ANNEX 83

EBC
Energy in Building and Communities Programme

International Energy Agency

Deliverable 4 - Demo Cases on Positive Energy Districts and Related Technologies

Positive Energy Districts (Annex 83)

Energy in Buildings and Communities Technology Collaboration Programme

June 2026

Technology Collaboration Programme
by iea

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)
The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.
At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of 'low tech', robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
– the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
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Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Resilient Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings
Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems
Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings
Annex 89: Ways to Implement Net-zero Whole Life Carbon Buildings
Annex 90: Low Carbon, High Comfort Integrated Lighting (EBC Annex 90 / SHC Task 70)
Annex 91: Open BIM for Energy Efficient Buildings
Annex 92: Smart Materials for Energy-Efficient Heating, Cooling and IAQ Control in Residential Buildings
Annex 93: Energy Resilience of the Buildings in Remote Cold Regions
Annex 94: Validation and Verification of In-situ Building Energy Performance Measurement Techniques
Annex 95: Human-centric Building Design and Operation for a Changing Climate
Annex 96: Grid Integrated Control of Buildings
Annex 97: Sustainable Cooling in Cities
Annex 98: Flexibilization and Optimization of Heat Pump Systems in Existing Buildings through Secondary-Side Digitalization
Annex 99: Air Cleaning for Sustainable and Resilient Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Summary

Database

The database for PEDs is a joint effort of IEA EBC Annex 83, COST Action 'PED-EU-NET', and JPI Urban Europe to provide a wealth of information about new and refurbished urban environments aiming to produce more energy than they consume. This paper reports the realisation of the PED-Database framework and its online implementation in the form of a web interoperable platform, which has been designed in a modular way, allowing the division of the general survey into smaller and independent sections that facilitate data entry and subsequent processing. The internal peer-review process for the data entry through the editors assures that the data in the database is sourced from reliable and verified information, ensuring its accuracy and reliability.
The development process moves through a database development life cycle (DDLC) starting with the scoping phase of establishing requirements expressed as a statement of requirements with the aim to create a framework for data collection from demo cases. Finally, a testing phase has been initiated and these are the main conclusions extracted from this first analysis:

- There is no one-fits-all solution for PED implementation. Overall PED framework definitions require further detailing in the local context. The PED Database provides an overview of not only different implementation strategies, but also existing different conceptualisations and approaches for the PED concept.
- Thanks to contributions, all inputs are collected in the Database, the users of the platform can visualise and compare different scenarios of PEDs by customising their selection. Before exporting, it can be displayed in the user-friendly frontend of the PED-EU NET Database that covers each KPI resulting from the gathered information by DB editors. Then, the selected comparison can be saved as an output file and successively can be exported as a .csv format file. In this way, users of the tool can select and work on the information that best meets their expectations, goals, and then build their own further storytelling.

Guidelines

PEDs are a crucial concept in the transition towards sustainable urban energy systems, representing a shift from individual building-centric approaches to a district-scale perspective for integrated, efficient, and sustainable urban development. Identified as a strategic priority by the European Commission (EC), the PED concept has evolved from Net Zero Energy Districts (NZEDs) and Positive Energy Blocks (PEBs), emphasising the systemic integration of renewable energy, smart grids, and energy sharing at the urban level. The EC actively supports PED development through funding pilot projects under Horizon 2020.

Various definitions of PEDs exist across organisations and initiatives, though a single universally accepted definition remains elusive, posing challenges for project comparison due to varying baseline assumptions. Key definitions highlight aspects such as achieving net-zero energy imports and CO_2 emissions annually with a local renewable energy surplus, being energy-efficient and flexible urban areas with net-zero greenhouse gas emissions and a renewable energy surplus integrating energy, mobility, and ICT, actively regulating energy exchanges to maintain a positive annual energy balance by maximising renewable production and efficiency, comprising multiple buildings actively managing energy usage for an annual positive balance within the city's energy system, and maintaining net-zero energy imports and CO_2 emissions while working towards a renewable energy surplus, integrated with regional energy systems and active energy flow management.

Despite differing definitions, **common principles underpin the PED concept**: **energy efficiency and flexibility** of interconnected buildings and urban areas to optimise energy use; the active management of an **annual surplus of locally or regionally produced renewable energy** with net-zero GHG emissions; the **integrated nature of urban systems**, including buildings, mobility, energy, and ICT; prioritising **social, economic, and environmental sustainability** with secure energy supply and inclusivity; **integration within urban and regional energy networks** supplied by renewables; and often incorporating **net-zero direct carbon emissions**.
Key topics covered in the document include:

