heating is emerging, Denmark already largely utilises district heating that consists of supplying sustainable heating to urban areas. Here the challenge is shifting to lower temperature district heating and to integrate more renewable heat sources, including industrial waste and geothermal heat and heat pumps, among others. Coupled with this is the need to refurbish buildings to lower heat demands. Denmark has a high share of renewable electricity already but to shift to high levels of renewable energy requires production of hydrogen-based fuels to replace transport fuels and this requires more electricity. This increased electricity again is expected to cause congestion issues in the future. The common challenge of the FLEXPOSTS project therefore is to decrease electricity demand and to increase electricity flexibility where possible.

1.2 The aim of FLEXPOSTS

FLEXPOSTS addresses the common challenges that both the Netherlands and Denmark face in various aspects of the energy transition. Furthermore, it emphasizes the need to integrate energy planning into existing urban planning processes. If these planning processes are not aligned, problems will arise, such as grid congestion or inefficient use of energy. Aligning both processes will enhance efficient use of space, energy resources and infrastructure. In this setting, PEDs are considered as a challenge within the currently available energy infrastructure, and as a solution for creating increased energy flexibility. The challenges which accompany the alignment of urban and energy system planning are the focus of this project. These challenges range from a lack of incentives or legislations for various stakeholders in investing in solutions for congestion, other than time and capital-intensive grid expansions, to a lack of renewable heat sources with sufficient reliability and flexibility, a lack of integrated planning procedures to align various requirements and aspects in developing PEDs. When stakeholders do invest in measures to reduce CO_2-emissions, this is often done on ad hoc basis without any overall strategy. Therefore, there is a huge potential in identifying relevant stakeholders, networks and partnerships and joining these up in an overall PED network, which actions are guided by a PED strategy. Yet it requires a different approach from todays' current practises.

FLEXPOSTS aims to develop and deliver such a 'different approach'. By including the existing energy system and pathways for future energy systems, urban development could be facilitated; PEDs could become the new standard for urban (de)development. However, FLEXPOSTS does not only aim at developing positive energy (urban) areas, but also at utilizing urban planning for improving the planning of energy systems. For example, to tackle congestion in the electricity system, or to make more efficient use of residual heat, etc. FLEXPOSTS aims to introduce new methods and approaches for *combined* urban and energy system planning, including all relevant energy carriers. It aims to do so by using existing (state of the art) knowledge, tools, and experience from earlier projects, and combining them into a unique toolbox. Moreover, inclusive, circular, and sustainable business case designs, including flexibility, which are adapted to the relevant planning and decision-making processes, are aimed to be developed, tested, and implemented in FLEXPOSTS. FLEXPOSTS will accelerate in both scientific and practical impact on combined urban and energy system planning, working further towards the implementation of PEDs. Ultimately FLEXPOSTS will contribute to a more fundamental unanswered question: how to best align urban planning with energy system planning to facilitate the energy transition?

1.3 PEDs in FLEXPOSTS

With the increasing challenges presented by climate change, planning for sustainable urban transition and transformation has recently become concerned with the energy transition and its impact on cities.

To this end, concepts such as Zero-Emission Neighbourhoods (ZENs) and Positive Energy Districts (PEDs) have been established as new models for planning in neighbourhoods and suburban areas with the aim of no excess greenhouse gases over the span of a year, and potentially positively contributing to the net energy production. JPI Urban Europe has defined a PED as:

> Positive Energy Districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability. (JPI Urban Europe, 2020: 4)

Within the JPI Urban Europe PED community, this definition of a PED has continuously been discussed, and it is recognised that there is a need to rethink the framing of the concept and move beyond the rather technical definition.

> The term “Positive Energy Districts” seems to be problematic to pick up by cities due to little attractiveness as a narrative (“PED” is not “catchy” or easy to understand). Specifically, the term “positive” with its reference to a focus on generating a local energy surplus, is rather a barrier for applying the concept in existing urban neighbourhoods. Arguments for a wider framing of the concept in terms of geographical scope (from a dominant local focus to an integrated perspective of local/regional/national/European perspectives), not least due to the vagueness of the concept of “districts” or “neighbourhoods” [and] its implications for governance issues. Also, a clearer link to climate-neutrality, net-zero, etc. needs to be established. (JPI Urban Europe, 2023: 12)

The FLEXPOSTS project follows the original definition outlined by JPI Urban Europa but recognises at the same time the need for expanding and elaborating the understanding of what a PED is or can be. It is recognised that there is a need to understand a PED in relation to and interconnectedness the surrounding urban area. It is important that optimisation at the local PED scale does not take place at the expense of sustainability efforts at a larger scale.

PEDs can be understood to operate in different domains of the relevant context, including (but not limited to):

- Technical: A label that an urban district can acquire if it fulfils certain technical parameters, e.g. an annual surplus of energy production. The emphasis at this level is to work towards technical solutions and systems integration and optimization involving both energy and urban infrastructures.
- Process: A framework for bringing stakeholders together to work towards energy efficiency at district level. The emphasis is on the process-oriented aspects of governing collaboration between actors and relevant stakeholders towards implementing PEDs. The aims of such governance processes can be multiple and go beyond successful implementation of a technical PED. Other aspects of working collaboratively with a particular aim in mind range from capacity and competence building among diverse actors, creation of self-reliant networks of e.g., businesses and public actors, as well as establishing a positive discourse about the green transition of a particular area.
- Policy/strategy: A step towards realising European, national, and city level commitments of net-zero, resilient and self-sufficient cities. This implies perceiving PEDs as a policy instrument for realising greater implementations. The local PED solution(s) should essentially be scalable and replicable in other contexts.
- Legal: A normative framework of several societal goals, principles and tasks that have been transformed into binding law. This layer indicates the available room for the other perspectives. I.e., the law places normative limits on the technical, social, and economic aspects of PEDs.

1.4 The aim of the report

The aim of this report is to design an enhanced methodology for implementing PEDs and applying this to the two demo sites: De Zwette and Aalborg East (T3.1). This task should be seen in relation to the tasks of developing business models and PED implementation strategies (T3.2), together with the development of a replication toolkit (T3.3) that will be reported separately. The task of developing the methodology for implementing PEDs (T3.1) have been divided into the five sub-tasks. This report outlines the methodology for each of these tasks by specifying

- T3.1.1: the methodology for analysing the existing energy system and energy balance at neighbourhood level
- T3.1.2: the methodology for developing future energy scenarios
- T3.1.3: the methodology for identifying regulatory, structural and technical barriers for implementing PEDs at national and local level
- T3.1.4: the interdisciplinary and transdisciplinary methodology for synergising energy planning and urban planning processes at neighbourhood scale towards the implementation of PEDs
- T.3.1.5: the methodology for local stakeholder engagement and establishing local partnerships and networks to support the establishment of public-private partnerships.

The report is structured as follows. Section 2 presents an overview of the two demo sites in the FLEXPOSTS project and introduces the challenges of each demo site. Section 3 presents the methodological guide for the FLEXPOSTS project, outlining the methodologies for each of the five sub-tasks presented above. Section 4 concludes and outlines the next steps in the FLEXPOSTS project.

2 The FLEXPOSTS demo sites

This section introduces the two demo sites in FLEXPOSTS, De Zwette in the Netherlands and Aalborg East in Denmark, and outlines their special characteristics, challenges, and their respective potential for transforming into a PED.

2.1 De Zwette, Leeuwarden

De Zwette business and shopping park is located on the southwestern side of Leeuwarden in the Netherlands, see Figure 1. This is the largest business park in Friesland with app. 400 companies facilitating app. 6000 jobs. Industrial sectors on de Zwette range from production industry, wholesale, retail and business services to kitchen stores, hardware stores and offices. De Zwette is a spacious business park with lots of water and greenery, centrally located directly on the N31, near the A32. A special project on De Zwette is the WTC area development with the new Soccer (FC Cambuur) stadium: the Eleven Cities Park that will transform the area. The construction of a new soccer stadium for Cambuur will create more dynamics in the area in combination with shops, catering, offices, and indoor activities (leisure). Two new supermarkets have been established, and the new Cambuur Stadium will also house education (ROC Friese Poort). The business park is divided into different zones (De Zwette I to VI). Each zone has its own specifications and conditions. There are various locations available on Zwette IV and V. Zwette VI is currently in development, see Figure 1. There are currently no companies located at De Zwette VI. Construction is expected to begin on this new site in a number of years (Leeuwarden Municipality, 2025).

De Zwette also has a sustainable ambition: it intends to be an energy-neutral and circular business park by 2035. The Energy Campus has been located on De Zwette since 2019. Here, organizations work together on the energy transition through smart cross-pollination between companies, knowledge institutions and government. There are companies that produce sustainable energy, startups for innovations and close collaboration with knowledge institutions. The site consists mainly of light and medium industry, with mostly small to medium enterprises and a few large consumers of electricity (Connection of >400 kW). There is also renewable energy production in the area. There is currently 4 MW of installed solar PV capacity on the roof of the companies at De Zwette, and some large solar parks are situated close to the Zwette connected to the same electricity grid (see Figure 2). Additionally, there are 2 wind turbines, 0.9 MW each (see Figure 2).

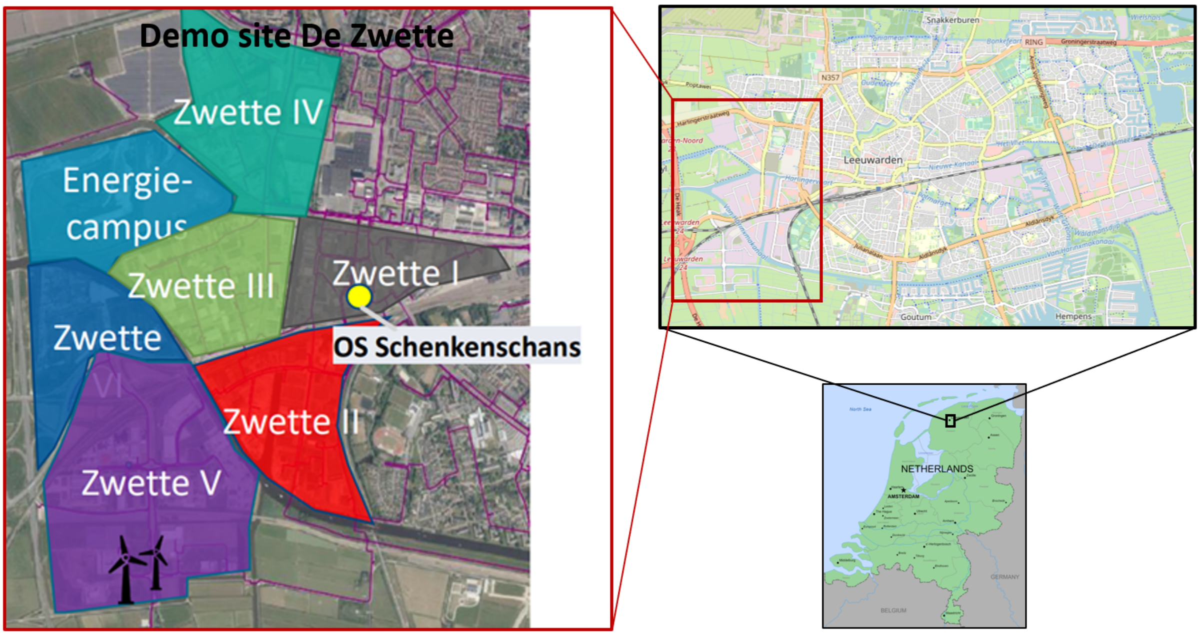


Figure 1: Location of the demo site De Zwette

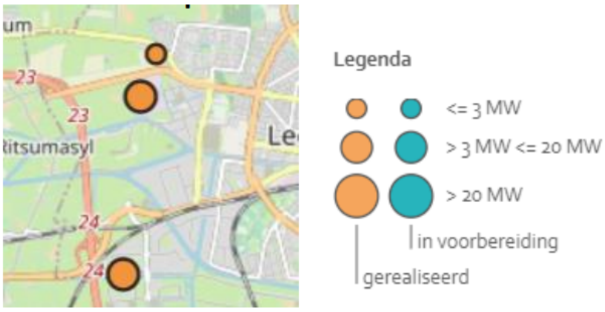


Figure 2: Location of large solar parks at the demo site De Zwette

Currently there are plans to further expand the site, creating space for more industrial development and renewable production. However, the recent development of the area has resulted in congestion of the electricity grid, such that there is no longer space for adding production. The congestion for feed-in is at TenneT level or high voltage transport connection at the Schenkeschans substation, see Figure 3. This implies that for the time being no electricity can be returned to the grid. The congestion for electricity supply is at the DSO Liander or station and substation level. The congestion is caused by overloading of the installations at the Schenkenschans substation, see Figure 3. There is no congestion in the distribution network (Mid Voltage cables). Grid expansion will only be available from 2027 onwards, when the construction of new connections at the Leeuwarden substation (the other main substation in the city of Leeuwarden).

