PED StepWise

WP3 – D3.2 – Required information and data for PEDs: Modelling and Assessment

Deliverable	D3.2 Required information and data for PEDs: Modelling and Assessment
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Acronym Table

Acronym	Definition
PEDs	Positive Energy Districts
aFRR	Automatic Frequency Restoration Reserve
ATES – WKO	Aquifer Thermal Energy Storage / Warmte Koude Opslag
BESS	Battery Energy Storage System
BKI	Building cost index
Bkl	Besluit kwaliteit leefomgeving (decision quality living enviornment)
CBC	Connection Capacity Control
CHP / WKC	Combined Heat and Power plant / Warmte Kracht Centrale
DKTI	Demonstratie Klimaattechnologieën en Innovaties
ESCO	Energy Service Company
EVB	Erneuerungs- und Verbesserungsbeitrag (English: RIC)
GIS	Geographic information system
GOPACS	Grid Operators Platform for Congestion Solutions
GvO	Guarantee of Origin
HER +	Hernieuwbare Energie Regeling Plus (renewable energy scheme plus)
HTES	High Temperature Heat Storage
HU	Hogeschool Utrecht (Utrecht University of Applied Sciences)
IRR	Internal Rate of Return
ISU	International School Utrecht
MFH	Multi family home
MWp	Mewawatt-peak
NPV	Net Present Value
PV	Photovoltaic
RIC	Renovation and improvement contribution
SDE++	Stimulering Duurzame Energieproductie en Klimaattransitie (Incentive Scheme for Sustainable Energy Production and Climate Transition)
SFH	Single family home
SSH	Stichting Studenten Huisvesting (student housing association)
TCO	Total Cost of Ownership
TSN	Thermal source network
UMC / UMCU	University Medical Center Utrecht
UNESCO	United Nations Educational, Scientific and Cultural Organization
UU	Utrecht University
USP	Utrecht Science Park

1.Introduction

District decarbonisation is inherently complex. Existing neighbourhoods differ in their spatial, physical, social and organisational characteristics, and Positive Energy Districts (PED) development requires a multi-dimensional information basis.

This deliverable defines the data requirements necessary for developing and assessing Positive Energy Districts (PEDs) within the PED StepWise project, with a focus on district-level decision-making. It provides a structured overview of the datasets, data qualities and access conditions that enable evidence-based planning, modelling and decision-making for district-level decarbonisation. The document serves as a methodological bridge between the step-by-step PED implementation process (D3.1) and the technical, economic and participatory activities in WP4 and WP5, while allowing for data needs that arise independently from the process map.

This deliverable outlines why a broad set of data domains is needed, how these domains relate to the PED StepWise process, and which minimum datasets are essential for progressing PED planning in different local contexts.

The document also clarifies the link to WP4, where the data are used for technical and economic scenario development, and explains the limitations of the current data landscape in the three Living Labs. Data needs in WP4 are partly derived from the StepWise process and partly from local techno-economic assessment requirements. The final sections summarise the available datasets, identify gaps and special conditions, and describe approaches for handling missing data and establishing practical data-access routines.

Scope and limitations

This deliverable focuses on the data domains relevant for PED development in existing neighbourhoods. It covers spatial and physical context, building stock, energy systems and loads, socio-demographic and behavioural characteristics, ownership and governance, and economic and financial parameters. The scope includes minimum datasets, defined as the data required to proceed with PED planning at a basic decision level, recommended datasets for more detailed analysis, and special considerations for the Living Labs.

However, several limitations apply. Data availability varies across countries, cities, and housing cooperatives. Access to sensitive data—such as consumption and personal data—may be restricted due to privacy regulations and governance conditions. The document, therefore, includes guidance on handling data gaps, using proxies where necessary and adapting the framework to local constraints.

Structure of the document

The report is organised into three main parts. First, it establishes the framework for PED data requirements, explaining why Positive Energy Districts require multidimensional data and discussing key issues such as data quality, granularity, interoperability, and privacy. Second, it presents a comprehensive overview of the data domains needed for PED development, covering technical, economic and financial, social, and organisational dimensions. Third, the report provides living-lab-specific sections, where each living lab describes its own data collection process, including available data, identified gaps, local constraints, and any special conditions affecting data access or use.

2. Conceptual Framework for Data Requirements

Why PED development requires multidimensional data

The development of Positive Energy Districts (PEDs) requires multidimensional data because a PED is not only an energy concept, but also a spatial, technical, social, economic and governance-related transformation process. Unlike a general energy mapping exercise, which often focuses on identifying energy demand, supply potentials or efficiency opportunities, PED development is linked to a specific purpose in a specific area. The type of data required therefore depends on what is to be investigated, what transformation goals are being pursued, and what local systems are already in place.

This means that the PED concept needs to be understood not as a fixed technical solution, but as a framework for achieving defined objectives within a given urban context. In one district, the main purpose may be to reduce fossil fuel dependency by connecting buildings to a local renewable heat network. In another, the focus may be on increasing local electricity generation, improving energy flexibility, supporting building renovation, reducing energy poverty, or coordinating investments across multiple stakeholders. Each of these purposes requires different types of data and different levels of detail.

For example, if the aim is to assess the potential for local heat supply, data on building heat demand, temperature levels, existing heating systems, renovation status, available waste heat, geothermal potential or groundwater resources may be central. If the objective is to evaluate photovoltaic self-sufficiency, roof areas, shading, electricity demand profiles, grid capacity and storage options become more relevant. If the goal is to enable implementation, then technical data alone is insufficient; information on ownership structures, investment cycles, financing capacity, regulatory constraints, user acceptance and stakeholder roles is also needed.

For this reason, multidimensional data is essential for defining realistic PED pathways. It allows planners and decision-makers to understand not only what is technically possible, but also what is economically viable, socially acceptable, institutionally feasible and strategically aligned with local goals. The required data must therefore be selected according to the purpose of the PED investigation, the characteristics of the area, and the specific transformation questions that need to be answered.

Data–process relationship in the PED StepWise process

In the PED StepWise process, data is closely linked to the different phases of district transformation. Data is not collected only once at the beginning of the process, nor is it used only to describe the current situation. Instead, data continuously informs decisions, supports the comparison of alternatives, and helps refine the PED pathway as the process develops. This means that the role of data changes over time: in early phases, data is often used to understand the local context and define ambitions; in later phases, it becomes more detailed, operational, and implementation-oriented.

A key characteristic of PED development is that decisions depend on multiple types of data simultaneously. Technical energy data alone is not sufficient to determine which pathway is feasible or desirable. It also requires economic data on investment costs and financing options, social data on user acceptance and stakeholder needs, institutional data on ownership and

governance structures, and regulatory data on permits, responsibilities, and planning constraints.

The PED StepWise includes multiple phases throughout which data evolves. During the visioning and planning phase, data is needed to define the overall direction of the PED development. At this stage, the focus is not yet on detailed technical design, but on understanding the district's current situation, identifying local challenges, and clarifying the purpose of the PED intervention. In the analysis phase, data is used to assess the existing conditions and identify possible transformation potentials. This includes more detailed information on building energy demand, building typologies, renovation status, heating and cooling systems, renewable energy potentials, grid conditions, mobility patterns, and local energy flows. At the same time, economic and social data becomes important for understanding feasibility beyond technical potential.

Later comes the design phase, in which data supports the development and comparison of concrete PED scenarios. Different technical and spatial solutions can be tested, such as building renovation packages, renewable energy systems, heat networks, storage solutions, energy communities, or flexibility measures. At this stage, data needs to become more specific and comparable. Decision-making may require data on system performance, costs and benefits, CO_2 reduction potential, energy balance, implementation timelines, risk factors, and responsibilities.

The last phase is the implementation phase, here data becomes increasingly operational. It is needed to support procurement, financing, construction planning, stakeholder coordination, permitting, and monitoring. Data on investment commitments, contracts, ownership models, technical specifications, implementation schedules, and regulatory requirements becomes especially relevant. At the same time, data from monitoring and feedback can be used to check whether the implemented measures are achieving the intended outcomes.

The relationship between data and process is therefore iterative. As the PED StepWise process progresses, earlier assumptions are refined, missing data is identified, and decisions are adjusted based on new information. Data does not only inform individual decisions within each phase; it also creates continuity between phases.

Data quality, granularity and privacy principles

In PED development, data quality is important, but it is also difficult to define in a universal way. What counts as "good" data depends on the purpose of the analysis, the project phase, the decision to be supported, and the data domain involved. While high-resolution and complete datasets are generally desirable, PED planning must usually work with partial information, uncertainties, and assumptions.

In this project the data domains have been grouped as follows: technical, economic and social. In the technical domain, more detailed data can improve the accuracy of analyses and simulations. However, such data is often incomplete, outdated, unavailable, or inconsistent across buildings and stakeholders. Therefore, missing technical data often needs to be complemented with assumptions based on scientific literature, engineering knowledge, benchmarks, and practical experience. The quality of technical data should therefore not only be judged by its

completeness, but also by whether assumptions are transparent, documented, and appropriate for the decision being made.

In the economic domain, data quality is strongly linked to uncertainty and risk. Costs, energy prices, funding conditions, interest rates, construction costs, and market developments can change over time. As a result, economic data cannot provide certainty about future outcomes. Instead, it should support robust decision-making by making assumptions explicit and by considering ranges, scenarios, and sensitivities. A high-quality economic dataset is therefore not one that predicts the future perfectly, but one that clearly shows the basis of the calculation and the uncertainty around it.

In the social domain, data is even more dynamic. Stakeholder priorities, user acceptance, willingness to participate, and behavioural patterns can change during the process. Social data may be influenced by communication, trust, external events, political debates, financial concerns, or personal circumstances. In addition, social data often involves sensitive information about individuals, households, ownership, income, preferences, or behaviour. Privacy protection is therefore a central principle. Only data that is necessary for the PED process should be collected, and personal or sensitive data should be anonymized, aggregated, or handled with clear consent wherever possible.

Granularity is another important consideration. More detailed data is not always better if it creates privacy risks, increases complexity, or exceeds what is needed for the decision at hand. In early phases, aggregated data may be sufficient to identify potentials and strategic directions. In later phases, more detailed data may be required for design, financing, implementation, or monitoring. The appropriate level of granularity should therefore be defined according to the purpose of the analysis and the phase of the PED StepWise process.

3.Required Data Domains for PED Development

3.1. Technical Data Domains

To assess decarbonization pathways, renewable energy integration, network energy density, and other factors that are essential for PED Development, a consistent and verifiable technical dataset is required. The data typically covers six main areas: (1) consumer/building information and load profiles, (2) spatial and network layout inputs, (3) electricity demand and peak load, (4) hydraulic, thermal, and system boundary conditions, (5) potential energy sources and supply constraints, and (6) grid infrastructure, congestion and flexibility.

Table 1: Technical Data Domains

Category	Description
Building and consumer data (demand side)	• Number and type of buildings (education, research, residential, hospital, office), gross floor area, and occupancy assumptions • Construction years, and renovation status • Thermal characteristics, annual and peak space-heating demand, and load profiles • Domestic hot water annual and peak demand, and load profiles. • Temperature requirements at consumer level • Optional: cooling potential/loads
Spatial data and network topology inputs	• Georeferenced building locations (coordinates or polygon footprints to enable spatial validation) • Potential pipe routing corridors (road centrelines, right-of-way corridors, or predefined route geometries)
Electricity demand, peak loads and consumption patterns	• High-resolution electricity consumption data (e.g. 15-minute intervals) • Load duration curves, and seasonal and daily demand profiles • Peak frequency analysis, coincidence factors, and identification of major consumers.
Heat network design criteria and technical assumptions	• Heat carrier fluid and its relevant thermophysical parameters • Design criteria (velocity ranges, temperature limits, and simultaneity/diversity factors) • Hydraulic settings (pressure drop, pump operating) and pipe parameters
Supply and storage potential and energy source data	• Technical and spatial potential assessments of wind energy, geothermal energy, High Temperature Thermal Storage (HTO), heat pumps, Battery Energy Storage Systems (BESS), and solar energy integration. • Other local heat sources (as applicable): industrial/commercial waste heat, data centers, and wastewater heat recovery potential.
Grid infrastructure, flexibility and congestion management solutions	• Contracted transport capacity, private grid structure, congestion risks, demand-capacity gaps, electrification impacts, interaction between energy demand across buildings and organisations, and future grid expansion constraints. • Demand response options, peak shaving, load shifting, staggered operation strategies, Energy Management Systems (EMS), Group Transport Agreements, battery optimisation, flexibility services, and collective energy management approaches.

3.2. Economic & Financial Data Domains

Similar to the technical data domains, the feasibility assessment of a PED project requires economical and financial data. The data domains can be classified into five main categories: (1) Energy cost structures, (2) Investment and maintenance costs, (3) investment cycles that reveal practical deployment windows, (4) available funds that improve affordability, and (5) financing mechanisms that define how PED transformation can be delivered at scale.

Table 2: Economic and Financial Data Domains

Category	Description
Energy cost structures	• Electricity tariffs and price forecasts • Natural gas prices • Biomass or alternative fuel costs • Waste heat purchase prices • Carbon prices and emissions costs • Standing charges, demand charges, and network fees • Peak and off-peak pricing structures
Investment and maintenance costs	• Capital investment costs (split into network and building levels • Monthly/annual Maintenance costs
Investment cycles and renovation economics	• Building renovation cycles • Boiler and heating system replacement timelines • Planned refurbishment projects • Building age and condition • Energy efficiency retrofit costs • Payback periods for renovation measures • Coordination opportunities with roadworks or utility upgrades
Available funds	• Local, national, and EU funding programmes • Climate and decarbonisation grants • Urban regeneration funds • Energy efficiency subsidies • Innovation funding • Municipal investment budgets • Private sector co-investment opportunities
Financing mechanisms for PED transformation	• Public-private partnership models • Green loans and climate finance • Energy performance contracting • On-bill financing • Concession models • Energy service company models • Revolving funds • Community investment models • Blended finance structures

3.3. Social & Organisational Data Domains

For a transition project not only technical building data is relevant, but especially the social, organizational, and economic data of the involved stakeholders. The social capacity to manage the process often has a greater impact on success than the technical solution itself. Therefore, the objective of data collection should be to:

- identify conflicts and resistance at an early stage,
- design communication strategies tailored to specific target groups,
- establish appropriate participation processes,
- and realistically assess financial and organizational feasibility.

The data covers six main categories: (1) stakeholder landscape, ownership and governance structures, (2) sociodemographic data, (3) behavioural characteristics, (4) attitudes, motivations and ambitions, and (5) social networks and stakeholder interactions, and (6) communication infrastructure.

Table 3: Social & Organisational Data Domains

Category	Description
Stakeholder landscape, ownership and governance structures	• Identification of key stakeholders • Ownership structures • Roles • Responsibilities • Influence • Internal decision-making processes • Visions, strategies and transition pathways • Existing culture of participation • Existing or potential governance structures for collaboration
Sociodemographic Data	• Age • Education • Nationality • Language • Income • Financial burden • Voting behaviour • Employment status • Occupation • Household size • Digital literacy
Behavioural Characteristics	• Energy consumption profiles • Heating and cooling behaviour
Attitudes, Motivations and Ambitions	• Satisfaction with the current situation • Specific burdens or challenges (heat, cold, mold, etc.) • Knowledge of climate and energy topics • Attitudes toward climate protection • Attitudes toward renovation and other measures • Trust in property owners / property management • Interest in participation and co-creation

Social Networks and Stakeholder Interactions	• Existing stakeholder relationships and community structures • External decision-making structures and forms of collaboration and coordination • Informal key figures within the community • Existing conflicts
Communication Infrastructure	• Existing channels (email distribution lists, bulletin boards, meetings, messenger groups) • Accessibility and reachability of residents

4. Living Lab–Specific Data Situation

4.1. Vienna Living Lab

The Vienna Living Lab is an existing residential district consisting of approximately 100 townhouses and three multi-family houses. The overall objective of the living lab is to investigate how the district can be transformed into a Positive Energy District by relying, as far as possible, on renewable energy sources available on site.

The availability and quality of data in Austria depends on the geographic context and the level of detail provided by local datasets. In practice, the required information is typically obtained from a combination of official/regional data sources. The initial datasets are then subject to plausibility checks, and when necessary, engineering assumptions, derived from prior heat network planning and PED development experience, are applied. The main data sources and their constraints that were used in the Vienna living lab are detailed in this section.

4.1.1. Technical Data

A preliminary feasibility study confirmed that the groundwater potential in the area is sufficient to cover the heating demand of the entire district. Based on this finding, groundwater was selected as the main local energy source for the proposed district heating concept. As a result, the technical data collection focused specifically on the information needed to assess, design, and evaluate a groundwater-based heat network solution for the district.

The collected technical data therefore covered four of the main data categories introduced in Chapter 3. The first category was building and consumer data, the second category was spatial data and network topology, the third category was heat network design criteria and technical assumptions, and finally the fourth category was supply and storage potential and energy sources.

Since the preliminary assessment showed sufficient groundwater availability, data collection focused on the use of groundwater as the main renewable energy source. Relevant parameters included the available groundwater potential, expected temperature levels, extraction possibilities, and the role of groundwater in covering the district's heating demand.

The remaining two technical data domains introduced in Chapter 3, namely electricity demand and grid infrastructure, were not considered in detail for this specific PED development pathway. This is because the investigated concept focused primarily on the transformation of the district's heat supply through a groundwater-based local heat network.

1) Building and Consumer Data (Demand Side)

As a first step, publicly available data from the City of Vienna and the Energieatlas were retrieved and processed to establish the data foundation for the project area. These data were obtained from MA20, the Energy Planning Department of the City of Vienna. The Vienna Energieatlas is a high-resolution, GIS-based spatial planning tool used by the city administration for spatial energy planning. It maps the city's energy landscape at the individual building level and supports Vienna's transition away from fossil fuels.

The collected data sets include both single-family homes and multi-family homes in the project area. For the individual buildings, georeferenced information—in particular location coordinates, heated floor areas, heating loads, years of construction, and domestic hot water demand—was taken into account.

Constraints and Gaps:

- Incomplete attribute coverage: not all buildings contained complete or consistent entries for the required parameters (e.g., missing floor areas or heating load)
- Plausibility issues / aggregation errors: certain building types (e.g., townhouse rows) were represented as aggregated objects, which resulted in unrealistic heating demand values or incorrect building counts.
- Cooling loads not included: The data set did not include the cooling loads for buildings. This required the team to manually estimate the cooling loads using local standards. This was not a major issue for the project, as the buildings that include cooling make up less than 5% of the entire district.
- Need for manual validation: due to the above, the dataset has required manual plausibility checks (e.g., comparison of building footprints, use types, and demand ranges) and corrections were made prior to importing the data into the simulation software.

2) Spatial Data and Network Topology Inputs

Additional information on existing utility lines and possible route options was requested from the City of Vienna's Central Utility Line Registry (MA28). While this data is not publicly available, it can be used as a supplementary information source during the project. The utility cadaster contains information on existing underground utility infrastructure and thus enables an initial assessment of potential route alignments. Based on this information, possible utility routes can be derived and taken into account in the subsequent planning and simulation process.

Constraints and Gaps

- Geometry consistency: building footprints and identifiers did not always match one-to-one across datasets (e.g., multiple units represented as one polygon, and a few new building additions were not included). With the help of Google Maps the geometry inconsistencies were amended manually in QGIS.
- Routing relevance: potential pipe corridors require interpretation (e.g., selecting feasible routes along public right-of-way) and cannot always be derived directly from source data. Previous understanding of the district (right-of-way and their ownership) is required, in addition to the GIS dataset, to better route the network.

- Accuracy validation requirement: spatial plausibility checks in QGIS are generally required before network routing and pipe sizing are performed in the simulation model. After the GIS data was imported into the simulation software, another manual check was performed to confirm accuracy.

3) Network Design Criteria and Technical Assumptions

Hydraulic, thermal, and pipe parameter settings were defined based on engineering standards and internal planning experience from comparable heat network projects. Since the study was conducted in an early design stage, some project-specific constraints were not available yet, in that case the simulation setup relied on conservative, widely used design assumptions.

Typical assumptions and constraints

- Hydraulic limits: the design flow velocity in the network is typically constrained (e.g., an upper limit of approximately 2 m/s), and the permissible pressure conditions in network pipes must remain within defined thresholds (e.g., maximum allowable pressure levels as applied in project practice e.g. 150 Pa).
- Pipe system assumptions: depending on the application and temperature level, typical early-stage assumptions may include the use of plastic pipes and, where applicable, uninsulated installation types (subject to verification against heat loss requirements and local installation constraints).
- Experience-based parameters: simultaneity/diversity factors, allowable pressure drops, and pipe roughness/friction factors are commonly set using values proven in prior projects and adjusted as more project-specific information becomes available.

4) Supply Potential and Energy Source Data (Generation Side)

To assess the available groundwater potential, expected temperature levels, extraction possibilities, and the role of groundwater in covering the district's heating demand, publicly available hydrographic information was combined with targeted confirmations from the competent authorities.

Resource Screening and Feasibility

- Digitales Wasserbuch (Vienna): The Digitales Wasserbuch of the City of Vienna can be used as an initial screening tool to identify registered water rights and water uses and to support an initial assessment of local groundwater relevance for heat extraction concepts.
- Authority confirmation (MA 20): Where possible, findings are typically validated through direct coordination with the responsible municipal department (MA 20 – Energieplanung), particularly when project-specific clarifications or confirmations are required.
- eHYD (Hydrographic Data Platform): Groundwater temperature data can be derived from Austria's hydrographic data platform (eHYD) using available measurement stations and time series.