Therefore, in the demo site De Zwette, the specific issue is electricity grid congestion. The (local) electricity grid congestion is partly caused by the large increase of demand, and the non-dispatchable nature coupled with the decentralized production capabilities of solar and wind, which at times give a large surplus in production and congestion on a local level. This can raise issues, such as a limit on the amount of newly distributed intermittent energy resource projects that can be integrated, the number of new consumers/businesses that can be connected to the grid, and/or the ability of existing consumers/businesses to switch from fossil fuel energy to (renewable) electricity sources. As such these local constraints can stifle the energy transition.

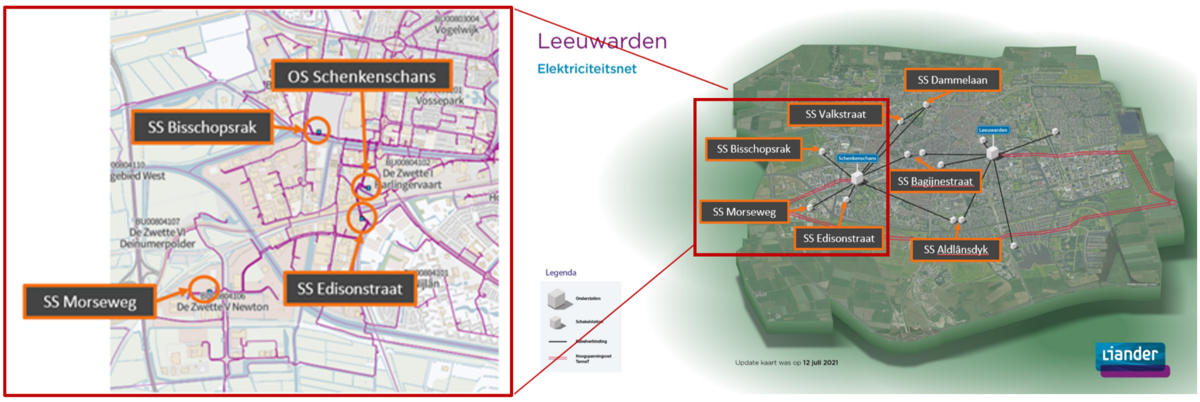


Figure 3: Map of de Zwette area with electricity grid and main electricity grid transformation and switching stations in Leeuwarden

Traditionally, the intervention by the electricity grid system operator is to reinforce/expand the grid, while other options such as flexibility and storage are not studied in depth. This brings up questions such as: Is the grid being expanded just to transport locally produced renewable energy to other locations? Are there ways to use this energy locally and forego grid expansion? What is the optimal intervention to eliminate grid congestion taking into account different technological options? What is the optimal intervention needed on a local level such that there is minimum delay in the development of a PED? These are the challenges being analysed in the demo site De Zwette, where we want to quantify the techno-economic impact of different possible solutions that can ameliorate grid congestion, while taking into account regulatory, structural and technical barriers.

To achieve this, close collaboration is required between local and regional stakeholders. Main stakeholders in the process, amongst others, include: The municipality of Leeuwarden; the local grid operator Liander; the businesses located in De Zwette area; and the Energy campus. The linking pin within this network of stakeholders is the municipality of Leeuwarden, they are actively engaging the stakeholders, supporting ideas, and coordinating projects. The DSO Liander is openly collaborating with the FLEXPOSTS partners in the search for solutions to the local grid congestion. Finally, the companies in De Zwette are proactively following any development that can help create more room on the electricity grid for companies to grow or new companies to settle in De Zwette.

2.2 Aalborg East, Aalborg

Aalborg East is located at the eastern side of Aalborg, Denmark, see Figure 4. Aalborg East is a vibrant and diverse area that comprises various stakeholders and infrastructure. The area is structured to accommodate different sectors, including industry, households, allotment gardens, a harbour, and soon a new university hospital. This diverse mix of stakeholders creates a unique blend of economic, residential, and recreational activities. Understanding the intricacies of this structure is crucial for developing a comprehensive strategy that addresses the unique energy consumption challenges and opportunities within the area.

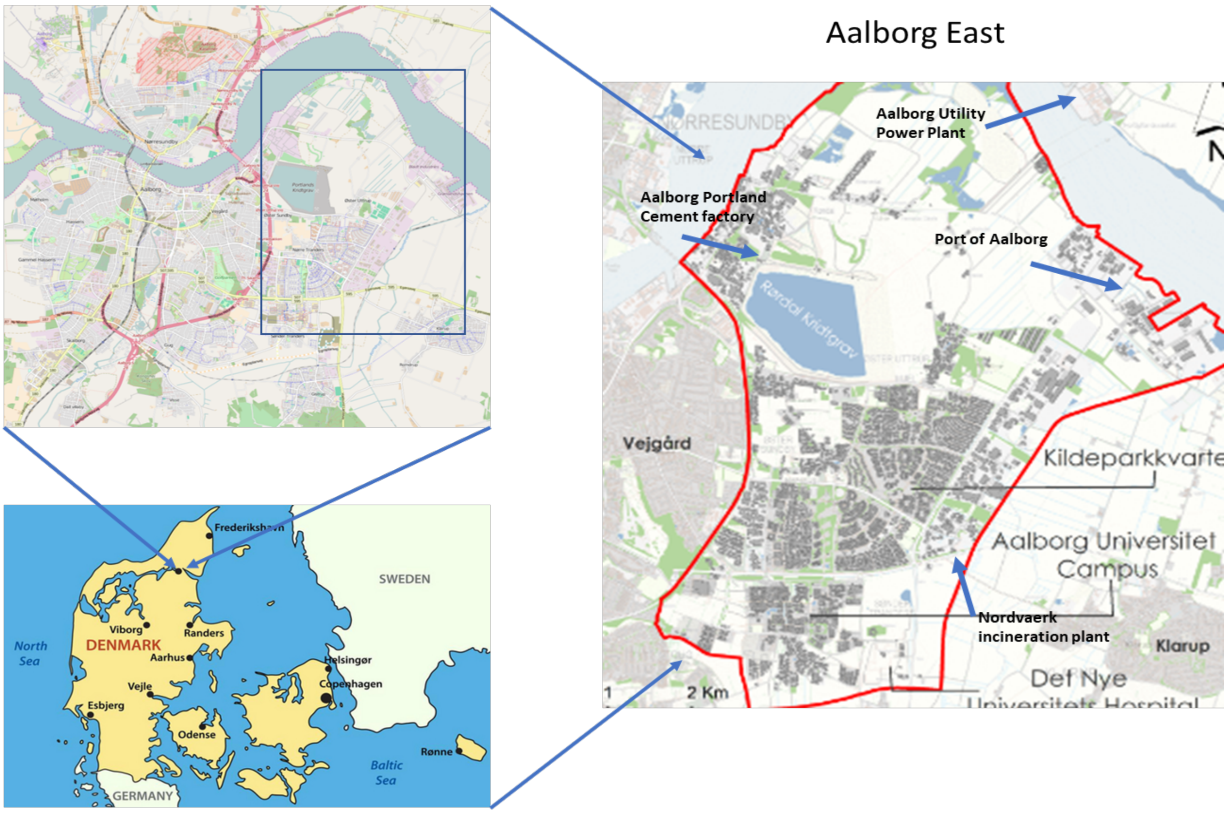


Figure 4: The location of the Aalborg East demo site

There are a substantial number of companies operating within Aalborg East. Currently, there are 1887 registered companies within the postal code 9220. When excluding holding companies, the number remains significant at 1736, with 629 companies having at least 5 employees based on their CVR number. These businesses contribute significantly to the local economy, employing 25,520 individuals. More importantly, Aalborg East features several energy-intensive companies. Aalborg Portland alone consumes a quite substantial 330 GWh of energy per year, highlighting the significant energy needs of this cement and building materials producer. Other notable energy-heavy industries in the area include Bladt Industries, Siemens Gamesa Renewable Energy, and Fibertex Nonwovens. These companies play a vital role in driving economic growth, employment, and energy consumption within Aalborg East. (Aalborg Municipality, 2023)

In Aalborg East there are currently 27,737 residences and 51,251 residents and the area is expected to grow in the future. The housing area is mainly made up of social housing, but it also features single-family housing. A large proportion of social housing has been renovated in the last decade to reduce energy consumption and make the housing units more attractive for the tenants. (Aalborg Municipality, 2023)

Aalborg East has a good foundation for being converted into a PED. The majority of Aalborg East is already connected to the district heating network. The challenge is here how to integrate more renewable energy sources into the grid and transition to lower temperatures. This becomes even more important as the municipal power plant is planning to phase out its coal-fired power plant by 2028. In addition, new major energy consuming and energy producing activities are planned, which must be taking into account in the future development of the area.

Given the complex structure of Aalborg East and the diverse mix from industry to households, it becomes increasingly important to develop a strategic approach to address energy consumption and potential challenges. In Aalborg East networks of stakeholders exist, which are actively involved in promoting sustainable urban development and supporting the transition towards renewable energy sources. Some of the stakeholders are for example engaged in a project on industrial symbiosis.

Furthermore, new projects are planned in the area, which will add an additional layer of complexity to the energy landscape. These includes the development of two Power-to-X facilities, which holds great potential for promoting renewable energy and enhancing grid stability through storage. The first PtX is a collaboration between Copenhagen Infrastructure Partners, Nordværk, and Aalborg Utilities. The second plant is a partnership between European Energy and the Port of Aalborg. The project aims to produce 75,000 tons of e-methanol. Additionally, there are plans to establish solar parks in the vicinity of the new PtX plant located at Port of Aalborg. These projects will require substantial energy demands and require careful consideration of infrastructure and grid integration. Therefore, they should be considered when devising the overall energy strategy for the Aalborg East area. In addition to these projects, a new super university hospital is currently being constructed in Aalborg East, which will be integrating smart technology and will play a significant role in the grid demand.

The wide range of energy needs within the area, combined with the potential energy congestion, necessitates a well-thought-through strategy that ensures stability, efficiency, and sustainability in energy management and infrastructure. By addressing these aspects and leveraging the unique strengths of the various stakeholders, Aalborg East can pave the way towards becoming a PED area that promotes sustainable development and a harmonious community for its residents and businesses alike.

Some of the key questions to explore in the Aalborg East demo site are: How can Aalborg East transition towards a 100% renewable energy system? Which technological solutions should be implemented, and how should these be fitted into the existing urban landscape? How can the experiences with industrial symbiosis and other renewable energy projects in the area be utilised to develop a PED? How can the existing partnerships and stakeholder networks in the area be utilised to further the PED agenda in the area?

2.3 Demo site comparison

Each of the two FLEXPOSTS demo sites has their own unique challenges and potentials for developing into a PED. These challenges and potentials can be labelled as regulatory, structural and technical barriers. In addition, each demo site is also located in their specific national context, which adds another set of challenges and opportunities, for example in terms of the regulatory context. When comparing the two demo sites in the project, it is in other words possible to do this comparison on multiple scales. In addition, each demo site and its respective national context can provide helpful insights into the societal relevance of the PED concept on an abstract and conceptual level. Rather than conducting a traditional comparative study, the FLEXPOSTS project seeks to explore comparisons between the two demo sites across these multiple scales. This approach allows some flexibility and a greater possibility for paying attention to the unique characteristics of each demo site, whilst still maintaining the overarching goal of exploring the feasibility on implementing PEDs locally. The approach supports the idea that knowledge in the FLEXPOSTS project can be generated 'within' each demo site and their respective national context, 'between' the demo sites and their national context, but also 'above' the demo sites and their national context on a conceptual level, see Figure 5.