Constraints and Data Limitations

- Spatial coverage and representativeness: Measurement points (e.g., groundwater temperature stations) may not cover all project areas with sufficient density; therefore, temperature levels may need to be transferred from the nearest representative stations and complemented by conservative assumptions.
- Permitting and feasibility not captured in datasets: Public tools are generally suitable for screening and plausibility checks but do not replace project-specific feasibility assessments (e.g., hydrogeological constraints, reinjection feasibility, or permitting requirements), which typically require authority input and/or specialist studies.

4.1.2. Economic & Financial Data

For the economic and financial assessment of a heat network, the required price and cost assumptions were derived from a combination of official price comparison tools, supplier quotations from comparable projects, and internal economic methodologies.

- **Energy prices (electricity, gas and other reference tariffs)**

  Up-to-date energy tariffs were obtained from the E-Control tariff calculator, which provides a structured comparison of available electricity and gas offers based on consumption and location inputs (e.g., postcode)

- **Investment costs**

  Investment costs per equipment item (e.g., water wells, pumps, substations, piping components where applicable) were taken from the most recent reference projects. In practice, these values were based on supplier quotations that were requested and documented within prior e7 projects, and were then transferred to the project context with appropriate adjustments (e.g., scale effects and project-specific boundary conditions)

- **Maintenance costs**

  Maintenance costs were defined as a percentage of the respective investment cost. The applied percentages are determined based on established engineering practice and experience from comparable heat network projects.

- **Macroeconomic parameters (inflation and interest rates / discounting)**

  Inflation and interest rate assumptions were derived from internal economic studies that e7 performs on a regular basis using dedicated economic analysis tools. These parameters were applied consistently across project evaluations to ensure methodological alignment and comparability of results

- **Available funds and financial mechanisms**

  The information on available funds was collected through desk research on funding opportunities at different governance levels, with a particular focus on regional funding programs in Vienna and national funding schemes in Austria. This included funding sources related to decarbonization, energy efficiency and housing renovation.

As the scope, eligibility criteria, and funding rates of several programs have changed repeatedly over the past three years, the information had to be reviewed and updated regularly throughout the project.

The sources used to identify and assess financial mechanisms included direct exchanges and interviews with the housing cooperative of the district. These discussions provided insights into existing financing practices, internal decision-making processes, and potential financial models applicable to the case study.

In addition, relevant legal and regulatory information was considered, particularly provisions related to the Austrian Limited-Profit Housing Act (Wohnungsgemeinnützigkeitsgesetz, WGG). This was used to better understand the financial framework within which limited-profit housing associations operate in Austria.

Constraints and Data Limitations

- Dynamic energy prices: Energy prices change over time and are strongly influenced by market developments, political decisions, taxation, subsidies, and regulatory frameworks.
- Preliminary investment cost estimates: Investment costs are a key decision-making factor, but they can only be estimated roughly during the feasibility study stage.
- Uncertainty around inflation: Inflation can significantly influence construction costs, equipment prices, operation costs, and overall project economics, but it can only be projected at this early stage.
- Uncertainty around interest rates: Interest rates affect financing costs and long-term affordability, but future financing conditions are difficult to predict.
- High financial risk factor: Since energy prices, inflation, interest rates, and investment costs may change, the economic dataset includes a high level of uncertainty and should be tested through scenarios or sensitivity analyses.

4.1.3. Social & Organizational Data

For the social and organizational data we used a combination of sources and methods with both qualitative and quantitative data.

Main data sources used:

- Quantitative data from the register-based census: The research team relied on existing quantitative sociodemographic data from Statistics Austria's register-based census. The data, aggregated at census district level ("Zählsprengel"), are representative because one district largely overlaps with the living lab area. Using the most recent available data (2022), the team gained insights into the sociodemographic characteristics and motivations of the residents.
- Electoral data: To complement the sociodemographic analysis, we also used electoral data from the most recent elections. The corresponding electoral district ("Wahlsprengel") largely overlaps with the living lab area, making the data suitable for approximating local

political orientations and broader societal attitudes. These data helped contextualize potential resident perspectives on topics such as climate policy

- Survey: An anonymous resident survey was conducted to better understand the current living conditions, needs, concerns, and expectations related to the planned refurbishment and heat transition measures within the settlement. The survey collected information on housing comfort, indoor climate, technical building conditions, heating and hot water systems, energy costs, renovation preferences, mobility and accessibility needs, and attitudes towards renewable heating and cooling solutions. Socio-demographic information was also gathered in anonymised form.
- Informal discussions and meetings: Numerous informal meetings, workshops, and discussions were conducted with key stakeholders, including representatives of the housing cooperative Kriegerheimstätten and residents. These exchanges supported the collection of qualitative data on stakeholder structures, governance and decision-making processes, socio-demographic characteristics, energy-related behaviour, attitudes towards climate protection and renovation, participation culture, existing social networks and conflicts, as well as communication channels and the accessibility of residents for future co-creation processes.
- Analysis of documents: Relevant documents, including housing cooperative statutes and protocols, were analysed to better understand governance structures and decision-making procedures, stakeholder responsibilities, participation mechanisms, and long-term development strategies.

Constraints and data limitations:

- Spatial resolution of census data: The spatial resolution of available census data represents a major limitation. In this Living Lab, the statistical census district largely overlaps with the project area, but not entirely. In many other case study areas however, these boundaries differ significantly, making census data unsuitable or misleading for detailed local analyses and limiting the comparability and transferability of results.
- Informality: Informal decision-making structures play a central role within the Living Lab but are difficult to systematically assess. Informal meetings and conversations provided valuable insights into relationships, influence, and negotiation processes, yet many dynamics remained opaque. As these exchanges were not representative, the collected information may contain biases and unexpected developments or conflicts can still emerge during the project process.
- Accessibility: Access to residents was initially restricted, as direct contact was not permitted by the cooperative board for an extended period. This considerably limited the available knowledge about residents' needs, attitudes, and living conditions. While census data served as an initial substitute, the later implementation of resident surveys enabled the collection of much more detailed and context-specific information. Even after access to residents improved, certain sensitive topics could not be addressed in the survey process. Questions regarding household income, detailed financial circumstances, or current heating systems were considered too sensitive by stakeholders and were therefore excluded. Limited accessibility remains a key challenge in many Living Labs.

4.2. Malmö Living Lab

The Stadium Area in Malmö is being developed as a complex and cross-departmental urban development project, with the ambition of integrating functions for sports, education, housing, and services within a mixed-use and vibrant urban environment. The area accommodates a wide range of stakeholders, including arenas, educational facilities, multi-family housing, retail, and an ice rink. It is characterized by high levels of use with varied patterns of activity.

The Stadium Area has served as the Swedish Living Lab within the PED Stepwise research project. The Living Lab has provided a real-world context for analyzing PED opportunities, facilitating stakeholder dialogue, and assessing how district-level energy solutions could support the ongoing development of the area. The area comprises a total of 15 buildings, both existing and planned, along with associated sports facilities. Most of the land is owned by the City of Malmö.

The development is characterized by a gradual transformation in which existing buildings are complemented by new planned developments, such as a multi-sport facility and a new athletics and football stadium. A more detailed description of the area's properties, including aspects such as heating systems and gross floor area (GFA), can be found in D4.2/D4.3 – *Application of a step-by-step PED implementation plan in Living Labs with stakeholders*.

Within PED Stepwise, the conditions for developing a Positive Energy District (PED) have been studied, with particular focus on the local context. This includes examining how local energy solutions could be integrated with existing, overarching energy systems, as well as how the potential for local energy generation—primarily through solar photovoltaics—could contribute effectively to the area's overall energy balance.

Both existing and planned energy system solutions may involve bidirectional energy flows, for both heat and electricity, across the geographical system boundary of the area.

The following section describes the conditions for developing a Positive Energy District (PED) in the Malmö Stadium area. In this report, the urban development project means the planned new buildings. The PED project includes the whole defined area, with both new and existing buildings. The assessment covers technical, economic, social, and organizational aspects.

4.2.1. Technical data

For the analysis of technical PED conditions in the Stadium Area, input data is structured according to the *Technical Data Domains table* described in the methodology chapter, adapted to the Swedish energy system and available data sources.

The analysis is conducted at the district level and includes local electricity generation, mainly solar power, together with existing energy infrastructure such as district heating. As the urban development project progresses, more detailed energy calculations can be carried out for each new building. This provides more specific energy data and allows the assumptions to be gradually refined as more information about the planned buildings and activities becomes available. The process should therefore be iterative and continuous, with the implementation of the Positive Energy District (PED) developing in parallel with the development of the area. In

addition to the methods and data sources described below, project-specific analyses are carried out within the PED StepWise project, as described in *D4.2/D4.3*.

1) Building consumer data

Existing buildings

The analysis for the existing buildings within the area is based on a mapping of the building stock and of the use of energy in the buildings. Data regarding use of heat and electricity in existing buildings and therefore also demand profiles were primarily obtained through measured and operational data from the properties, such as data from sub-meters in different technical systems, and/or energy data from grid owners or energy company. In the Stadion area in Malmö, E.ON is grid owner both when it comes to heat and electricity. Data regarding heat has been delivered by E.ON Energy Infrastructure that is both grid owner and energy retailer regarding district heating and by E.ON Energy distribution that is the grid owner for the electrical grid when it comes to electricity data. In addition, energy performance certificates (EPC) prepared according to national standards were used to determine the energy use of existing buildings.

Energy audits used in the Stadium Area were provided by RISE and EON:

- RISE 230313
- Mapping, E.ON 241104
- Mapping, E.ON 250307

To perform these energy mappings, data was extracted from EON Navigator, a tool for energy monitoring. Data from Navigator can be shown in various time series and for different time frames. The data was collected via separate customer accounts for those customers who own properties in the Stadium Area.

Data from years 2021-2023 were collected in different time series. Monthly values within this time frame were collected for all existing buildings in the area. Comparisons of electricity consumption profiles were made between the different years to identify trends and determine a representative year. 2023 was chosen as the representative year.

All energy consumption data in Navigator is connected to the customer's debiting meter measuring the property's electricity. Therefore, the data represents what occurs in front of the meter, meaning it reflects the amount of electricity purchased from the grid.

If a property has on-site solar PV production, this generation is already accounted for before the meter reading. As a result, the reported energy use reflects the net electricity demand (i.e., purchased electricity after on-site production has been utilized). Consequently, the actual electricity demand of the building would have been higher without the contribution from the solar PV system.

The results from EON's energy mapping of existing properties show that five stakeholders account for the largest share of the area's total energy demand; see more under the section *Electricity demand, peak loads and consumption patterns.*

Planned development

A challenge regarding user data for the planned buildings is that the area accommodates several specialized activities for which relevant standard assumptions are lacking or inadequate. Since, for obvious reasons, there is no measured data regarding the energy demand of the planned buildings, it is significantly more complex to estimate demand profiles for these buildings. For certain types of facilities, such as arenas, energy use is highly dependent on the extent of the operations, where the number, size, and frequency of events have a decisive impact on both energy demand and peak load. Energy data for planned new construction is a source of uncertainty, as urban planning is ongoing and the area is in an early stage of development, meaning that conditions may change.