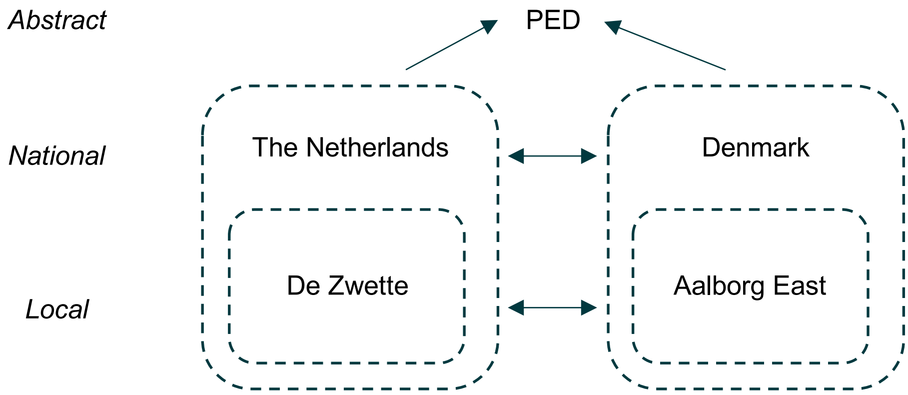


Figure 5: The FLEXPOSTS comparative approach

3 Methodology for implementing PEDs

This section will outline the methodologies for implementing PEDs in FLEXPOSTS (T3.1). The task of developing methodologies for implementing PEDs in the two demo sites has been divided into five sub-task that will guide the analyses in the two demo sites. These sub-tasks are:

- T3.1.1: methodology for analysing the existing energy system and energy balance at neighbourhood level
- T3.1.2: methodology for developing future energy scenarios
- T3.1.3:methodology for identifying regulatory, structural and technical barriers for implementing PEDs at national and local level
- T3.1.4: interdisciplinary and transdisciplinary methodology for synergising energy planning and urban planning processes at neighbourhood scale towards the implementation of PEDs
- T.3.1.5: methodology for local stakeholder engagement and establishing local partnerships and networks to support the establishment of public-private partnerships.

In accordance with the comparative approach outlined above, the analyses in each demo sites will follow the same methodological guide, whilst allowing some flexibility in terms of how the analyses are conducted. In this section, we outline the overall methodological approach that will be applied in both demo sites.

The tasks and the methodologies associated with these are highly interlinked. Stakeholder engagement will for example be utilised in developing future energy scenarios (T3.1.2) and in identifying regulatory, structural, and technical barriers for implementing PEDs (T.3.1.3). In the same way, the interdisciplinary and transdisciplinary methodology for synergising energy planning and urban planning processes (T.3.1.4) will form the foundation for all the other tasks in FLEXPOSTS. Figure 6 presents a conceptual diagram of the synergies between the different sub-tasks in FLEXPOSTS. The rest of this section outlines the methodologies of each task.

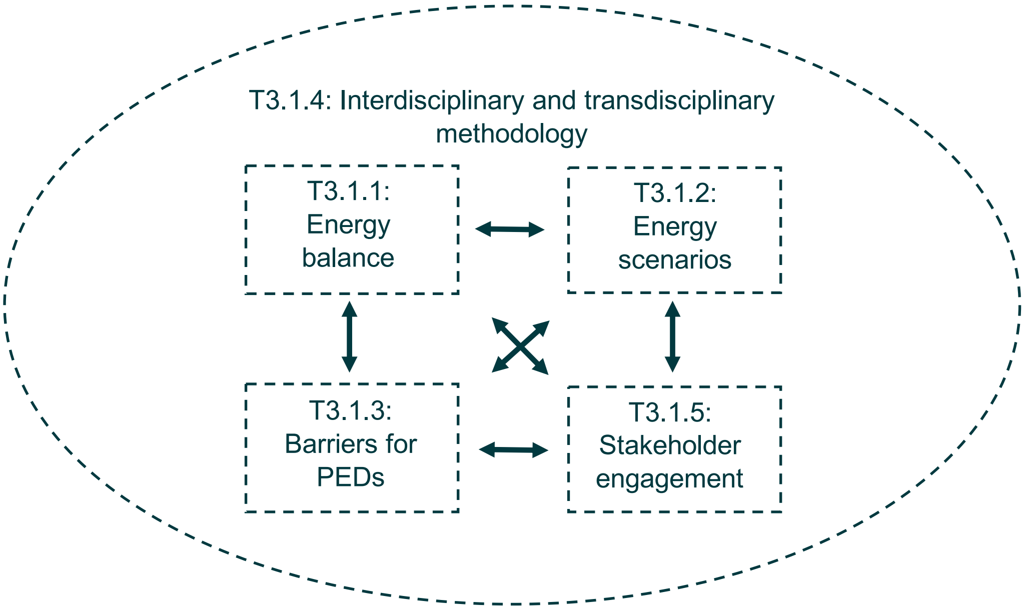


Figure 6: The synergies between the tasks in FLEXPOSTS

3.1 Methodology for analysing the existing energy system and energy balance at local level

Section 3.1. presents the methodology for analysing the existing energy system and energy balance in the two demo sites. First, Section 3.1.1. outlines the methods that will be used in the analyses. Second, in Section 3.1.2. the expressions used in the methods are presented. Third, in 3.1.3. the validation approach for the models is discussed.

3.1.1. Methods

This section outlines the five methods that will be used subsequently to analyse the existing energy system and energy balance in the two demo sites De Zwette (T.4.1) and Aalborg East (T5.1). In each section it is highlighted whether the method will be used in both or only one demo site.

Method 1: Assessing the current state: the energy scan

In order to develop future scenarios, the current situation within the demo sites must be clearly defined. For this purpose, two methods are used; The Energy Scan method, to map the current energy system; and the Area passport method, for giving a clear picture of the current energy system.

Energy Scan method: When developing future (PED) scenarios the current situation in terms of energy use, efficiency, and renewable energy production or potentials must be clear and accurate. With the current state, energy scan (*nulmeting* in Dutch) data is collected on the current situation in a specific area regarding energy transition related topics, for instance, energy use, building stock, energy labels, or electricity grid capacity etc. Overall, a clear picture of the current energy system is required to create strong scenarios. For this purpose, the Energy Scan method is used which utilizes a clear approach and structure for performing a baseline measurement. The method contributes to the comparability, transparency, and reliability of baseline measurements. The basis of the proposed approach consists of five steps, which will be performed using mainly literature study together with stakeholder interviews (Figure 7). Step 1 focusses on determining the goal of the energy scan and following scenarios to create a clear picture on the required data and/or knowledge. In Step 2 the required data is divided into clear elements that can be individually researched or measured, which can include current renewable energy production, or electricity demand etc. In Step 3 the methods and/or database and sources for gathering the data per element are selected for a transparent data collection process. In Step 4 the used units are clearly indicated to avoid confusion, for instance between m^3 gas, GJ of heat and or KWh of electricity etc. In Step 5, after all previous steps are clearly defined, the tasks for collecting the specific elements can be divided and executed. By following this procedure every Energy Scan will be comparable, transparent, and reliable. This method will be used in demo site De Zwette (T4.1) and demo site Aalborg East (T5.1).

Figure 7: The five main steps in the energy scan method for performing a baseline measurement

Method 1: Electricity grid simulators G**ridNodes and Pan*****dapower***

Grid congestion can be a very localized problem which happens on an object level basis. To identify where exactly grid congestion occurs in the system, it is necessary to model the exact electricity grid where congestion is occurring. For this purpose, within this project two models are used, namely GridNodes and Pandapower.

GridNodes: Most electrical grid simulation programs are specialist programs that require high domain knowledge to understand, operate and thus get conclusions from. This project takes a stakeholder-wide approach to provide insight into the specific problems. GridNodes is the model used for this stakeholder communication. By reducing the electricity grid into its most important components, it attempts to understand the grid congestion problem and, also, give possibilities to model the most important effects and see their impact. The GridNodes approach is designed in such a way that in one interactive session with stakeholders, they can use the model and identify their grid congestion problem. In general, the grid is one of the most efficient ways to transport energy. The approach is based on the assumption that most of the energy losses occurring in the grid can be attributed to two components: transformers and power lines. This implies that by modelling only these components almost all of the energy going through the system can be accounted for. Aside from transformers and power lines, there are also switching stations, which in GridNodes Figure 8 illustrates the conceptual model of GridNodes. Just like PowerNodes, it is also based on different modules which are linked together. By linking together these modules according to the exact grid topology, the grid in question is thus modelled on an object level basis. For each object the object characteristics is defined based on what type of object exists in reality.

The main assumption in the GridNodes model is that the power flows from the end of the grid to the higher levels. Therefore, the modelling begins at the nodes farthest down the grid and goes upward. If there is surplus decentralized production in the lowest level of the grid, the assumption is that if there is a demand on the way to the higher levels, it will be met by the lower-level decentralized production. The input into the object modules are the consumption/production profiles connected to that certain object (e.g. house, company, transformer station, or switching station, etc.). For a transformer this could be a business or neighbourhood or multiple of these. For the power lines this is the power flows from the lower levels (left side) and the power flows from the transformer connected to the line. Flexibility possibilities is one of the main topics that this methodology want to bring to light. Therefore, the modelling is done in 15 minutes intervals as this is the highest resolution measured by the distribution system operator. Because flexibility possibilities are highly dependent on the types of consumers/producers located in the specific network, real data from the parties at the site is used as much as possible to render results that can be applicable in reality. In the case this data is not available standard procedure in approximating profiles will be used. This method will be used in demo site De Zwette (T4.1).

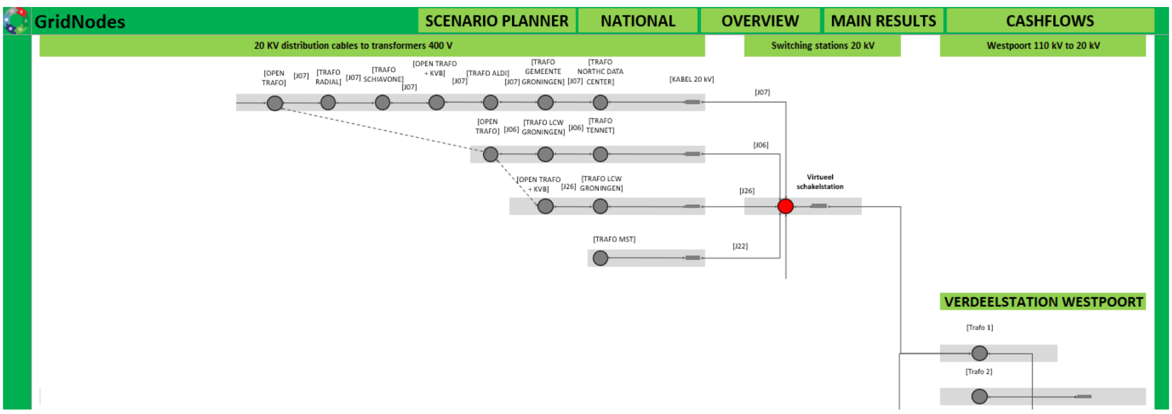


Figure 8: Main overview (conceptual model) of a GridNodes model.

Pandapower: Electricity grids are complex networks that consist of different component types which are all connected to each other and influence each other. In order to model such a complex system on an hourly to 15-minutes basis and incorporate multiple technological options such as decentralized electricity production, storage, curtailment, power to X etc. Specialist programs are needed to make the work less manual and increase computational speed. The open-source python module Pandapower is used to perform this detailed modelling. This program was developed to close the gap between commercial and open-source power system analysis tools. The open-source nature is desirable because if stakeholders want to help solve these types of problems in the future, they also have the possibility to learn to use the program. As such our methods have no paywall or entry barrier. Pandapower is designed to perform static analysis of three-phase power systems. This allows modelling of transmission, subtransmission and three-phase distribution systems. Pandapower was validated by comparing all Pandapower element and power flow results against to DIgSILENT PowerFactory or PSS Sincal. These are high level commercial packages and ensure that high professional standards are reached. For more information on Pandapower see (Thurner et al., 2018). This method will be used in demo site De Zwette (T4.1).

Method 2: Demand and production peaks: FlexLoads

To get a better insight into the characteristics of the demand and production peaks appearing within the electricity grid of a selected area, a python-based tool called FlexLoads is under development. This tool is based on the metric defined in reference (Sandell, 2022). Additionally, in FlexLoads, the recovery capacity will be added to the metric, which could be represented in De Zwette as renewable production. The aim of FlexLoads is to give insight in the peaks of demand or overproduction occurring in the local electricity system (Figure 9), leading to possible solution paths to study further, such as opportunities for load shifting or suitable storage methods.