A challenge concerning user data applies specifically to the planned buildings within the urban development project, rather than to the Stadium Area as a whole. The area includes properties at different stages of planning and development. For the planned buildings, there are no measured energy data, making it more difficult to estimate their energy demand and demand profiles. This is particularly relevant for specialized activities for which standard assumptions may be lacking or unsuitable.

For some facilities, such as arenas, energy use depends greatly on how the facilities are operated. The number, size, and frequency of events can significantly affect both total energy demand and peak loads. Energy data for the planned buildings therefore remains uncertain, as the urban development project is still under development and the plans and conditions may change over time.

No detailed building-level energy calculations have been carried out at this point; instead, energy demand has been estimated based on standard assumptions and experience-based values, considering the type of activity, form factor, and gross floor area (GFA) for each building.

As many new buildings are to be constructed in the Stadium Area in the coming years, projections of future electricity demand need to be developed for these buildings. The method involves collecting data from buildings in Malmö with similar building use and building envelope, based on their energy use, estimating the energy demand of the new buildings.

The calculation method consists of dividing the hourly electricity consumption for one year by the building's floor area, resulting in a value in kWh/m². This value is then multiplied by the estimated floor area of the new building to obtain its projected energy use.

In some cases, the floor area of the reference building is not available in Navigator and has therefore been obtained from energy performance certificates provided by Boverket (the Swedish National Board of Housing, Building and Planning). All projections for future buildings are based on hourly data from similar buildings for the year 2023, which were then aggregated into monthly values.

EON subsequently estimated the energy demand based on references from other similar buildings in terms of function, building form, and building envelope. Both local examples from Malmö and national examples with similar functions (e.g. for the arena) were used. The following are examples of factors that influence the energy demand of buildings and the energy use of the planned buildings.

- Building types and activities, including operating hours (residential, sports, education, retail, etc.)
- Building area – Gross Floor Area (GFA) and heated floor area (Atemp)
- Annual energy use (electricity and heating) per building
- Energy carriers (electricity, district heating)
- Energy use patterns based on national standard assumptions from Boverket's regulations and guidelines for assessing building energy performance under normal use and standard-year conditions, by activity type. For example, well-established standardized values exist for domestic hot water use in offices, residential buildings, and schools.

Thus, even though the energy demand of the planned development naturally involves a degree of uncertainty, this is not unique to the project in question; on the contrary, it is the norm for urban development projects.

Since area-wide energy strategy initiatives must be discussed early in an area's development to be realistically achievable, ways to manage this uncertainty must be found. This is usually not a problem, as energy system solutions usually can accommodate a margin of error regarding the energy demand in planned buildings. However, as planned buildings and the energy solutions themselves become more complex, this can present a challenge and, maybe above all, an economic risk. In the Stadium area, the primary planning-related challenge has been that certain strategic buildings with unique demand profiles was removed from the plans for the area quite late in the development process.

2) Electricity demand, peak loads and consumption patterns

Building usage patterns were used to describe variations over the day and across the year. In the absence of detailed data at early stages, typical load profiles and assumptions were used and iteratively refined. The focus has been on identifying the area's load profile and peak demand. In a PED with the possibility to export electricity, temporal matching is less critical for the overall energy balance, but it is central for analyzing and minimizing peak loads within the area.

Current grid regulations in Sweden mean that locally produced electricity can primarily only be utilized within the same connection point, which limits the ability to balance electricity demand and peak loads between properties. This contributes to higher simultaneous peak loads and less efficient use of local generation, such as solar power. However, a regulatory change will come into effect on January 1, 2027, introducing new legislation that enables so-called energy sharing between properties via the public electricity grid. This means that produced electricity can be credited at another location within the same electricity price area, which over time may help balance loads across time and space and reduce the need for installed peak capacity, although grid tariffs and taxes will continue to be based on physical transmission and thus remain governing factors.

Energy storage or redistribution of energy could be beneficial to reduce peak loads and balance the PED area in terms of energy use. Certain forms of energy storage were studied within the project; see further in D4.2/4.3.

To better understand the opportunities and challenges associated with implementing a Positive Energy District (PED) concept in the area, it is necessary to map the energy loads and technical systems within the Stadium Area in Malmö. Currently, there are fifteen energy consumers (buildings) in the area, while the development plans indicate the addition of thirteen new buildings.

At present, four buildings are equipped with rooftop photovoltaic (PV) systems. Energy mapping also includes an assessment of the potential electricity production capacity if PV systems were installed on all planned buildings.

Electricity consumption data from existing buildings presented here are based on measurements from 2023. The aggregated data shown in Figure 1 represents electricity purchased from the grid (so-called "in front of the meter"), meaning that self-consumed electricity from on-site PV systems is not included. This dataset is used to identify the primary energy consumers within the area.

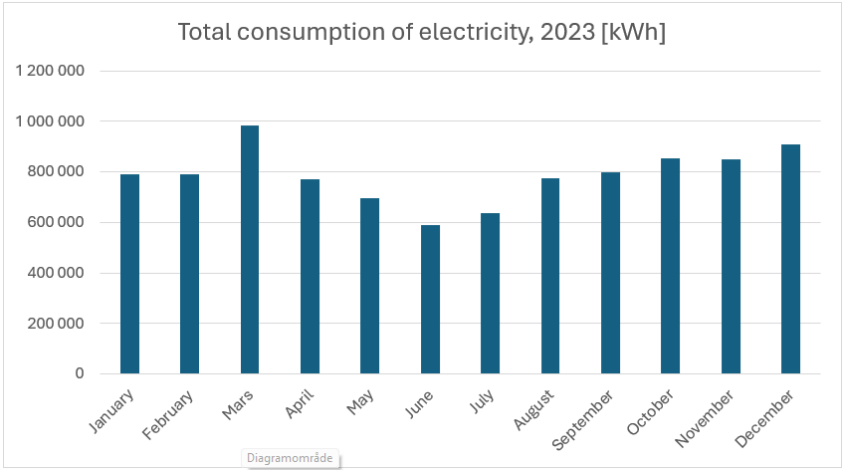


Figure 1: Total monthly electricity consumption (kWh) for existing buildings in 2023, in front of the meter.

As previously noted, the development plans include thirteen new buildings and the demolition of three existing ones. To further analyze future electricity demand, the project also assessed the projected consumption of the planned buildings, as illustrated in Figure 2.

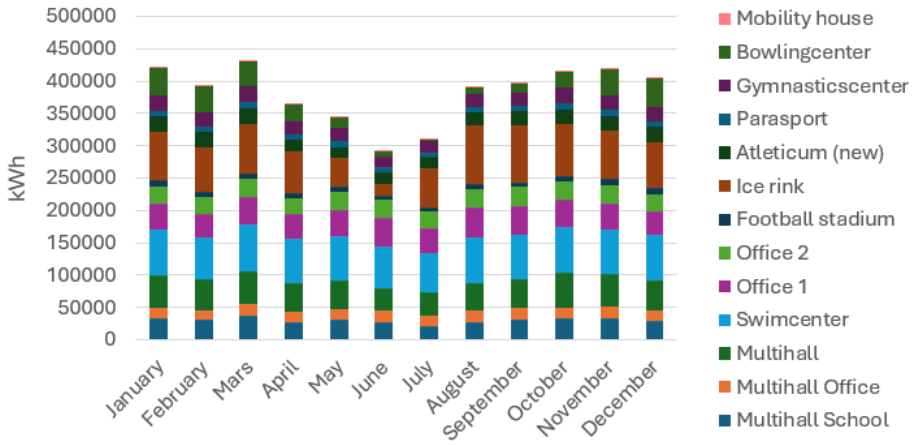


Figure 2: Total projected electricity consumption (kWh) for planned buildings, based on reference data from buildings with similar functions in Malmö and elsewhere in Sweden.

A comparative approach was applied to evaluate future electricity demand by analyzing current consumption patterns alongside a projected scenario that incorporates both planned developments and the removal of existing buildings. This method enables the identification of how new energy users may reshape the overall consumption structure in the area (see Figure 3Figure 3).

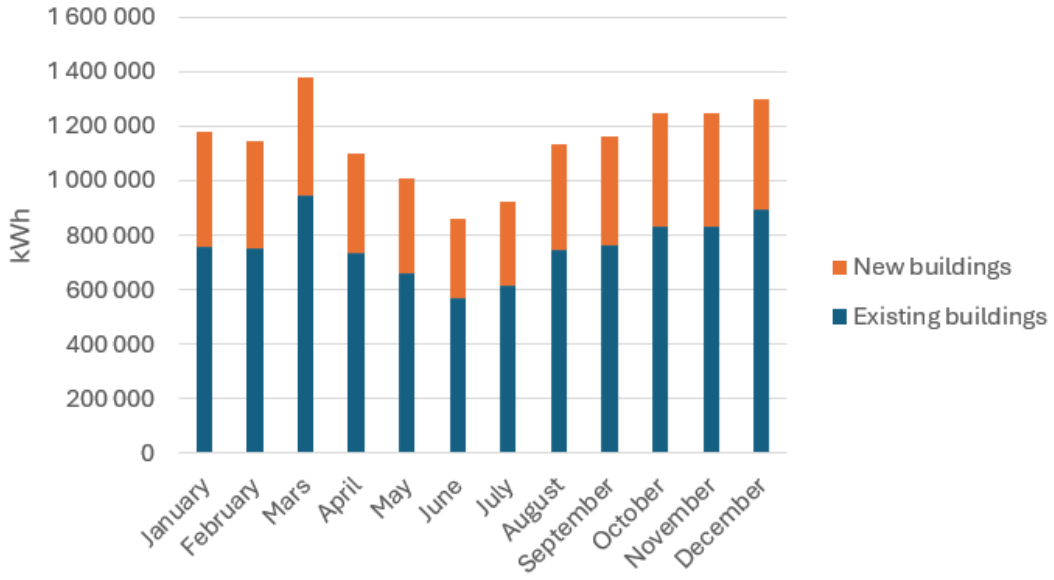


Figure 3: Total electricity consumption (kWh) from existing and planned buildings in the Stadium Area, excluding the buildings slated for demolition.

In addition, the solar energy production potential of the planned buildings was assessed. Based on the applied assumptions, the resulting production profile indicates peak generation during May, June, and July, and the lowest output during January, November, and December.

The analysis focuses on the maximal potential of rooftop photovoltaic (PV) systems. To further implement the technical solution the property managers must consider financial aspects such as the 500 kW threshold, which is relevant for taxation of self-produced electricity in Sweden. This threshold refers to the installed capacity of an electricity production facility and applies per grid connection point (i.e., per electricity meter). Facilities with an installed capacity of up to 500 kW are exempt from energy tax on electricity produced and consumed on-site, providing a significant economic advantage for smaller producers.

For installations exceeding 500 kW, the conditions change considerably. In such cases, energy tax must also be paid on self-consumed electricity, leading to increased costs and, in practice, reduced economic feasibility for larger systems.

To evaluate the potential for achieving a positive energy balance in the area, a comparative analysis was conducted between projected electricity demand and estimated local energy production. This method involves modelling both demand and on-site generation within a defined system boundary that includes both existing and planned buildings.