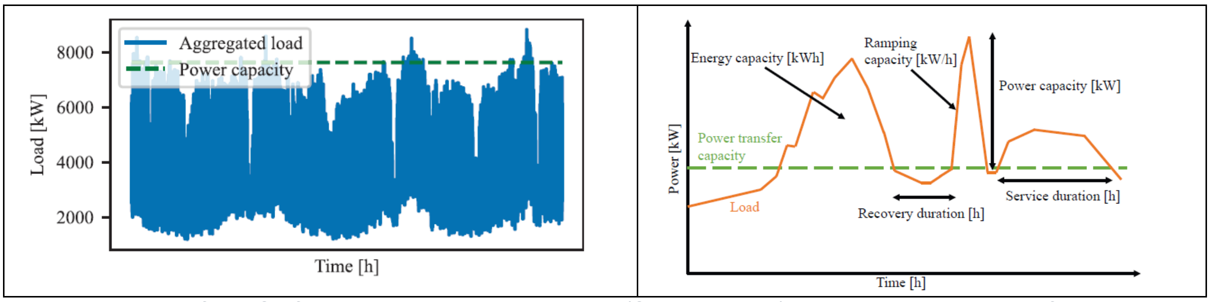


Figure 9: To the left: NLS of researched electricity system (Sandell, 2022). To the right: Diagram of transportation cable (Sandell, 2022)

The tool will have an interactive interface where different cables and/or stations can be selected via a dropdown menu, and a specific weekday can be studied in more detail by another dropdown menu. In Figure 10 a snapshot of the current status of the interface. During the development process, further features can be added as the needs occur within the project. This analysis tool can help gain insight in moments during the day, week, month or even years when demand or overproduction is peaking and what is causing this. This insight could help find focussed solutions in specific areas of the electricity grid. This method will be used in demo site De Zwette (T4.1).

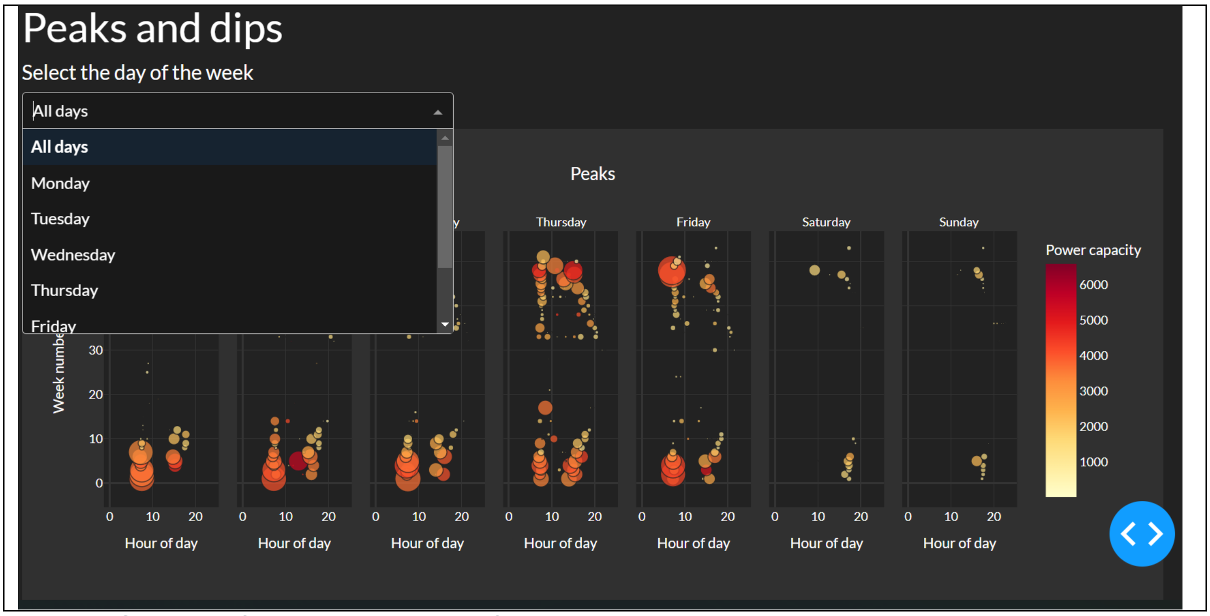


Figure 10: Snapshot of the current status interface

Method 3: Options for managing grid congestions: the PowerNodes approach

To find possible options for managing grid congestion a new approach is used called PowerNodes (Figure 11); which schematically represent an energy system in an area through a collection of nodes that each represent a specific element (e.g. solar PV park, wind turbine, demand village etc.). The model can simulate a specific section of an energy grid and calculate the impact on the energy system at a specific point, for instance an electricity transformer or a gas hub supplying a business area or neighbourhood, based on research (Pierie et al., 2021). Behind this connection point a selection of technologies can be simulated represented in so called individual Power Nodes. In a Power Node, a separate technology (e.g. wind turbine, solar PV) is described on technical, economic, environmental, and spatial aspects (e.g. energy production per hour, NPV over 25 years, kgCO2eq/kWh, and ha space used), (Figure 11). All these individual nodes are a model by themselves and can operate independently if desired (e.g. for calculating the businesses of a single solar park). This approach makes it possible to add, remove or turn off a node, without a redesign of the model. This adds to flexibility in use, and it also adds to transparency, as models can be verified individually per node. The Power Nodes method works on an hourly basis for the energy demand and production elements to include variation in demand and production by for instance solar or wind production and demand for electricity and heat over a period of one year. The result of this hourly pattern for a whole year is called the Net Load Signal (NLS) and is the main connection between the nodes in the model (similar of connecting technologies to an electricity cable). By combining all sub-modules together, the Net Load Signal (NLS) will be the result. If the demand signal is negative, there still is a demand from the national grid at that hour. If the demand signal is positive, there is overproduction and this overproduction (electricity, natural gas) can be stored or sold. This model will be integrated in the Excel modelling environment to generate results regarding production, planet, profit, and balance. This method will be used in demo site De Zwette (T4.1) and demo site Aalborg East (T5.1).

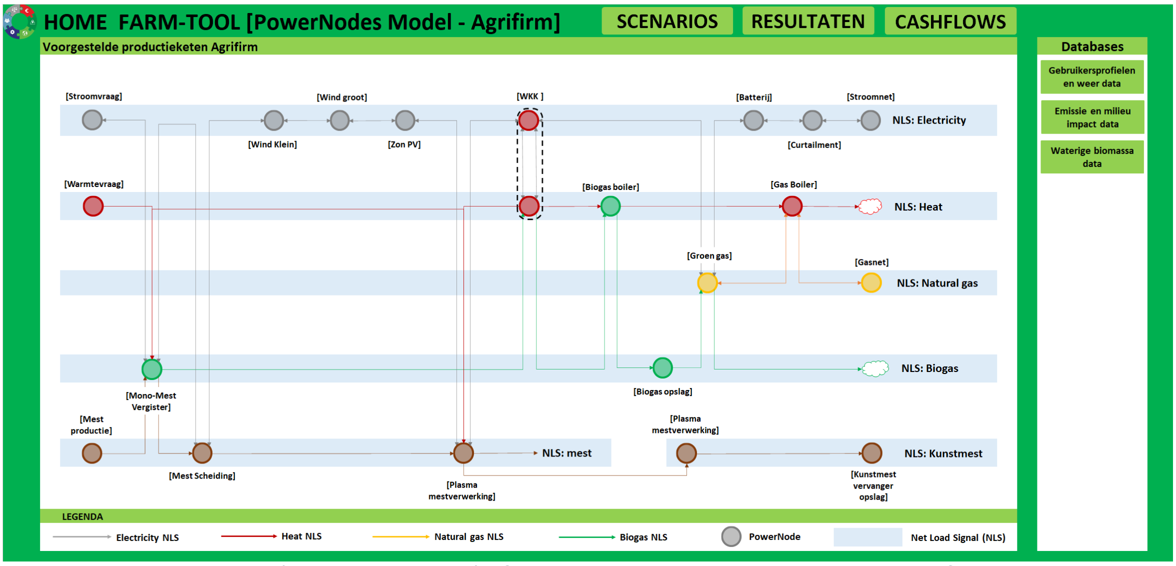


Figure 11: Main overview (conceptual model) of a PowerNodes model including legend of elements

Method 5: Advanced energy system modelling: EnergyPlan

EnergyPLAN is an advanced energy system modelling tool. It simulates the operation of an energy system for every single hour during an entire year (Lund et al., 2021). EnergyPLAN allows for the simulation of entire energy systems, including all energy sectors, including electricity, heating, transport, cooling and industry. It is widely used, with over 10,000 users, and used in a large number of research studies looking at various geographic scopes, including cities, regions and countries.

EnergyPLAN provides a tool for investigating system integration and coupling between renewable electricity production and transport, industry, and heating. EnergyPLAN has a well-developed district heating interface that allows for utilisation of industrial excess heat, as well as including heat production from combined heat and power plants, heat pumps, boilers, and excess heat from sources such as electrolysers. This, combined with the hourly modelling of storage, allows for the assessment of system flexibility. FLEXPOSTS marks the first time EnergyPLAN will be used on the case of a PED.

To model in EnergyPLAN, the user needs to define energy demands as well as the needed production capacities and efficiencies. In principle EnergyPLAN can operate without economic inputs, as the default technical simulation is based on a merit order, where renewables will provide energy first, followed by CHPs and finally peak load power stations will provide the remaining electricity demand. However, by inputting economic parameters, it is possible to also obtain total annual costs as a result from the model.

EnergyPLAN provides results in form of an output file, which includes energy balances across all energy grids, costs, CO^2-emissions and fuel balances. The energy balances can be outputted both as an annual, monthly, and hourly value. This method will be used in demo site De Zwette (T4.1) and demo site Aalborg East (T5.1).

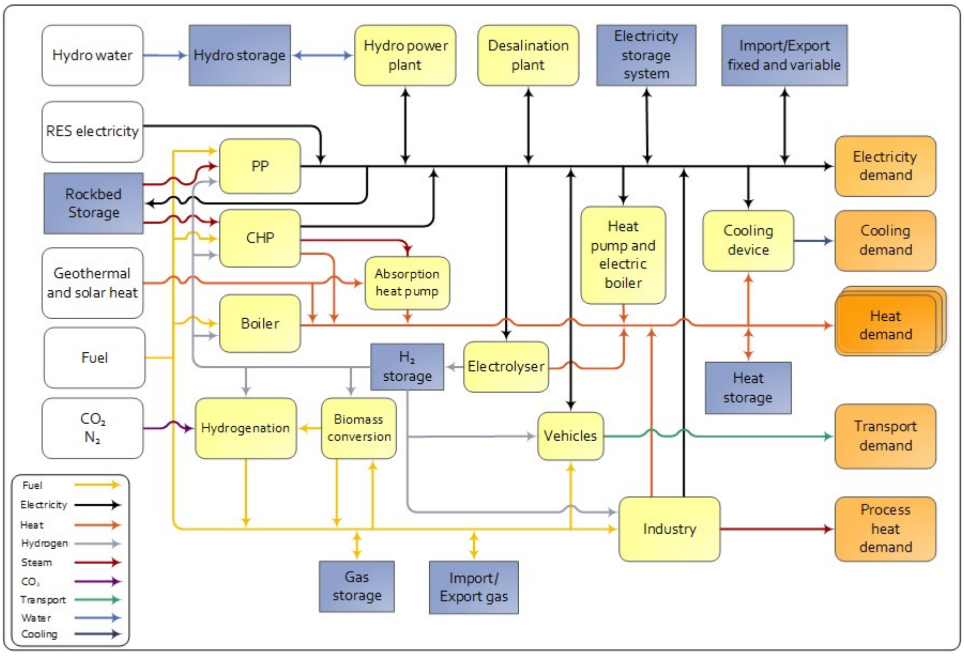


Figure 12: Overall schematic of EnergyPLAN's energy flows (Lund et al., 2021: 6)

3.1.2. Expressions used in the methods

From the perspective of Positive Energy Districts, insight in the most important elements require clear and transparent expressions which are comparable between models and scenarios. Within the demo site De Zwette (4.1) and demo site Aalborg East (T5.1), the following main indicators are used:

Demand and production indicators (PowerNodes / EnergyPlan):

- Demand mix: The share of demand types within the area on a yearly basis is indicated in percentiles of the total electricity demand of the area (Figure 14a).
- Production mix: The share of renewable energy within the area on a yearly basis is indicated in percentiles of the total electricity demand of the area (Figure 14b).
- Self Sufficiency (SS) and Self Consumption (SC): Indicates import from and overproduction transported to the national electricity grid. Also, the self-consumption and overproduction in the area on a yearly basis is indicated (Figure 14c).

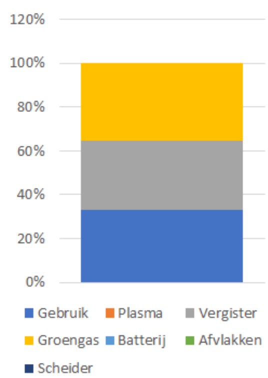


Figure 13a: Demand mix

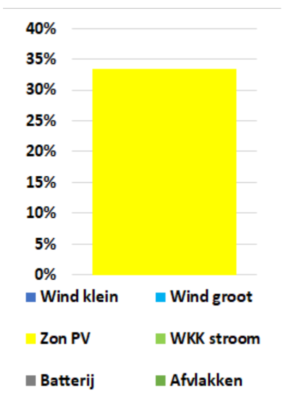


Figure 14b: Production mix

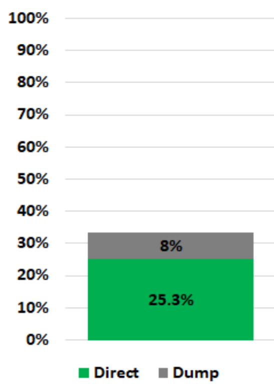


Figure 14c: Self consumption and self sufficiency

Economic indicators (PowerNodes):

Within the PowerNodes model a basic economic calculation is added based on a Net Present Value approach over 25 years. The indicators used within this approach are:

- The capital expenditures (CAPEX) including all the required investments at the start of the project (Figure 15a)
- The operational expenditures (OPEX) including all the operational and maintenance cost during a 25-year technical lifespan (Figure 15a).
- The net present value (NPV) including weighted average cost of capital (WACC) inflation and taxation (Figure 15a).
- Additionally, a levelized cashflow of the project, also including weighted average cost of capital (WACC) inflation and taxation is included (Figure 15b). Both the cashflow and cumulative cashflow give good insight in the expected yearly income and total return on investment over a 25-year period.

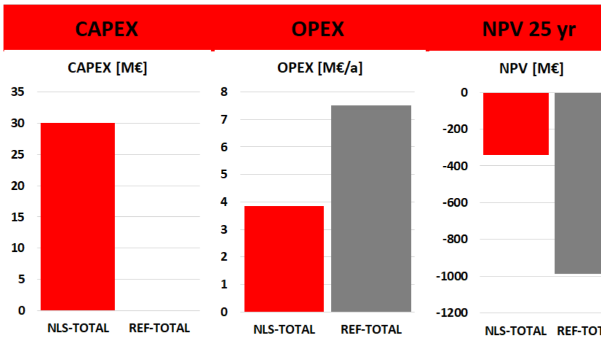


Figure 14a: Main economic indicators

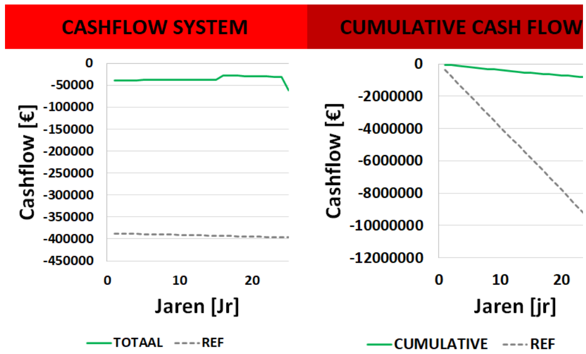
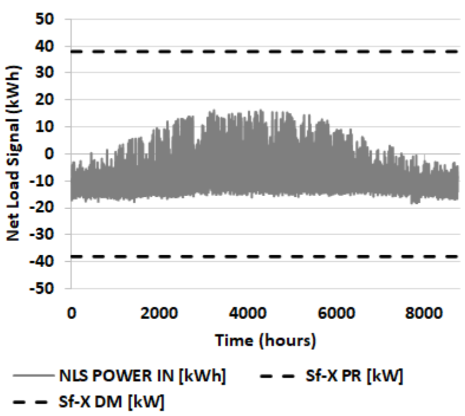


Figure15b: Additional economic indicators

Grid strain indicator (PowerNodes / GridNodes / Pandapower):

The indicator for grid strain is the Net Load Signal (NLS), which indicates the amplitude of the demand (in kW) per hour over a year [3,4]. To indicate both demand and overproduction in the Net Load Signal the local demand (P_D) is subtracted from RE production (P_{I-RE}) per hour, which indicates either over or under production, see Equation (3) (Ueckerdt et al., 2015). When the NLS is positive, there is overproduction; when negative, there is demand, and when zero, local production is equal to demand (Figure 16a).

$$NLS = P_{I-RE} - P_D \quad \text{(kW)} \tag{1}$$



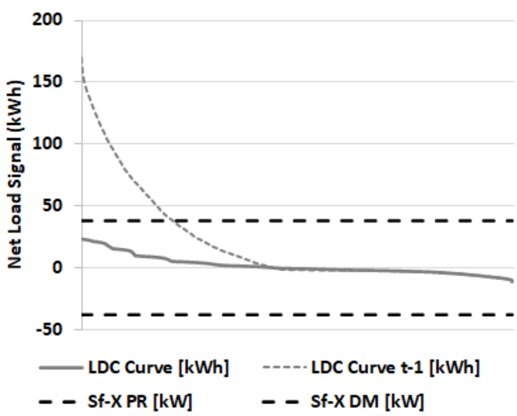


Figure 15a: Net Load Signal Figure 16b: Net Load Duration Curve

Balance indicator (PowerNodes / GridNodes / Pandapower / EnergyPlan):

The indicator for (im)balance is the Net Load Duration Curve (NLDC), which is based on the Load Duration Curve (NLS). By ordering the NLS from the highest amplitude or overproduction to the lowest amplitude or demand a NLDC curve will take shape (Figure 16) that indicates overproduction and demand in kW per hour as a function of time, distributed over a year. Within the NLDC multiple indicators are included:

- The amount of overproduction or remaining demand as surface above or below zero
- The maximum peak loads and the time in hours per year this occurs
- The hours per year that demand and supply are met

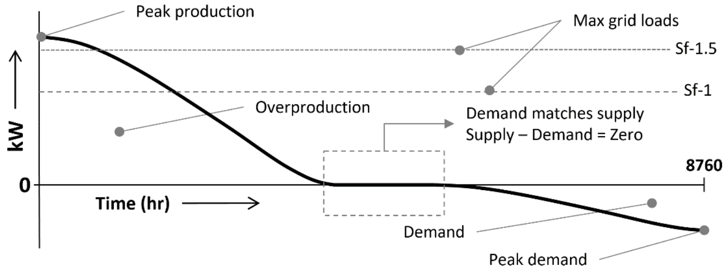


Figure 16: Example of NLDC and maximum grid loads based on Sf factors.

Max grid load indicator (Sf) (PowerNodes):

Within the average area, the maximum grid load is defined as “the maximum amount of electricity load that can be accommodated without impacting system operation (reliability, power quality, thermal limits, spatial placement, etc.) under existing control and infrastructure configurations”; which is determined by the Distribution System Operator (DSO) using a simultaneity factor (Sf) multiplied with the number of households. The Sf factors are based on historical data and the experience of the local DSO (Table 1). Additionally, the contracted power rating of the electricity connections from industry can be summed up in a specific area to indicate the required capacity of the electricity grid. When the NLS passes the set grid capacity within a section of the grid, steps are required to safeguard the electricity grid (e.g., shut down, grid expansion).

Table 1: Simultaneity factors grid.

	Simultaneity Factor (Sf)	Unit	Abbreviation	Source
Old grid pre 1990	1.0	kW/household	L-Sf	[42]
New grid 2012	1.5	kW/household	H-Sf	[42]

Environmental impact indicators (PowerNodes / EnergyPlan):

The resulting environmental sustainability will be expressed in three known indicators which correlate with the definition of strong sustainability" (Mori & Christodoulou, 2012), wherein environmental quality precedes social prosperity and then economic prosperity (Elkington, 1999; Mori & Christodoulou, 2012). The indicators used are: the (Process) Energy returned on Invested (P)EROI, indicating the efficiency of the chosen scenario; the carbon footprint (GWP100), indicating global warming potential; and the Eco Indicator ReCiPe 2008 (Goedkoop et al., 2008), indicating the overall environmental impact to the ecology, nature and human health. The three units will be expressed per Gigawatt hour (GWh) of energy produced (e.g. kgCO2eq/GWh). Taken together, these indicators will give a clear overall impression on the efficiency and sustainability of green gas production pathways. The indicators are elaborated in the following section, below is a short introduction:

- Efficiency expressed in (P)EROI (EMBODIED): To indicate the energy efficiency of a process the (Process) Energy Returned on Invested factor, or (P)EROI, will be used. (P)EROI is defined as the ratio between the energy obtained from a resource to the energy expended in the production and processing of a resource (The factor is based on the EROI theory (A. S. C. Hall et al., 2009)). The (P)EROI will be expressed in a single factor. When the (P)EROI of a resource is greater than one it can be classified as a net energy producer, meaning that more energy is obtained from the resource than is expended in processing it. When the (P)EROI is equal or less than one the resource in question will become an energy sink or net energy consumer (e.g. storage system), meaning that less energy is obtained than is expended [45]. In theory the threshold between energy producer and energy sink is set at one, however in practice this point is often higher due to uncertainties (e.g. 1.5 up to 3, (C. a S. Hall & Gagnon, n.d.)), (Figure 17).
- Carbon footprint expressed in GWP 100 (EMISSIES): The carbon footprint is expressed in carbon dioxide equivalents (CO2eq) using the relevant 100-year global warming potential scale or GWP100, (Ipcc, 2007). Within the approach the carbon footprint will be quantified as a net increase or decrease of GWP100. There are two main net producers of GWP incorporated in the approach; first, carbon dioxide absorbed in biomass may be converted and emitted as a stronger greenhouse gas (e.g., methane), therefore increasing the overall GWP potential; second, use of fossil energy sources in the green gas production pathway will create anthropogenic emissions resulting in a net increase of GWP. The increase or decrease in GWP caused by the green gas production pathway is a simple and transparent ruler, making it comparable to other energy sources of fossil and renewable origin (Figure 17).

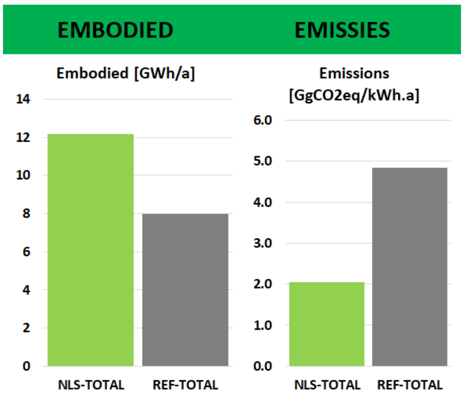


Figure 17: General environmental impact indicators

3.1.3. Validation of models

In the validation phase the new modelling methodologies will be verified using multiple validation techniques, retrieved from Sargent, 2013 (Sargent, 2013a). The focus points are separated into two main parts.: First, the validation will focus on the goal of the model, in order to identify whether the correct model was built for answering the main research questions (*Did I build the right thing?*). Second, the model itself will be verified, through a testing structure, in order to assess transparency and correctness. (*Did I build the thing right?*). The validation and verification (V&V) process will be performed with the help of multiple verification techniques addressing the concept, the overall model, or a particular area of the model.

Definition of validation and verification:

Validation confirms that the realized system complies with stakeholder requirements (the right system was built); defined as the 'substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model' (Sargent, 2013a). Verification confirms that all elements of the system meet technical requirements (the product was built right) (Sargent, 2013a) defined as 'ensuring that the computer program, the computerized model, and its implementation are correct' (Sargent, 2013a).

Validation of concept: Did I build the right thing?:

The first step in the overall V&V process will be focusing on the problem entity (Figure 18) and the conceptual model. When building a model, it is important to keep in mind that most models have the purpose of providing answers to complex issues. From this perspective it is important to start with the right question, and verify your question, or in short: Did I build the right model? To validate this, the concept must comply with the following statements. Does/is the model:

1) Add to scientific understanding or add to societal benefit?
2) Refer to clear answers which can be provided through modelling?
3) Reviewed (e.g., literature review etc.) and verified by experts in the field (e.g., professors, researchers)?