Local energy production was estimated based on the potential PV generation from available rooftop areas on new buildings. This production profile was then compared with projected electricity demand over time—typically on a monthly basis—to capture temporal variations and mismatches between supply and demand.

The difference between total projected consumption and local production determines the residual demand that must be met through external energy sources, such as the electricity grid (see Figure 4). This analysis provides insight into the level of self-sufficiency and the feasibility of achieving a PED target under the given assumptions.

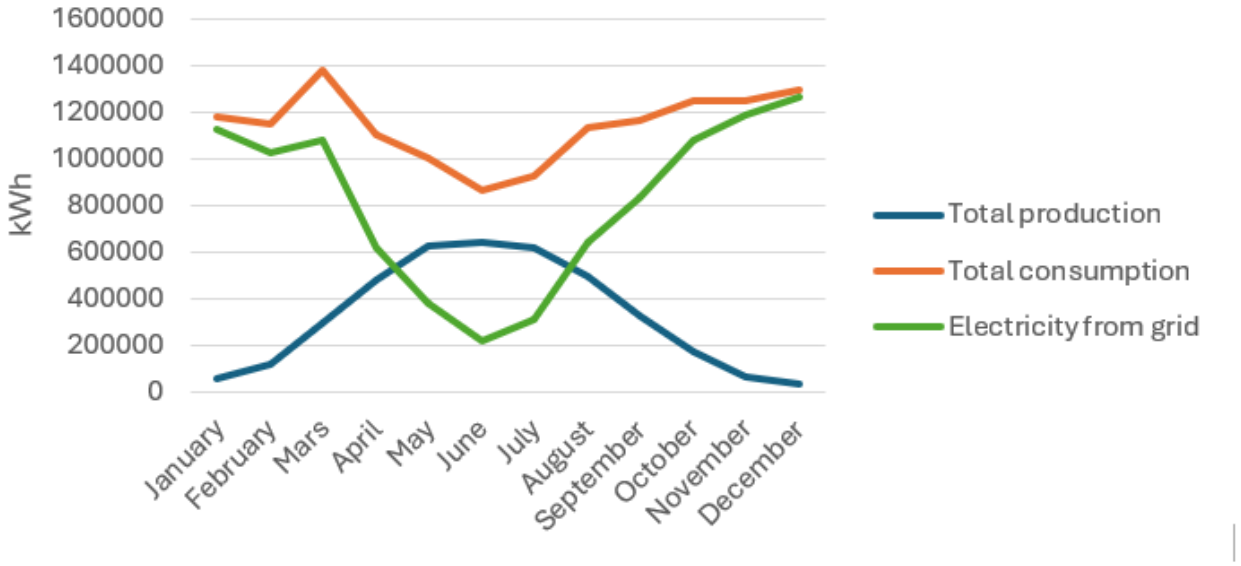


Figure 4: Total monthly electricity consumption (existing and planned buildings) compared to total projected local production. The difference represents the electricity that must be imported from the grid.

The method can further be used to explore alternative scenarios, such as increased PV capacity, additional surfaces for energy generation, energy storage solutions, or demand-side management strategies, in order to improve the local energy balance.

Further analysis is needed to assess how energy sharing could influence the area's level of self-sufficiency, as well as to evaluate the financial and regulatory implications of such arrangements. These aspects are addressed in the spin-off project "*Enabling Grid and Customer Benefits via Virtual Energy Sharing*[12]

3) Heat network design criteria and technical assumptions

Within the area, there have since long existed district heating distribution pipelines as part of Malmö's district heating network (see the general description of district heating in Sweden and Malmö in *report D4.2/4.3*). The energy sources for the distributed heat in the district heating system are as follows:

- Waste incineration (approx. 58–60%)
- Renewable/bio-based energy (approx. 20–25%)
- Recovered energy (approx. 15–20%)

[2] Information – from the funding agency – about the project Enabling Grid and Customer Benefits via Virtual Energy Sharing can be obtained from the Swedish Energy Agency project database, citing project number P2025-01323 and/or case reference number 2025-203765.

- Fossil fuels (close to 0%)

Today, all facilities in the area are connected to Malmö's district heating system, owned and operated by E.ON. The existing operations in the area use district heating both for space heating and for the production of domestic hot water. At present, district heating is also used to heat football pitches to the extent required to enable professional operation and maintenance of grass surfaces in football settings.

As is customary for district heating distribution pipelines, these are primarily installed in streets and public spaces. In practice, this means that facilities within a geographically large area such as the Stadium Area are supplied from multiple directions. The district heating supply within the area is therefore not a separate local network but part of the city's overall district heating system.

A completed pre-study of system solutions to meet the heating and cooling demands of the planned developmentin the area, performed by E.ON Energy Infrastructure, has resulted in a solution involving connection to existing district heating and reuse of waste heat from local ccoling. (see 6.3.1 in D4.2-3). This means that distribution pipelines for district heating needs to be extended to connect each facility.

The conducted feasibility study has primarily been driven by ongoing urban development projects aiming at securing the energy supply for the planned development. However, both the feasibility study and the final solution have been influenced by ambitions within PED StepWise.

The simple conclusion to be drawn from this is that projects like PED StepWise have a positive impact on driving innovation, but that their potential impact is dependent on the extent of alignment with parallel urban development processes.

As the area's development involves demolition of certain buildings (including the older stadium) and their replacement with new facilities, as well as the addition of entirely new functions—resulting in significant changes in land use—the implementation of the energy supply system within the area will also require relocation of some existing pipelines to enable connection of both existing and new buildings.

4) Supply and storage potential and energy source data

Solar PV

When analyzing local electricity generation from solar PV in Sweden, the starting point has been input data on available installation areas—primarily rooftops and potentially façades—based on GIS data or early-stage massing studies. These surfaces must be assessed in terms of tilt, orientation, shading, and technical constraints. In early phases, when detailed design is not yet available, simplified assumptions are made that a certain share of the roof area is usable for installation.

Solar PV production in Sweden is characterized by a clear seasonal variation, with very low output during the winter half of the year and a high concentration of production in summer. In Malmö, however, conditions are relatively advantageous

compared with northern Sweden, partly due to shorter periods of snow cover and higher solar irradiation, resulting in better annual output and higher utilization rates.

Assumptions regarding installed capacity and specific electricity yield are typically based on Swedish reference benchmarks, with the annual specific yield commonly assumed to fall within 900–1,000 kWh per kW_p of installed capacity under Swedish climatic conditions. These include simplified consideration of system losses such as temperature effects, conversion losses, snow coverage, and degradation over time. Since much of the development in the stadium area is still in the planning phase, the analysis relies on generalized assumptions that need to be progressively refined as the design process develops.

In the Swedish context, PV systems are often sized to maximize self-consumption, since the compensation for exported surplus electricity is usually lower than the cost of purchased electricity. Self-produced and self-consumed electricity from installations up to 500 kW is normally exempt from energy tax. If this level is exceeded, energy tax may also be levied on self-consumed electricity, which affects profitability. At the same time, tax must be paid on revenue from electricity sales regardless of system size. Overall, this creates an economic incentive both to maximize self-consumption and to remain below 500 kW of installed capacity.

From a PED (Positive Energy District) perspective, the total annual production volume becomes particularly important, since surplus electricity can be exported to the grid and contribute to the area's energy balance. At the same time, there is a trade-off between maximizing total electricity generation and optimizing economic value within an individual system, where high self-consumption is often more profitable. The conflict thus is not only about technical optimization but largely about economic incentives and system boundaries. This trade-off is further compounded by the fact that incentives for sharing or selling surplus electricity—particularly within local energy communities—remain under development in Sweden, both from a regulatory and market perspective. As a result, the conditions for capturing the value of electricity not consumed on-site are uncertain and likely to evolve over time.

At the same time, power-related issues must be considered, as high simultaneous generation can affect grid capacity and impose requirements on grid connection, subscribed capacity, and potential control or limitation of export. The grid operator's connection conditions and local grid constraints may therefore become dimensioning factors and, in some cases, limit the installed capacity or the amount of electricity that can be fed into the grid.

In practice, this means that PV systems in some cases need to be able to limit or temporarily disconnect export to the grid, for example through so-called zero-export or inverter-based power limitation, when the grid cannot accept additional electricity.

In addition to technical constraints, economic signals may apply, such as feed-in tariffs or capacity-based tariffs, where costs are influenced by how much power is fed into the grid at a given time. These models aim to reflect the load on the grid and can in practice lead to higher costs during periods of high simultaneous export, creating incentives to control production or self-consumption. Regulations, tariffs, and grid connection conditions in Sweden thus constitute important boundary conditions for the design and operation of PV systems.

Examples of key regulations and national legislation to consider when designing and installing PV systems on rooftops include the 500 kW rule described in the section Electricity Demand, Peak Loads, and Usage Patterns. This mainly concerns energy tax, but other national regulations must also be considered, such as:

- The Electrical Safety Act (2016:732)

- The Electrical Safety Ordinance
- Regulations from the Swedish Energy Markets Inspectorate
- The grid operator's technical connection requirements
- SS-EN 50549 (Connection of generating plants to the electricity grid)

In addition, regulations apply concerning rooftop PV installations with respect to structural load-bearing capacity and roof watertightness:

- The Swedish Building Regulations (BBR)
- EKS and Eurocode (structural capacity)
- AMA Hus (execution requirements for fixings and roof sealing)

For existing buildings, verification of the roof's load-bearing capacity is required, along with consideration of the roof's condition and future maintenance needs. In the stadium area, property owners have generally assessed that existing buildings currently lacking PV installations are not suitable for installation, mainly due to insufficient load-bearing capacity or other technical constraints. The PED focus is therefore on implementing PV systems on newly constructed buildings.

For existing buildings that already have PV systems installed, E.ON is conducting an analysis of the potential for self-sufficiency from solar panels in the area. Statistical data on solar production is collected from the City of Malmö (the owner of the PV systems) for Atleticum. For the same building, hourly data is retrieved from Navigator to illustrate how hourly electricity consumption relates to the hourly solar energy production from the rooftop installation.

Hourly data from 2021 to 2023 is compiled, and average values for each hour (1–24) per month are calculated using Excel. The same procedure is applied to two additional buildings, using data from the year 2023, to create a scenario for energy sharing.

To calculate production potentials from PV panels on roof tops in the area the tool/website Global Solar Atlas3 is used. Coordinates within the Stadium Area are selected, and the PV system is defined as a medium-sized commercial installation with an azimuth of 180° and a tilt of 0°. The installed capacity is set to 1 kWp to enable straightforward scaling of PV output for different system sizes in the area.

It is assumed that all new buildings will have PV panels on their rooftops. To calculate the estimated size of the PV-systems for all new buildings the following estimations and assumptions are made:

1. Estimation of roof top area in square meters.
2. 70% of the roof area will be covered by solar panels.
3. The solar panels used will have a size of two square meters.
4. The solar panels used will have an installed capacity of 0,4 kWp per PV panel.