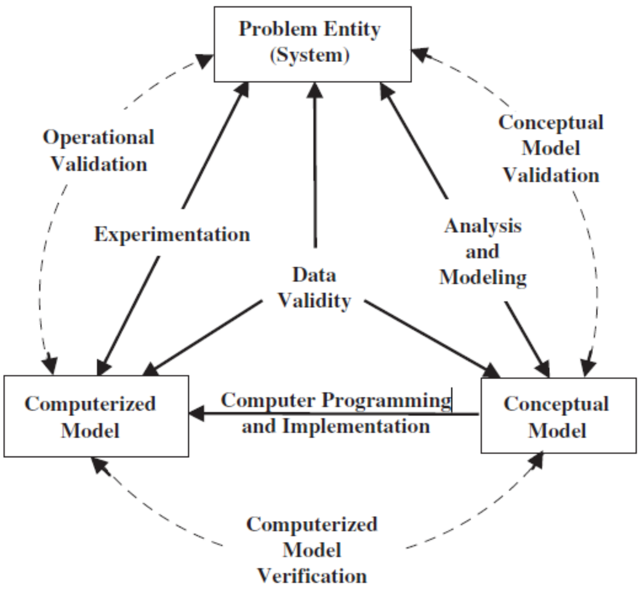


Figure 18: Main list of subjects used in the V&V process (Sargent, 2013b)

Model verification: Did I build the thing right?:

The V&V techniques selected for the used models in both the demo site De Zwette (T4.1) and demo site Aalborg East (T5.1) are discussed. Most of the techniques described here are found in literature, although some may be described slightly differently to specifically fit the used models. The V&V techniques can be used either subjectively or objectively. By subjectively, we mean common reasoning by modeler and experts in the field and by objectively; we mean using some type of mathematical procedure or statistical test, e.g., hypothesis tests or confidence intervals (Sargent, 2013b). A combination of techniques is used within the V&V process, which can be used for verifying individual components within the model and the complete model. The following list of verification techniques is retrieved from Sargent, 2013 (Sargent, 2013b) for use in this article and in the V&V process of the EBS model.

- **Comparison to other models:** Various results (e.g., outputs) of the simulation model being validated are compared to results of other (valid) models. For example, simple cases of a simulation model are compared to known results of analytic models, and the simulation model is compared to other validated simulation models. Specifically, in this research the models used in De Zwette demo site and the Aalborg East demo site with similar function will be compared with similar inputs, e.g. the PowerNodes and EnergyPlan model, the GridNodes and Pandapower model.
- **Data relationship correctness:** Data relationship correctness requires data to have the proper values regarding relationships that occur within a type of data, and between and among different types of data. For example, are the values of data collected on a system or model correct for some known relationship within some type of data such as an inventory balance relationship or a dollar relationship? The first step is to separate the model from the data and treat data as a separate entity for verification. The data will be checked with similar data and reviewed by experts in the field, e.g. the DSO or municipality.
- **Event validity:** The 'events' of occurrences of the simulation model are compared to those of the real system to determine whether they are similar. For example, comparing outcome of models simulating the electricity grid in demo site De Zwette (T4.1) and demo site Aalborg East (T5.1) with real measurements from the DSO or energy producing companies.
- **Face validity:** Individuals knowledgeable about the system are asked whether the model and/or its behaviour are reasonable. For example, is the logic in the conceptual model correct and are the model's input–output relationships reasonable? The consortium of the FLEXPOSTS project and or other JPI-PED projects partners including the expert facility can provide professional feedback or input on our modelling process and or used data.
- **Parameter variability–sensitivity analysis:** This technique consists of changing parameters in the model to determine the effect upon the model's behaviour or output. The same relationships should occur in the model as in the real system. This technique can be used qualitatively—directions only of outputs—and quantitatively—both directions and (precise) magnitudes of outputs. Those parameters which are deemed sensitive because of significant changes in the model's behaviour or output should be made sufficiently accurate prior to using the model. (This may require iterations in model development.) This technique will be continuously used during the scenario modelling process, in demo site De Zwette (T4.1) and demo site Aalborg East (T5.1), to verify outcomes of the models and indicate sensitive variables or data requiring additional scrutiny.
-

3.2 Methodology for developing future energy scenarios

This section presents the methodology that will be used to develop future energy scenarios in the two demo sites De Zwette (T4.2) and Aalborg East (T5.2). Based on the established energy balances and energy models it is possible to investigate a number of scenarios to highlight different future development paths. These pathways can highlight a number of different story lines, depending on the intend of the modelling. Again, it is important to emphasize the modelling of the entire PED, including demands across all energy sectors, to know the total impact on the energy system.

In the development of scenarios, two primary questions will be used to lead the discussion:

- Based on inputs from local stakeholders, what are aspects of PEDs? This includes input and feedback from stakeholders in the areas, to identify what type of projects are being conducted. This includes local energy production, changes in demand (both flexibility, efficiency and increases compared to current demand), utilisation and changes in waste-heat, and other inputs that might come.
- How does the PED fits in municipal and national plans for a green transition of the energy system? This includes utilizing knowledge from local municipal plans, as well as national energy strategies, to identify what measures could be feasible to implement in the PED. This requires in depth knowledge both in terms of the local area as well as the overall plans and strategies.

Besides these broad scenario logics, the scenarios also provide the opportunity to dive into the individual sector, in terms of electricity, heating, cooling, transport and industry, and analyse how these are all impacted by a PED approach.

Finally, the PED needs to be seen in interaction with the surrounding energy system, both locally and nationally. Thus, the scenarios need to show the impact between the PED and the surrounding energy system, to quantify to what extent a PED is achieved, but also that it is not a sub-optimisation of the overall national transition of the energy system.

3.2.1. T4.1 Scenarios for De Zwette demo site

For the demo site De Zwette and the main approach as described in section 3.1 will be followed which contains a multitude of approaches, methods, and tools (Figure 19). First the current state of De Zwette demo site will be analysed using the Energy Scan and Area passport methods. Next scenarios are set up with the focus of understanding and solving grid congestion. During the research process the main scenarios will be further defined in collaboration with the connected stakeholders in De Zwette demo site. The following main scenarios can currently be determined:

- **The reference scenario** will map the current situation of the electricity grid in De Zwette demo site using the Neighbourhood passport, GridNodes, FlexLoads, and Pandapower methodologies. The area will be mapped looking at general features using the Energy Scan and Area passport e.g. number of companies, households, installed RE production, vailable infrastructure etc. The electricity grid will be visualized including the area of grid congestion and the location using Pandapower and GridNodes. With the system boundaries set, we define the current condition of this system (base case) as accurately as possible (see Figure 19), taking into account factors such as (temporal) energy demand, energy production, net load signal and various component specific technical constraints (cable capacity etc.). The best-case scenario would be to base this all on measured data, by working together with the distribution system operator Liander, businesses with high energy use in the area, and the municipality to procure the data taking all stakeholders along on the journey. As necessary, energy flows must be approximated using simulations. This will give insight into the organizational side of things. In case no data is available, system components will be modelled. The summation of modelled components and data will be compared to measured data on a higher level in the topology to validate the base case.
- **Solution scenarios** will explore future possible solutions using the PowerNodes methodology and their impact using the GridNodes and Pandepower methodology. Future interesting solution could include battery storage, heat storage, hydrogen production and storage, curtailment, demand side management, etc. From the multitude of possible solution scenarios, the best performing will be selected for further analysis and or fine tuning. These selected scenarios will be further evaluated on according to the PESTLE(S) framework. With the base case established, the net load signal of the electricity grid model (PowerNodes) will be analysed on a per node basis to identify nodes that can be contributing to the congestion and/or act as bottlenecks. With all the suspected nodes identified, the PowerNodes model will be used to quantify the impact which different interventions, such as flexibility, storage, and grid reinforcement, could have on the congestion and the (economic) results of the intervention. Based on all the different scenarios modelled, an intervention to eliminate grid congestion will be proposed, whereby the regulatory barriers and social acceptance are taken into account. Eliminating the grid constraints on new distributed intermittent energy resource projects makes developing PEDs and expanding (sustainable) industrial areas feasible. The interventions also provide insight into new innovative flexible energy system business models. These, along with knowledge gathered on the organizational level, help promote the growth of PEDs in a mixed urban-industrial setting.

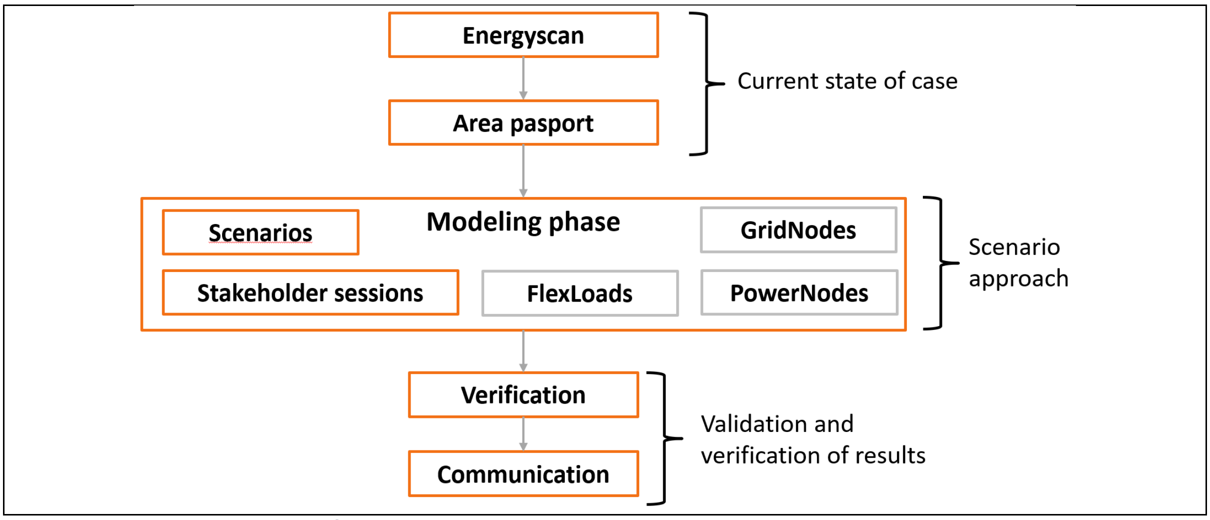


Figure 19: The main approach for developing energy scenarios

3.3 Methodology for identifying regulatory, structural, and technical barriers for implementing PEDs at national and local level

The emerging literature on PEDs identifies numerous barriers for the implementation of PEDs. These barriers can broadly be divided into regulatory (or legal), structural (non-technical), and technical barriers. In the FLEXPOSTS project an initial literature review was conducted with the aim of identifying already known barriers for implementing PEDs. Parallel to the literature review, an initial mapping of the potential barriers for implementing a PED in each demo site (and its corresponding national context) was carried out based on existing knowledge of each demo site and an initial desk research. The next step will be to verify these barriers through further desk research, input from stakeholders and expert interviews. An example of this initial mapping of barriers for demo site Aalborg East is presented in Figure 20.

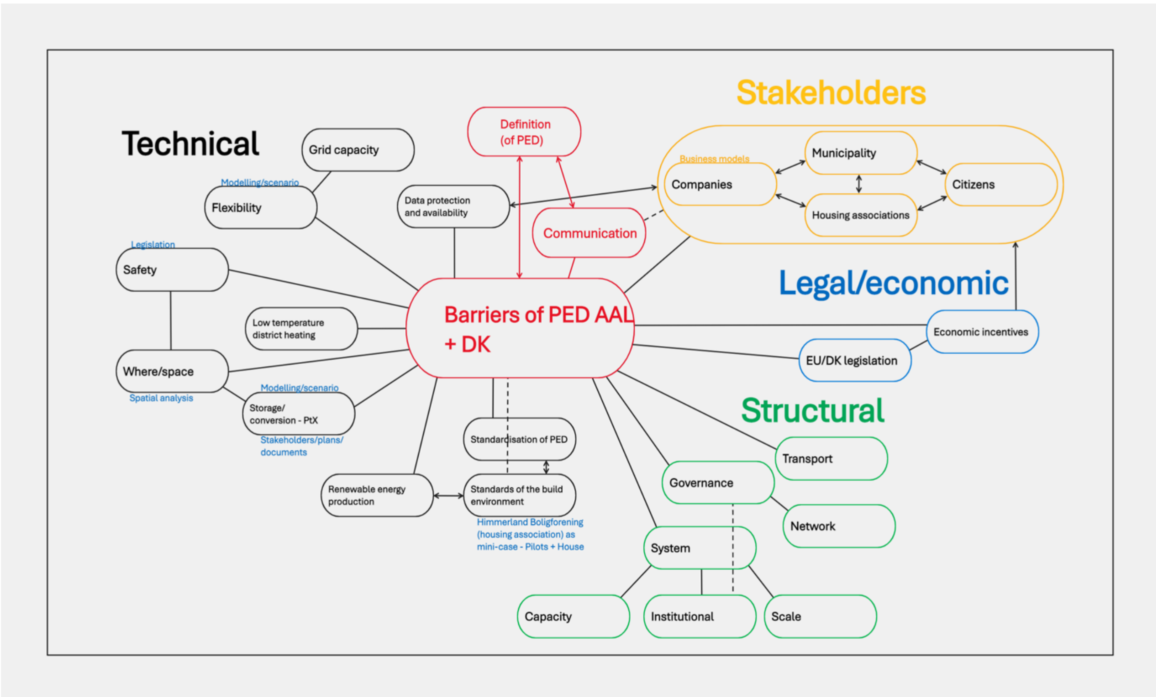


Figure 20: Initial mapping of the barriers for implementing PEDs in Aalborg East and Denmark

Even though the barriers for implementing PEDs may be mapped separately, it is important to recognise that these barriers are highly interlinked. The regulatory barriers depend for example on which type of technical solutions will be implemented as part of the PED, which again is depended on political goals, the local and/or national economy, social acceptance, environmental impacts, and the spatial characteristics of the district. The barriers (and potentials) for implementing PEDs must therefore be analysed and understood across the type of barriers. Box 1 and Box 2 provide an example of the considerations that must be taken when examining the regulatory barriers for implementing PEDs in general and exemplified in the demo site De Zwette.

Box 1: Initial assessment of the regulatory barriers for implementing PEDs

The analysis of the general regulatory barriers will focus on both the national and local level. To identify relevant regulation, it is necessary to know how the PED will be achieved. For instance, PEDs relying on heat grids will face different regulation than PEDs relying on electricity. The regulatory freedom for each type of energy will furthermore be different, with EU regulation exerting substantial influence over electricity but hardly any on heat grid regulation. The legal analysis will therefore begin with a general inquiry into the relevant law on energy per nation and the form of energy they are most likely to use. A nation like Denmark – with substantial heat grid infrastructure already in place – will likely attempt to achieve PEDs with tools already at their disposal. The Netherlands, in turn, has almost no heat grid infrastructure. A general inquiry for the Netherlands must thus focus on the electricity grid.

Then, as it becomes more clear which technical solutions might be preferred in each demo site, the legal analysis can begin to zoom in on specific topics that relate to these solutions. This approach begins with a general review of energy related topics which a particular country's infrastructure is suited for. Then, taking into consideration the other types of barriers, the legal analysis will zoom in on specific regulation. Only this approach will enable a legal analysis that will identify the relevant legal barriers in each demo site. Any other approach risks becoming a general description of regulation, which does not touch upon specific barriers that PEDs face. The analysis of the legal barriers for PEDs therefore requires close consideration with the other barriers of PEDs.

The type of law that PEDsz run into can influence which stakeholders can influence these barriers. If the PED requires substantial storage capacity, the size and the nature of that storage will determine the likelihood of permits being necessary. The ability of the PED to acquire a permit will then be dependent on building norms and, potentially, environmental impact assessments. The law for a nation can assign the competence for the assessment of these permits to different levels of government, such as the municipal level, the provincial level or the state level. Depending on the level, the designers of a PED would have to focus on different stakeholders and different norms when acquiring permits.

If the PED requires all houseowners to install solar panels and small batteries, that requirement could collide with property law. In principle, citizens of the EU enjoy private property rights. These rights allow them to use their property as they see fit, without government interference. Should the modelled PED require all or nearly all homeowners to purchase infrastructure for their home, it would only take the refusal of a few homeowners to threaten the PED. The use of private property by a PED requires either the consent of homeowners or some manner of derogation from private property.

Should the PED face issues related to public infrastructure, then it becomes necessary to determine the regulation for that infrastructure. With public infrastructure, the owner or operator of that infrastructure will usually face all sorts of regulation determining its use. A PED may require certain demands put on this infrastructure that this owner or operator cannot fulfil, at least not while adhering to the regulation. Any PED that faces this issue will then have to find derogations for this regulation or find ways to limit the use of this public infrastructure. Attempts to do the latter may include increased local energy generation and storage, which could cause the PED to face other laws. Think for instance of the previously discussed law surrounding private property and permits.

BOX 2: Regulatory barriers for implementing a PED in De Zwette

The major impediment to a PED in De Zwette, from a technical and social perspective, concerns congestion. The problem has a link to the technical aspects of the PED due to the amount of electricity exceeding the technical limit of the distribution system. The result of that exceedance of capacity is technical. The problem touches upon the social aspects of a PED, because the simultaneous use of the distribution system exceeds what the system can handle. This simultaneous use – that forces the system to cope with loads it could easily handle if it were more spread out – has a social cause. The legal aspects become relevant due to failures from the social and technical aspects of a PED to solve the issue. The relevant law for De Zwette, based on the current issues of congestion, concerns all law that touches upon the usage of the distribution system.

The methodology for determining the legal limits of a PED in De Zwette has several issues that touch upon electricity law. At the highest layer, European law limits the approaches available for the social and economic approaches. Per art. 32 (1) Directive 2019/944, DSOs must attempt to use flexibility to increase distribution capacity – both for the intake and outtake capacity of the system – through market-based methods. The Dutch regulator has responded to this requirement by altering the Dutch net code to facilitate these market-based methods. Only after the market-based methods are exhausted can a DSO fall back on miscellaneous forms of congestion management. These methods do not solve congestion, as they are largely limited to ad hoc, physical interventions of the distribution system. As a result, a Dutch DSO cannot meaningfully force users of the distribution system to alter their use profiles.

The ability of the DSO to solve congestion through market-based methods may be limited by its ability to facilitate markets. The Dutch net code focuses primarily on creating a demand for flexibility products. The net code sets a maximum budget that DSOs must exhaust before any of the other, more limited methods can be employed. If the prices that result from these budgets are insufficient to entice users of the distribution system to alter their use, the market-based method will not work. Neither will the market-based method work if the process is too complex for users. This will be of particular concern for smaller users of the grid, who must aggregate their loads prior to participating in congestion management.

At the national level, the DSO is limited in its ability to alter the distribution rights of its users. The market-based methods of EU law require renumeration for users when altering their use. This does not change the legal right of the user but buys a change in its use. Recent national methods, either in development or recently enacted, focus instead on changing the legal right itself. These methods are known as: flexible transportation rights, GOTORK (a method for reducing contracted capacity to actual use) and group contracts. With the exception of GOTORK, these methods are voluntary. It is not possible to use flexible transportation rights or group contracts against a user's consent. GOTORK can do so but can only be activated if a distribution user has already forgone the use of capacity for a substantial amount of time. GOTORK is, furthermore, surrounded with procedural protections in order to ensure consumers are not harmed. A DSO can create some capacity through changes in distribution rights, but the law limits the extent to which DSOs can do so.

3.4 Interdisciplinary and transdisciplinary methodology for synergising energy planning and urban planning processes at neighbourhood scale towards the implementation of PEDs

PEDs are innovative urban areas that support the sustainable transition towards energy positive districts, including renewable energy and efficiency. While the integration within the energy system is essential, the built environment offers some of the key solutions to locate renewable energy infrastructures as well as allocation of industries and facilities to support an efficient energy system. PED implementation draws on a multitude of areas including different institutions, legal frameworks, and stakeholders. As a consequence, there is a need not only to empirically investigate these different areas, but also to draw on theories from within each area. PEDs therefore requires multidisciplinary knowledge and expertise, such as from urban planning, energy system engineering and planning, environmental planning, and legal, business and system design studies, to fully incorporate these different aspects and to create a wholesome analysis for PED implementation. As emphasized in the PED literature, collaboration between multiple disciplines is essential for successful implementation of PEDs:

> Collaboration between disciplines, sectors, institutions, and communities is essential for the successful planning and implementation of Positive Energy Districts (PEDs). However, silo thinking, defined in this document as the disregard of other groups' viewpoints or interests, poses a barrier to effective collaboration. (Yoo et al. 2020: vi)

The FLEXPOSTS project recognises the challenge of bringing different disciplines together in a shared project and the risk of the project to not transgress the multidisciplinary boundaries. When working from a multidisciplinary outset, strategies for integrating the various ways of understanding and seeing PEDs are needed. Otherwise, there is a risk of staying within the disciplines own ways of understanding the phenomenon and the conclusions simply becomes a multiplicity of monodisciplinary explanations. In truly interdisciplinary projects new knowledge emerges that creatively integrates and works "in between" the different areas of knowledge. Special attention has therefore to be put on the design of an interdisciplinary and transdisciplinary methodology for synergising energy planning and urban planning processes. Here, it is important to distinguish between interdisciplinarity and transdisciplinarity. Working from a multidisciplinary outset, it is crucial that the different disciplines gain knowledge about how the other disciplines are thinking and to do this there is a need for transdisciplinarity, which means understanding concepts and methods from other disciplines and trying to bring those into your own discipline to obtain real understanding of them. This could also be when researchers work together with practitioners in their field, citizens or other stakeholders and try to understand and work with their ways of understanding the problems. The methodology for stakeholder engagement outlined in section 3.5 constitutes therefore an important part of the transdisciplinary approach of the FLEXPOSTS project. When the transdisciplinary understanding is reached, the creative interdisciplinary phase can begin, and the research team can collaboratively work on answering the research question. In this phase new knowledge will emerge that would not be possible working from a mono- or multidisciplinary setting.

When engaging in trans- and interdisciplinary work, it is crucial to recognize and appreciate the different competencies and knowledge domains associated with each discipline or practice involved. Collaboration entails openly acknowledging these differences and striving towards a shared understanding of both the problem at hand and its potential solution. See Figure 21 for an overview of how FLEXPOSTS work interdisciplinary.

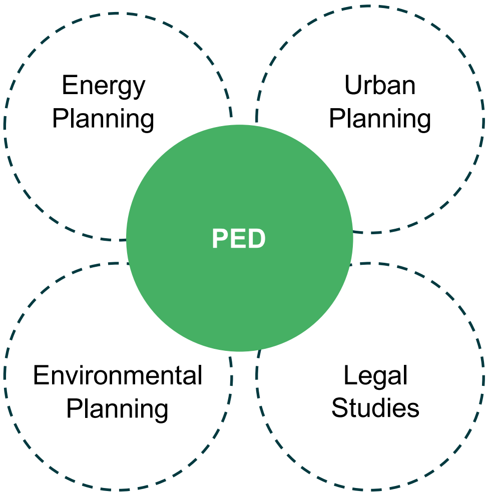


Figure 21: FLEXPOSTS' interdisciplinary approach. FLEXPOSTS utilises the PED concept as the starting point for integrating different disciplines to develop a common framework for implementation of PEDs.

The methodology employed in FLEXPOSTS primarily focuses on elaborating upon the varying competencies found within different areas of expertise, while also designing a collaborative process for effectively integrating knowledge across disciplines. The goal is to collectively work towards achieving a common *resolution* for the objectives set forth by this project.

As FLEXPOSTS is structured around the demo sites of De Zwette and Aalborg East, it is relevant to map out the research expertise that is located in each geographical context. In general, it is worth emphasising that both research teams consist of multiple disciplines, and therefore that a larger degree of interdisciplinarity can be achieved by combining the research expertise that can be found in each geographical context. An overview of the research expertise in the two demo sites are presented in Table 2.

Table 2: Overview of the research expertise present in the two demo sites

De Zwette	Aalborg East
• Energy system analysis research • Legal research • Urban and energy planning integration research • Urban planning practice	• Energy system analysis research • Urban planning research • Environmental planning research • Business stakeholder involvement practice • Circular economy research

As the overview of research expertise above show, there is not necessarily a one-to-one overlap between the expertise in the demo sites. Though the overall project aim remains the same, the two demo sites have different focus in their problem orientation, both due to the empirical circumstances, but also because of the involved expertise from the two teams. Necessarily this means the learning outcome from the cases and teams will not necessarily be similar and this begs for a closer integration between the knowledge sharing of the teams and demo sites. Below is an overview of different methods and processes for trans- and interdisciplinary knowledge building, internally in the project.

Meetings: During the regular meetings (monthly) related to the work in the two demo sites, members of the other teams are present, meaning e.g. when the Dutch team have meetings about De Zwette demo site then a member from the Aalborg East demo site is present and vice versa. At each meeting, there is an update from the parallel case on progress and pressing issues. This ensures a knowledge transfer between the cases and possibility to draw on expertise from both teams to resolve issues.