Through these assumptions and estimations, the PV system size for respective roof could be calculated: $Pv_{size}[kWp]=(Area_{roof}*0,7)/2*0,4$

[3] https://globalsolaratlas.info/map

To assess self-sufficiency levels from PV systems, two planned buildings (new Atleticum and the Multiarena) are analysed using average hourly profiles. Hourly data for 2023 from similar reference buildings is retrieved from Navigator, and average hourly electricity use per month is calculated in Excel.

A corresponding hourly production profile is generated using Global Solar Atlas for a 1 kWp system and scaled to match the estimated PV system sizes of the analysed buildings. Self-sufficiency is calculated as the difference between hourly electricity consumption and PV production.

Based on these profiles, an energy-sharing scenario is developed for three buildings: one existing building without PV (Eleda Stadium) and two new buildings equipped with large PV systems. Surplus PV generation is compared with the energy demand of Eleda Stadium to assess the potential for energy sharing. Eleda Stadium is open to integrating PV generation within its property, provided that this is supported by a shared battery storage solution.

Surplus PV production is compared with the demand of Eleda Stadium to evaluate the potential for energy sharing. Eleda Stadium are open to integrate PV production withing their property, but that build on a shared battery storage solution.

In summary, the applied method enables an overall assessment of the potential for local solar electricity production, the degree of self-sufficiency, and opportunities for energy sharing between buildings in the area. However, for existing buildings, the feasibility of installation must first be investigated, primarily with regard to roof load-bearing capacity and technical conditions. As the urban development project becomes more defined, better decision-making data is created for well-founded choices regarding sizing and expansion. At the same time, fully utilizing the potential requires consideration of regulations, economic incentives, and grid capacity, as well as an increased level of system integration between buildings.

4.2.2. Economical data

In the process of developing the Malmö stadium area according to PED principles, questions arise early on regarding how shared energy solutions should be handled economically. When such solutions are incorporated into planning, questions simultaneously emerge about how they should be financed. This is because urban development in Sweden is typically financed through individual construction projects—such as buildings, streets, or technical infrastructure—where each sub-project is expected to be financially self-sustaining. Area-wide investments, however, often involve significant upfront costs as well as risks linked to long time horizons and uncertainties in market development.

In practice, there is a risk that the actor developing the first building must bear a disproportionately large share of the investment, even though the benefits are only realized once more properties are connected to the system. This creates an imbalance in the investment calculation and can lead to a reluctance to take on additional costs, especially when these are associated with uncertainties. Overall, this complicates the implementation of long-term efficient and resource-efficient system solutions at the district level.

The challenge is further reinforced by the long time cycles that characterize the development of the stadium area, where expansion occurs gradually and where uncertainties regarding future connections, energy demand, and energy price development affect the calculations. To address this, there is a need to develop business models at the district level, where costs, revenues, and

risks are shared among multiple actors over time. Energy communities may constitute a possible approach here, but to function in practice, technical solutions must be integrated with organizational structures and economic models. A functioning overall solution requires that no single actor has to bear the full financial risk; instead, this risk should be distributed in a transparent and long-term sustainable manner, for example through collaboration agreements or joint investment structures.

A cross-property system, such as for example a thermal storage tank, is also highly dependent on participation from larger energy users in the area—such as an arena and an ice rink—in order to achieve sufficient volume and stability in energy flows. Solutions based on local sharing and balancing of energy flows are naturally also dependent on planned buildings being constructed as intended, particularly in the case of building users with large energy demands and significant waste energy flows. These activities can contribute substantial energy streams, for example excess heat from cooling processes, which is crucial for the system to be technically robust and economically viable.

The economic analysis therefore needs to include parameters such as investment costs, operation and maintenance costs, energy price development, and payback time, but also system benefits such as flexibility and reduced peak load.

At the same time, important investigations remain regarding economics, business models, risk allocation, and technical system choices. These investigations need to be allowed as an integrated part of the urban development project in order to create sufficient decision-making support and room for action over time. This constitutes a key prerequisite for the successful realisation of the PED concept in the Malmö stadium area in a manner that is both feasible and economically sustainable.

So even though there, of course, are many aspects that affects the outcome of what solutions that are in fact realized, such as varying economic conditions among different stakeholders, energy prices, tax limits, regulatory aspects, market conditions for revenue potential, etc., it is clear that business models for investing in shared infrastructure is an area that needs to be explored further.

Regarding the stadium area, changes to strategic elements of the planned development—occurring late in the planning process—have also created uncertainty that has affected the feasibility of area-wide system solutions.

4.2.3. Social & Organizational data

To successfully implement a Positive Energy District (PED), not only technical solutions are required, but also, to a great extent, well-functioning organizational structures and social anchoring. A key success factor is the establishment of clear modes of collaboration between the relevant stakeholders, such as municipalities, property owners, energy companies, and business operators. Since a PED often relies on system solutions across property boundaries, there may be a need to define responsibilities, roles, and mandates at an early stage, particularly in cases where joint investments and operation are required.

Trust-based relationships between stakeholders are crucial, especially since investments and benefits are often realized at different times and by different parties. Transparency in decision-

making processes, cost allocation, and follow-up helps reduce uncertainties and facilitates joint decisions. In this context, organizational models such as joint company structures, collaboration agreements, or energy communities can play an important role, as they create platforms for both investment in and operation of shared infrastructure.

The social aspects also include the engagement of stakeholders such as property owners, energy companies and municipalities. To achieve an efficient energy system, behaviours and usage patterns must be considered, for example through information initiatives, incentives for flexibility, or participation in energy communities. A PED must therefore be designed with people at the center, where an understanding of local needs and drivers is integrated into the planning.

Furthermore, continuity within the organization is an important factor, particularly in urban development projects with long time horizons. Organizational changes and staff turnover can pose a significant challenge, as they risk leading to loss of knowledge, shifting priorities, and reduced progress. Knowledge transfer between project phases and between different stakeholders must therefore be ensured to maintain ambitions and goals over time. Integrating PED work as a natural part of the urban development process—rather than as a separate initiative—increases the conditions for successful implementation.

PEPP-process

The Malmö PED Stepwise-pilot has worked according to the steps in the PEPP-processen (Positive Energy Planning Process), see overview of the 7 steps in the PEPP-process in Figure 5 below. The PEPP-process was developed by White as a result of the PED-ID project and has been used in several other projects (ie municipality of Järfälla). It was decided during the application phase that the PEPP-process should be applied on the Malmö Stadion Area.

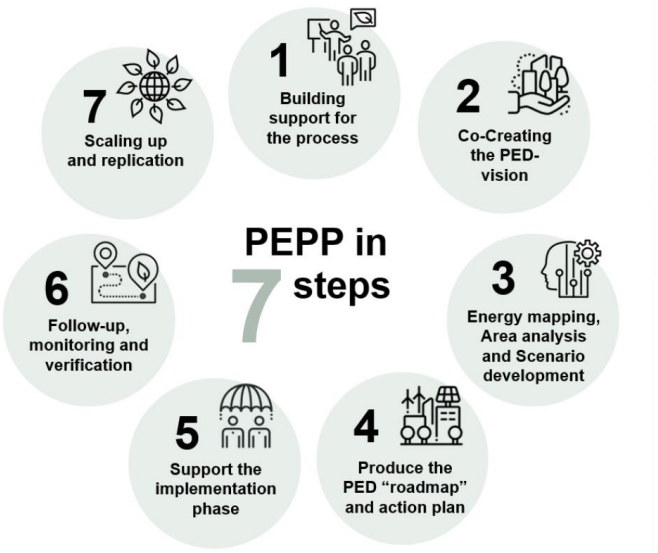


Figure 5: Overview PEPP-process in 7 steps

The PEPP model describes a structured, step-by-step process for planning and realising Positive Energy Districts. It covers the full journey from early preparation and vision development, through analysis and scenario building, to implementation, follow-up and wider replication. The model emphasises collaboration between stakeholders, a clear connection between goals and actions,

and continuous learning over time, providing a practical framework to guide complex urban energy transitions.

Activities that take place within each step of the process are presented in Figure 6 and Figure 7. These activities form a general, non-project-specific framework that can be applied to support the development of any Positive Energy District (PED).

It is important to emphasize that PEPP is not intended to be followed in a fixed sequence. Rather, it is an iterative process that can be adapted to the specific conditions and needs of different places, operations, and projects. PEPP can be understood as a flexible checklist, where the level of ambition for each step and activity is tailored to the context—such as the site, the phase of urban development, and the capacities of the stakeholders involved.

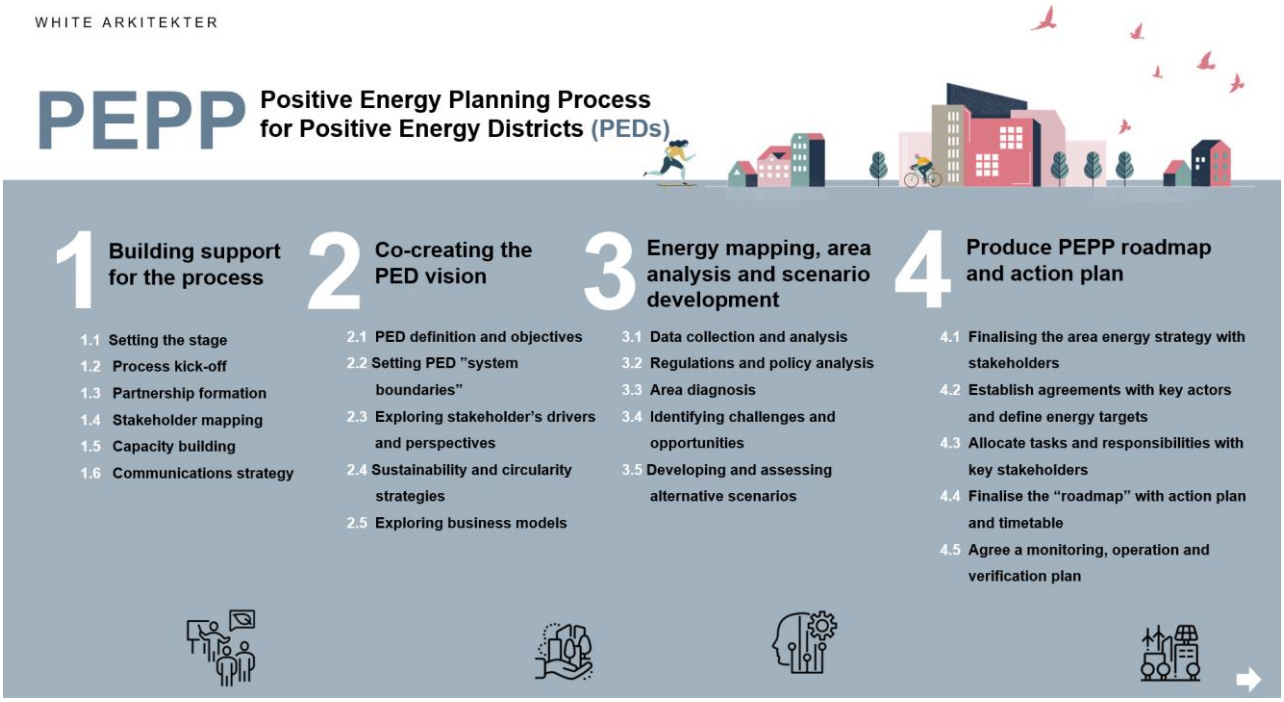


Figure 6: PEPP-process step 1-4 with corresponding activities

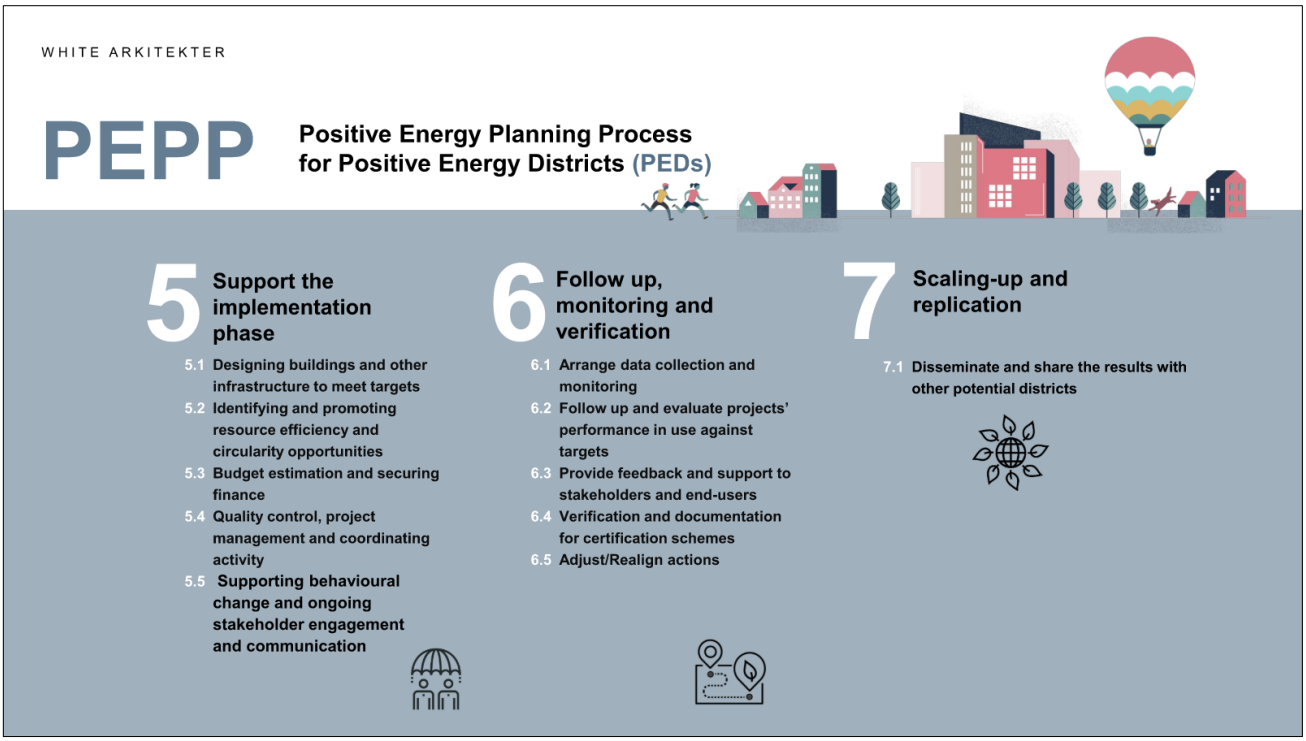


Figure 7: PEPP-process step 5-7 with corresponding activities

Stakeholder meetings and workshops are held continuously during the process

Regular meetings with relevant stakeholders enable ongoing dialogue between key actors, such as property owners, municipalities, and energy companies. These forums are essential for identifying shared goals, managing conflicting interests, and building broad support for the project.

For example, meetings can be used to gather property data, make joint decisions regarding system boundaries for the PED project, and discuss potential future energy-sharing strategies.

Workshops are used to deepen knowledge, develop ideas, and collaboratively design solutions tailored to the specific conditions of the area. They also help strengthen collaboration within the project team and foster a shared understanding of the PED concept.

Below are examples of activities within the first three steps, which provide an important foundation for step four—developing the joint roadmap:

Step 1: Building support for the process, examples of actions:

1.3: The core team is composed of the Swedish parties in the PED StepWise project and was formed during the research application phase. A "letter of intent" was signed between the actors (The City of Malmö, E.ON, KTH Royal Institute of Technology, Malmö FF consultants White Arkitekter).

1.4: Stakeholder analysis (other stakeholders are identified and categorized divided into core team, involved stakeholders and informed stakeholders)

1.5: The involved stakeholders turns out to be the other building owners in the area (P-Malmö, Europaporten, CA Fastigheter and BRF Lagmannen), so they are later in the process

invited to meetings focusing on building trust and knowledge, support for the process and informing about and making building owners of the existing interested in saving energy, cooperating on battery solutions and renewable energy etc.

Step 2: Co-creating the PED-vision, examples of actions:

2.1 The PED Stepwise Swedish core team creates a common vision and goals, to strengthen the co-operation focusing on energy in the area. The vision should be based on the areas already existing commercial and city planning vision. Den fungerar som en övergripande målbild som hjälper till att samordna aktörernas insatser, tydliggöra förväntningar och skapa långsiktig riktning i projektet.

During this phase an agreement with stakeholders on the PED definition should also be reached. The definition formulated by jpi-urbaneurope is used here (Figure 8).



Figure 8: PED Definition according to the Swedish consortia

Step 3: Energy mapping, Area analysis and Scenario development, example of activity

Non-disclosure agreements between project partners

To enable openness around sensitive information—such as financial calculations and technical data—non-disclosure agreements (NDAs) can be established. This creates a secure framework for information sharing and thereby improves the conditions for transparency and informed decision-making.

In step three, the area's current energy profile is mapped and different scenarios are evaluated. In step four, a roadmap is developed outlining how—and whether—the area can become a PED. If the area, despite energy-efficiency measures, shared energy solutions, and the addition of new renewable energy, does not achieve a net energy surplus, it would not qualify as a PED. However, it can still become an area with a strong energy focus.

In such cases, stakeholders may decide to jointly procure or develop new renewable energy, preferably in close proximity. Another option is to agree on a target for partial self-sufficiency, for example, aiming to cover 50% of the area's energy demand locally.

Step 4: Produce the PED "roadmap" and Action plan.

4.1 Finalising the area energy strategy with stakeholders.

4.2 Establish agreements with key actors and define energy targets.

4.3 Allocate tasks and responsibilities with key holders.

4.4 Finalize the "roadmap" with action plan and timetable.

4.5 Agree a monitoring, Operation and Verification plan.

The transition from planning to implementation is always challenging, as different organizations are often responsible for planning, construction, and operations. PEPP is designed to bridge this gap and ensure a smooth transition between these phases. Steps five and six therefore focus on supporting the implementation phase and ensuring that the action plan is effectively put into practice.

Step 5: Support the implementation phase.

5.1 Designing buildings and other infrastructure to meet targets.

5.2 Identifying and promoting resource efficiency and Circularity opportunities.

5.3 Budget estimation and securing finance.

5.4 Quality control, Project management and Coordinating activity.

5.5 Supporting behavioural change, and ongoing stakeholder engagement and communication.

Step 6: Follow-up monitoring and verification

6.1 Arrange data collection and monitoring.

6.2 Follow up and evaluate projects´ performance in use against targets.

6.3 Provide feedback and support to stakeholders and end-users.

6.4 Verification and documentation for certification schemes, where required.

6.5 Adjust/realign actions.

Step seven focuses on the important work of sharing successes and lessons learned, enabling other areas to benefit from the project and be inspired to collaborate in the energy transition. It also helps foster local pride and creates incentives to go further, as results are communicated

and an increasing number of stakeholders are motivated to contribute to local energy transformation.

In areas such as the Malmö Stadium district, this may also involve visitors taking inspiration from their experiences back home and sharing knowledge both privately and professionally. One example is an energy-positive hotel, which aims for its guests to leave with a deeper understanding of sustainability after their stay.

Step 7: Scaling-up and replication

7.1 Disseminate and share the results with other potential districts.

In summary, a successful PED process requires a holistic approach in which technical, economic, organizational, and social aspects work together. Clear allocation of responsibilities and shared, well-anchored expectations among stakeholders are essential to reduce risk, create incentives for collaboration, and ensure that no single actor bears sole responsibility for implementation. Without such a framework, even technically well-functioning solutions risk not being realized or reaching their full potential.

Well-functioning, joint communication is also crucial—both internally within the project team and externally. A key success factor is that the vision of a PED—or an area with a strong energy focus—is firmly anchored at the highest management level, enabling it to be communicated clearly and broadly.

4.3. Utrecht Living Lab

This section defines the information required for the assessment of energy supply, storage, renewable integration, and participatory planning at Utrecht Science Park (USP). It outlines the key data categories, sources, and methods used to support both the techno-economic analyses of decarbonization pathways, as well as the participatory activities carried out with USP stakeholders within PED-StepWise. By combining technical, spatial, organizational, and stakeholder-related information, this section provides the foundation for the analyses and collaborative processes developed to support the transition towards a more sustainable and integrated energy system at the USP.

4.3.1. Main data sources

To perform the analysis at the USP, information was collected from a combination of national datasets, institutional records, technical consultancy studies, stakeholder input, and policy and regulatory frameworks. These sources were used to support the techno-economic analyses, scenario modelling, and participatory processes related to the energy transition at the USP, as described in the previous section. The main data sources are summarised below.

National and regional datasets

Publicly available datasets were used to obtain general information regarding buildings, climate conditions, spatial characteristics, and energy use patterns, including:

- CBS (Statistics Netherlands) for demographic and energy-related statistics;
- BAG (Basisregistratie Adressen en Gebouwen) for building registry information;
- KNMI climate datasets;
- Spatial and GIS information from public databases and maps;
- Regulatory and policy documents related to energy infrastructure, environmental regulation, and spatial planning.

Institutional and stakeholder data

Core operational and infrastructural data were obtained through the main organisations and building owners located at the USP, including:

- Utrecht University
- Hogeschool Utrecht
- UMC Utrecht
- SSH
- Kadans
- Danone
- Hubrecht Institute

These organisations provided information related to:

- energy consumption,
- heating systems,
- contracted grid capacity,
- existing and planned energy infrastructure,
- sustainability ambitions and transition plans,
- operational constraints,
- and future campus developments.

Technical consultancy studies and expert analyses

Several technical and feasibility studies carried out by consultants, engineering firms, and research organisations were used as input for some of the techno-economic analyses performed. In particular, the following studies have been conducted by consultancy firms hired (most of the time) by Utrecht University:

- Aquifer Thermal Energy Storage (ATES/WKO),
- High Temperature Thermal Storage (HTO),
- Battery Energy Storage Systems (BESS),
- wind energy feasibility,
- geothermal energy,
- biodiversity impacts.