Site visits: Each team has been invited to visit the parallel demo site to gain in-depth knowledge about the site. The visit to De Zwette was conducted in April 2023 and the visit to Aalborg East was conducted in October 2023 - each of them in the first phase of the project. During the visits the teams have met up with partners, other stakeholders, and authorities to learn about their perspectives on the issues related to the demo site. In addition, internal face-to-face seminars has been held during these visits to dig deeper into subjects concerning the project collaboration. An example of topics discussed during these seminars are energy system analysis, legal framework analysis, and collaboration on deliverables in the project.

Collaboration on specific methods: Even within each discipline there will be differences in the preferred methodological approaches. The two teams have each their own familiar and preferred set of methodologies, e.g. on how to carry out energy system analysis. An extra effort has therefore been made to introduce the other team to one's own preferred sets of methodologies, as a starting point for exploring how the methodologies could be combined and utilised in the analyses of both demo sites.

3.5 Methodology for local stakeholder engagement and establishing local partnerships and networks to support the establishment of public-private partnerships

This section outlines the methodology for stakeholder engagement and establishing local partnerships and networks that will be applied in the demo site De Zwette (T.4.3) and the demo site Aalborg East (T.5.3)

The importance of involving the relevant stakeholders in the implementation of PEDs is continuously stressed in the PED literature. In fact, the involvement of stakeholders has been highlighted as one of the biggest success factors for the implementation of PEDs (Bossi et al., 2020). Developing a strategi for engaging (local) stakeholders in the development of a PED in the two demo sites is therefore an important step in the PED implementation process. The (local) stakeholders will not only provide important (local) knowledge and different perspectives into the process in accordance with FLEXPOSTS' transdisciplinary approach, but their engagement is also important for developing a local governance capacity, e.g. a public-private partnership, that can take on and promote the PED-agenda in the demo sites beyond FLEXPOSTS' lifespan. In other words, stakeholder engagement is crucial for establishing a permanent network working towards the sustainable energy transition in the two demo sites. The (local) stakeholders will therefore be involved in various phases throughout the FLEXPOSTS project, also beyond the tasks described in this report (T3.1.).

The main stakeholder engagement methodology is illustrated in Figure 22 (see also The Carbon Trust, 2018). First step is to identify the relevant stakeholders in the project. This is important to do in the early project phase, whilst still recognising that more stakeholders may be identified at a later stage as the project evolves. Second step is to map out the stakeholders to develop an understanding of how the stakeholders relate to the aim of the project and to each other. Here, it is also important to think about what the stakeholders' motivation for engaging in the project would be. Third step is to prioritise between the stakeholders. Stakeholder engagement can be a long and time-consuming exercise. It can therefore be necessary to prioritise between the stakeholders in terms of who are the most important stakeholders to engage for the success of the project. A useful exercise can be to group the stakeholders into different categories, e.g. some stakeholders are key to involve in meetings and workshops, whilst others can be informed about the progress of the project through newsletters or other types of information.

Fourth step is to plan the engagement. In other words, prepare a stakeholder engagement strategy. Here, it is important to think about who to involve, why, where, and how. It is important that the stakeholder engagement strategy is linked to the other tasks in the project. An assessment of the existing energy balance of the demo site must for example be prepared, before stakeholders can take part in developing future energy scenarios for the neighbourhood. Fifth step is the engagement phase. Here, it is important to think about who should engage with the stakeholders and how. Stakeholders are for example more likely to engage in a process that is led by someone they already know and trust. It is also important that communication about the aim of the project is well prepared. It may be helpful to prepare a 30 sec elevator speech before the first engagement event (The Carbon Trust, 2018).

Figure 22: Five steps of stakeholder engagement (The Carbon Trust 2018: 7)

In FLEXPOSTS the initial identification, mapping, and prioritisation of the stakeholders in the two demo sites has been carried out in the first phase of the project. Figure 23 and Figure 24 present a list of the key stakeholders identified in each demo site. The stakeholder engagement activities in FLEXPOSTS will primarily be planned around these stakeholders.

Aalborg East is a mixed-use neighbourhood with already established networks and links between various local stakeholders. One example is the Business Network 9220. Another example is that some of the businesses in Aalborg East have previously been involved in an industrial symbiosis research project, which has resulted in continuous collaboration between stakeholders in the business community. Although there are many green initiatives in the area, there is no formalized strategy for synergising these initiatives. Therefore, a formalized PED network and strategy is needed to help link the various projects in the area. Five relevant stakeholders have been identified to help create an overview of local stakeholders' interests, needs and potential contribution to the design and implementation of a PED strategy. A description of the five main stakeholders can be found in Figure 23Figure 23.

Aalborg Forsyning	Aalborg Forsyning, a multifunctional utility company with over 225,000 consumers, is transitioning to a sustainable future, phasing out fossil fuels for a fossil-free district heating system by 2028. Additionally, they are consolidating operations in the 100-hectare Nobis Park, creating a test center for sustainable energy solutions.
PORT OF AALBORG	Port of Aalborg is Denmark's leading inland port, offering logistic solutions and business development. They prioritize sustainability, engaging in green initiatives and partnerships to reduce environmental impact and promote economic benefits, while aiming to make Aalborg a green capital.
HIMMERLAND BOLIGFORENING	Himmerland Boligforening is a public housing organization in Aalborg with approximately 7,000 rental units. They have a sustainability policy emphasizing energy reduction, renovation, and biodiversity. Their ambitious Green Hub House project aims to reduce urban housing's climate impact by 75% through innovative building practices.
Nordvaerk	Nordværk is a prominent waste management company in Northern Jutland. Their most notable project, Nordjyllands Ressourcepark, located in Aalborg East, aims to handle waste from multiple municipalities in an environmentally friendly manner, emphasizing resource utilization and waste reduction.
ERHVERVS NETVÆRK 9220	ErhvervsNetværk 9220 is an active network fostering collaboration and trade among businesses in eastern Aalborg, while contributing to the green transition and promoting sustainable business development. With a vision to actively engage in business policy considerations and form collaborations with relevant organizations, they aim to create attractive conditions for companies in the area.

Figure 23: The key stakeholders in the Aalborg East demo site.

In **De Zwette** the main issue is congestion on the electricity grid. Grid congestion is hindering economic development and achieving sustainability targets such as renewable energy production and electrification of industrial processes. Whilst planning for PED planning strategies, the existing net congestion will have to be taken into account. The first steps have therefore been focused on mapping the existing congestion in the area. Once the congestion has been mapped suitable measures can be thought of to implement PED strategy measures whilst staying within the boundaries of the electricity grid. For this process the main stakeholders have been identified, being the local grid operator Liander, province of Friesland, municipality of Leeuwarden and local businesses located in and around De Zwette, see Figure 24.

Liander is a key stakeholder in providing insight and data about the functioning of the local energy grid. However, detailed electricity data of individual companies is protected information under the Dutch law, permission from the individual companies located in De Zwette was required to access the data.

The local business located on De Zwette are currently most affected by the net congestion issues. The congestions hinders new developments, expansions plans and electrification of existing operations. Within FLEXPOSTS it is important to include the largest energy producing and consuming businesses, their energy data can be used to gain insight in the usage of the electricity grid and the opportunity for efficient PED solutions.

The municipality of Leeuwarden is responsible for the business operation and development of De Zwette. They play an important role in the stakeholder engagement strategy as the coordinator between the local businesses, Liander and the province of Friesland. The municipality has a special account manager who is responsible for managing relations with the businesses located on De Zwette.

The province of Friesland has been identified as supporting partner of the FLEXPOSTs project. Provinces play an important role in the energy transition in the Netherlands. They are responsible for the strategic and spatial planning of energy and sustainability strategies. Additionally, they have a coordinating role between regional initiatives and supervision over the local municipalities and the DSOs.

Figure 24: The key stakeholders in De Zwette demo site.

In FLEXPOSTS stakeholder engagement is an integral part of the project and stakeholders will be involved throughout the project to support the PED implementation in the two demo sites. The stakeholders will for example be actively involved in identifying the regulatory, structural, and technical barriers for implementation of PEDs at national and local level. Here, it is important not only to map the potential barriers for implementation of PEDs, e.g. from a national legal perspective. Stakeholders can play an important role in identifying the barriers for PEDs as they are experienced 'on the ground' in the specific local contexts. In FLEXPOSTS we will start the mapping of the barriers for PEDs from the local level, that is how barriers are experienced and come into effect on the ground – and then from there scale up to understand the barriers for PED in the given national context. Here, it may be necessary to involve other stakeholders to get the full understanding of the barriers for PED at a national level.

4. Conclusions and further work

Implementation of PEDs require integration of urban and energy planning processes, as well as a committed network of stakeholders from the public and private sector. The aim of the FLEXPOSTS project is to develop effective and replicable strategies to enhance the process of establishing PEDs. A major emphasis is placed on engaging stakeholders and developing innovative business models for flexible energy systems. FLEXPOSTS will apply an interdisciplinary approach for integrating energy and urban planning. This approach is demonstrated in two demo sites, Zwette VI (Leeuwarden, the Netherlands), and Aalborg East (Aalborg, Denmark).

This report has presented the methodological guide for how to implement PEDs in the two demo sites in FLEXPOSTS (D3.1). The report has outlined the different methodologies that will be applied in T3.1 Developing methodologies for implementing PEDs. This task has been divided into five sub-tasks. These tasks are to develop a:

- T3.1.1: methodology for analysing the existing energy system and energy balance at neighbourhood level
- T3.1.2: methodology for developing future energy scenarios
- T3.1.3: methodology for identifying regulatory, structural and technical barriers for implementing PEDs at national and local level
- T3.1.4: interdisciplinary and transdisciplinary methodology for synergising energy planning and urban planning processes at neighbourhood scale towards the implementation of PEDs
- T.3.1.5: methodology for local stakeholder engagement and establishing local partnerships and networks to support the establishment of public-private partnerships.

This report has outlined detailed methodologies for how to approach each task in the two demo sites to secure an overall common framework in FLEXPOSTS. Rather than conducting a traditional comparative study, the FLEXPOSTS project seeks to explore comparisons between the two demo sites across multiple scales. This approach allows some flexibility and a greater possibility for paying attention to the unique characteristics of each demo site, whilst still maintaining the overarching goal of exploring the feasibility on implementing PEDs locally. The approach supports the idea that knowledge in the FLEXPOSTS project can be generated ‘within’ each demo site and their respective national context, ‘between’ the demo sites and their national context, but also ‘above’ the demo sites and their national context on a conceptual level.

Task 3.1 Developing methodologies for implementing PEDs should also be seen in relation to the tasks of developing business models and PED implementation strategies (T3.2), together with the development of a replication toolkit (T3.3). The methodologies for these tasks will be reported separately. Appendix A presents a complete list of the tasks in FLEXPOSTS.

Appendix A: Overview of Tasks in FLEXPOSTS

WP 1: Project Management
T1.1: Project coordination and consortium management
T1.2: Administrative and financial management
T1.3: Risks and ethical issues management
T1.4: Stakeholder Engagement
WP 2: Expert Support Facility
Expert : Dr. Marten van der Laan
WP 3: Process innovation, business models and circularity
T3.1: Developing methodologies for implementing PEDs T.3.1.1: methodology for analysing the existing energy system and energy balance at neighbourhood level T3.1.2: methodology for developing future energy scenarios T3.1.3: methodology for identifying regulatory, structural and technical barriers for implementing PEDs at national and local level T3.1.4: interdisciplinary and transdisciplinary methodology for synergising energy planning and urban planning processes at neighbourhood scale towards the implementation of PEDs T3.1.5: methodology for local stakeholder engagement and establishing local partnerships and networks to support the establishment of public-private partnerships.
T3.2: Developing business models and PED implementation strategies
T3.3: Replication Toolkit
WP 4: Demo Site Zwette VI, Leeuwarden
T4.1: Assessment of energy demand, generation profiles, and local energy balance
T4.2: Identifying regulatory, structural and technical barriers
T4.3: Identifying existing partnerships and networks at Zwette VI
T4.4: Assessment of the quality of flexibility
T4.5: Developing business models
T4.6: Developing a strategy for implementing PED
WP 5: Demo Site Aalborg East
T5.1: Assessment of energy demand, generation profiles, and local energy balance
T5.2: Identifying regulatory, structural and technical barriers
T5.3: Identifying existing partnerships and networks at Aalborg East
T5.4: Developing future energy scenarios
T5.5. Developing business models and implementation strategy for PED

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