These studies provided technical parameters, scenario assumptions, financial analyses, environmental assessments, optimisation strategies, and implementation considerations.

Participatory and qualitative data sources

To support the participatory activities within PED-StepWise, qualitative and governance-related information was collected through:

- stakeholder interviews,

- mission mapping sessions,
- future-making workshops,
- collaborative discussions,
- and co-creation activities with USP stakeholders.

These activities generated insights into stakeholder roles and interests, governance structures, collaboration dynamics, organisational ambitions, barriers and enabling conditions, and opportunities for collective action and long-term cooperation.

Policy, regulatory and strategic frameworks

In addition, several policy and regulatory frameworks were used to contextualise the analyses and assess implementation feasibility, including:

- municipal, regional, and national climate policies,
- grid congestion regulations,
- UNESCO heritage frameworks,
- environmental and biodiversity regulations,
- permitting requirements,
- and institutional sustainability strategies and roadmaps.

4.3.2. Methods used per study

Different models, analytical methods, and participatory approaches were applied to process the collected information and evaluate the technical, financial, spatial, environmental, and organisational feasibility of various energy transition pathways at the USP. The selected methods varied depending on the objective of each study, ranging from techno-economic simulations and optimisation models to spatial impact assessments and participatory co-creation processes. The detailed assumptions, scenarios, and modelling results are further elaborated in *Deliverable 4.2 – Technical and Financial Report*. Below there is a summary of 8 key studies conducted at the USP that align with the activities of PED-StepWise.

1. Battery System analysis (BESS, 2025–2030)

- Method: Scenario-based load modelling and financial optimisation.
- Purpose: To determine the optimal battery size and operation strategy for peak shaving, PV integration, flexibility provision, and congestion management.
- Input: Electricity demand scenarios, contracted grid capacity (8.5 MW), solar PV generation profiles, battery characteristics, CAPEX/OPEX, electricity market prices, and flexibility assumptions.
- Output: Optimal battery capacity (MWh/MW), avoided curtailment, peak reduction potential, flexibility contribution, and financial performance indicators.

2. Collective ATES study (DWA, 2022)

- Method: Thermal energy balance and system cost modelling.
- Purpose: To evaluate the technical and economic feasibility of a collective Aquifer Thermal Energy Storage (ATES/WKO) network compared to decentralised systems.
- Input: Building-level heating and cooling demand, flow capacities, network configurations, investment costs, tariffs, and stakeholder agreements.
- Output: Total Cost of Ownership (TCO), CO_2 reduction potential, network configurations, and example tariff structures.

3. High Temperature Heat Storage (HTO, 2025)

- Method: Seasonal storage simulation and techno-economic comparison.
- Purpose: To assess the added value of High Temperature Thermal Storage (HTO) as a seasonal buffer within the future USP heat system.
- Input: Storage capacity, heat production sources, electricity price forecasts, heat demand, medium-temperature network characteristics, and CAPEX estimates.
- Output: Seasonal efficiency, storage performance, electricity cost reductions, flexibility potential, and comparative TCO analysis.

4. Geothermal energy (GOUD study, 2016)

- Method: Geological simulation and techno-economic feasibility assessment.
- Purpose: To investigate the technical and financial feasibility of deep geothermal heat production at the USP.
- Input: Geological formations, permeability, depth profiles, flow rates, seismic data, drilling assumptions, and investment costs.
- Output: Potential heat production, estimated heat prices, payback periods, and identification of technically or economically infeasible options.

5. Wind Energy and Spatial integration studies (2018–2025)

- Model: Wind yield modelling, spatial assessment, environmental impact analysis, and regulatory feasibility assessment.
- Purpose: To evaluate the technical feasibility and spatial integration of wind turbines at the USP under biodiversity, heritage, and regulatory constraints.
- Input: Wind resource data, turbine specifications, spatial layouts, biodiversity studies, UNESCO heritage assessments, noise regulations, and planning frameworks.
- Output: Estimated annual electricity production, contribution to campus demand, environmental impacts, spatial constraints, and implementation feasibility.

6. Decoupling of two UU buildings from the CHP gas plant and transition to ATES and heat pumps (sept 2025-feb 2026)

- Model: Technical energy system design study combining heat demand analysis, concept comparison, storage sizing, KPI assessment, and business case evaluation for the USP heat network transition.
- Purpose: To assess how the USP can transition from the existing high-temperature heat network to sustainable low-temperature systems using ATES, heat pumps, and thermal storage while reducing energy use and grid pressure.
- Input: Building and heat demand data, existing heat network characteristics, ATES and heat pump assumptions, climate data, technical sizing calculations, energy analyses, and financial calculations.
- Output: Comparison of alternative heat transition concepts, impacts on energy use and net congestion, technical and financial feasibility assessments, and recommendations at building, cluster, campus, and organisational level for future implementation.

7. Grid Congestion and Flexibility Analysis (ongoing study from UU students, 2026)

- Method: Peak demand analysis, coincidence analysis, linear programming optimization, and scenario modelling.

- Purpose: To analyse electricity demand patterns, peak coincidence between organisations, and the effectiveness of flexibility and congestion management strategies at campus level.
- Input: 15-minute electricity consumption data, contracted capacity, building characteristics, PV generation data, CHP/heat demand, and future campus growth scenarios.
- Output: Peak demand patterns, coincidence factors, flexibility potential, demand-capacity gaps, optimisation scenarios, and recommendations for congestion mitigation.

8. Participatory and governance-oriented methods

- Method: Stakeholder interviews, mission mapping, future-making workshops, backcasting, and co-creation sessions.
- Purpose: To understand stakeholder perspectives, governance structures, organisational barriers, collaboration opportunities, and collective transition pathways.
- Input: Stakeholder experiences, organisational ambitions, governance structures, participatory discussions, and collaborative exercises.
- Output: Stakeholder analyses, shared visions, process maps, governance recommendations, and proposed collaboration structures for campus-wide decarbonisation.

4.3.3. Typical constrains and gaps found

Several constraints and data-related gaps were identified throughout the studies and participatory activities conducted at the USP. Below, the most important constraints and gaps are briefly described.

Fragmented data landscape and institutional dependencies: Energy and infrastructure data (and results of all the various studies conducted in the past) are distributed across different building owners, but there is not yet a unified dataset at the USP. As a result, analyses require the integration of information originating from multiple actors, systems, and formats.

Critical data, such as building energy data, data on the technical installations, contracted grid capacities, and operational constraints, are largely owned and managed by individual organisations. This creates strong dependencies on stakeholder willingness and time to share information and has limited access to these datasets.

Use of external studies instead of raw data: Several analyses relied on feasibility studies, consultancy reports, and previously developed models prepared by external parties. In many cases, only processed results, or scenario outputs were available, while the underlying raw data, assumptions, and modelling structures remained partially inaccessible. This reduced transparency and limited the ability to fully compare, validate, or integrate datasets across our studies.

Heterogeneous of data formats, scales and resolutions across organisations

Some of the collected datasets differed significantly in temporal resolution (e.g., yearly data versus 15-minute interval data), spatial scale (building, cluster, or campus level), modelling assumptions, and reporting formats. This complicated the integration of datasets when conducting USP-wide analyses.

Organizational and governance-related constraints

Our participatory activities revealed several organisational and governance-related barriers affecting collaboration and implementation. These included differing institutional priorities,

fragmented decision-making structures, limited internal capacity, unclear ownership of collective infrastructure, and the absence of formalized campus-wide governance arrangements for energy coordination. We noticed that understanding how decision-making processes function internally within each organization proved challenging, particularly when we, as researchers, are not always directly involved in those processes. Decision-making pathways, approval procedures, budget responsibilities, and strategic priorities are often embedded within complex internal organizational structures that are not always transparent to other actors, within an organization and across organizations.

5.Cross-Living-Lab Synthesis

Across the Living Labs, data availability and data quality strongly influenced the PED development process. Although each city context is different, several common data gaps can be identified.

A common challenge across the Living Labs was the fragmentation of data sources. Relevant data was often distributed across different organisations, departments, external consultants, public authorities, and local stakeholders. This made it difficult to obtain a complete and consistent overview of the district. In all living labs, the PED process therefore depended not only on the existence of data, but also on access rights, institutional cooperation, and the ability to combine datasets produced for different purposes.

Another recurring limitation was the inconsistency of data formats, scales, and resolutions. In Vienna, the GIS dataset was incomplete or inconsistent with the current state of the buildings. Some townhouses were aggregated into one object, while heating and cooling loads were missing for others. In Utrecht, data was available from different organisations, but often in heterogeneous formats and at different spatial or temporal resolutions. In Malmö, in some cases, the floor area of the reference building was not available in Navigator and has therefore been obtained from energy performance certificates provided by Boverket (the Swedish National Board of Housing, Building and Planning).

A further common gap relates to the use of indirect or secondary data. In Utrecht, several analyses relied on existing feasibility studies, consultancy reports, and previously developed models rather than raw datasets. Similarly, in Vienna, missing or incomplete datasets required assumptions and interpretation, for example where GIS information did not fully reflect the current building situation.

The Living Labs also faced economic uncertainty. Dynamic energy prices, inflation, and interest rates created uncertainty for the economic assessment. These factors are not stable data points, but external conditions that may change significantly over time.

Malmö in specific had an additional economic uncertainty that arises from the way the stadium area is developed, where expansion occurs gradually. There is a risk that the actor developing the first building must bear a disproportionately large share of the investment, even though the benefits are only realized once more properties are connected to the system

In addition to technical and economic limitations, the Living Labs revealed important social, organisational, and governance-related data gaps. In Vienna, access to residents was initially restricted because direct contact was not permitted by the cooperative board for an extended period. This limited the collection of social data and delayed direct engagement with residents. Furthermore, informal decision-making structures played an important role in the Living Lab but were difficult to systematically assess. In Utrecht, participatory activities also revealed organisational and governance-related barriers affecting collaboration and implementation.

At the same time, each Living Lab was shaped by distinctive city-level constraints. In Vienna, the key constraints were closely linked to the existing residential structure, and the cooperative governance context. Data limitations were particularly visible in the GIS dataset, the mismatch

between available spatial data and the actual building situation, and the limited coverage of groundwater measuring points across the entire project area. These constraints affected the precision of technical modelling and required careful interpretation of local energy source potential.

In Utrecht, the main constraints were more strongly connected to the institutional and organisational data landscape. The data environment was fragmented, with relevant information held by different organisations and often shaped by institutional dependencies. The reliance on external studies and models also meant that the Living Lab had to work with processed information rather than fully transparent raw data. In addition, differences in data formats, scales, and resolutions across organisations created barriers to integration and comparison.

In Malmö, estimating future energy demand presents a key challenge due to the lack of measured data for planned buildings and the absence of suitable standard assumptions for specialised facilities. Energy use, particularly in buildings such as arenas, is highly dependent on operational factors, including the number and frequency of events. As the area is still under development, evolving planning conditions add further uncertainty to future demand profiles and peak load estimations.

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7.PED Stepwise Consortium

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DUT Driving Urban Transitions