1. **Definitions and Frameworks**: PEDs are defined within the context of sustainable urban energy transitions, emphasising their role in achieving net zero energy imports and CO_2 emissions. Frameworks for holistic energy planning and the systemic integration of renewable energy, smart grids, and energy-sharing mechanisms are discussed.
2. **Energy Balance Methodologies**: Various calculation methods and tools are provided to assess energy production, demand, and balance at the district level. These include dynamic modelling approaches, GIS-based tools, and standardised frameworks like ISO 52000-1.
3. **Technological Solutions**: The document explores energy efficiency technologies, renewable energy production systems, energy flexibility tools, and the integration of ICT solutions, e-mobility, and smart infrastructure. Emphasis is placed on optimised integrated designs and advanced energy systems.
4. **Monitoring and Evaluation**: A systematic approach to monitoring, assessment, certification, and evaluation is outlined, including the use of Key Performance Indicators (KPIs). The importance of data collection, visualisation, and governance frameworks is emphasised.
5. **Social Aspects**: The transformation to PEDs requires stakeholder engagement and inclusive planning. Strategies like urban living labs, co-creation platforms, and justice assessments ensure citizen participation and equitable energy access.
6. **Financial and Business Models**: Financing strategies for PEDs include public-private partnerships, risk mitigation measures and regulatory support. The document highlights innovative funding mechanisms and streamlined regulatory frameworks to overcome financial barriers.
7. **Urban Planning and Integration**: PEDs must be embedded into urban master plans for effective spatial integration. Land use evaluations, regulatory alignment and synergy between energy and urban planning are essential for successful implementation.
8. **Governance and Legal Aspects**: Collaborative governance models, policy frameworks, and systems thinking approaches are critical for overcoming institutional silos and regulatory barriers. Multi-stakeholder coordination and quadruple helix models are recommended to align PEDs with broader urban strategies.
9. **Implementation Processes**: Structured methodologies like the **Smart City Guidance Package (SCGP)** and **PED-LAB** model are proposed, focusing on adaptive, step-by-step approaches for PED deployment. Feedback loops and stakeholder-driven processes ensure continuous improvement.
10. **Alignment with Urban Sustainability Initiatives**: PEDs are positioned as integral elements of climate-neutral and smart cities, aligning with initiatives like the European Climate Neutral Cities programme, Nearly Zero-Energy Buildings (NZEBs), Nature-Based Solutions (NBS), New European Bauhaus (NEB) and others. Their contribution to achieving EU climate goals is highlighted.

Dissemination

The dissemination activities encompassed all Annex 83 working meetings, summer schools organised by Annex 83, events and conferences in which Annex 83 participated or co-organised, as well as all related publications between 2021 and 2025. In addition, the dissemination includes the impact achieved through social media channels and websites in both English and German.

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Abbreviations

ABBREVIATION / TERM	DESCRIPTION
BAU	Business as usual
BEE	Building Environmental Efficiency
DDLC	Database Development Life Cycle
DGNB	German Sustainable Building Council
DQA	Data Quality Assessment
DSO	Distribution System Operator
EPB	Energy Performance of Buildings
EPBD	Energy Performance of Buildings Directive
EU	European Union
IEA	International Energy Agency
ICT	Information and Communications Technology
IoT	Internet of Things
IRR	Internal Rate of Return
KPI	Key Performance Indicator
M&V	Monitoring and Verification
nZEB	Nearly Zero-Energy Building
NPV	Net Present Value
OpEx	Operating Expenditure
PED	Positive Energy District
PED-EU-NET	Positive Energy Districts European Network
PEN	Positive Energy Neighbourhood
RES	Renewable Energy Sources
SPEN	Sustainable Plus Energy Buildings
TSO	Transmission System Operator

Definitions

The definitions of energy performance are based on EN 15603:2008 (Official Journal of the European Union, 19 April 2012, p. C 115/9):

Energy source: source from which useful energy can be extracted or recovered either directly or by means of a conversion or transformation process.

Energy carrier: substance or phenomenon that can be used to produce mechanical work or heat or to operate chemical or physical processes.

1. Introduction

1.1 General Context

Positive Energy Districts (PEDs) should be designed in a highly structured manner, considering local resources and specific challenges, while involving urban stakeholders at a high level and strongly linked to global governance models, where all factors are important (JPI Urban Europe, 2020).
Several factors are critical to Positive Energy Districts (PEDs) and involve both technological and non-technological elements that impact the three main components of energy: efficiency, renewable energy production, and flexibility with storage and demand side-management. The PED concept emphasises the decentralisation of the energy system, which enhances energy security and resilience, actively involves end-users in energy management, and transitions urban environments towards fossil-free and climate-neutral solutions. Integrating PED solutions into existing urban contexts presents a significant challenge, as it requires addressing differences in geographical, historical, economic, social, and cultural backgrounds. Achieving this objective requires concepts that go beyond technical feasibility and embrace a diversity of different approaches.
The capacity building process is essential for stakeholders to develop each element of the PED in close collaboration with partners, which underscores the need for a shared strategic vision among all actors involved in the process. While previous studies have examined specific aspects of PEDs, such as energy or social dimensions (Maestosi, Andreucci & Civiero; Gouveia et al. 2021), other authors have identified associated challenges and barriers (Hearn & Castaño-Rosa, 2021). Zhang et al. developed a dedicated database that must be further expanded/interoperated through an interactive dashboard (Zhang et al. 2021). It reports and visualises the initial analytical results of 60 existing PED projects in Europe about their main characteristics, including geographical information, spatial-temporal scale, energy concepts, building archetypes, finance source, keywords, finance model and challenges/barriers. The COST Action 'PED-EU-NET', and JPI Urban Europe, together with partners in IEA EBC Annex 83, all of which are pioneer initiatives conducting research on Positive Energy Districts (PEDs), collaborated to develop a tool called the 'PED Database'. This tool facilitates the mapping, filtering, sorting, and comparison of PED experiences, providing a balanced overview of the technological and non-technological solutions adopted in different PED projects that require the cooperative involvement of multiple stakeholders. The capacity-building process encourages the participation of all stakeholders involved, including researchers, policymakers, industry experts, and community members.

The aim of Subtask D spans all the objectives of Annex83 by testing and demonstrating their operationalisation in demonstration cases reaching objective 5.

STRUCTURE OF THE DELIVERABLE

This deliverable is divided into 3 sections:

- In the first section (Chapter 2) the development of a PED database is described. A framework for data collection from demo cases was established through a Scoping Phase outlining all the necessary domains and notions that are needed to collect. References from other initiatives (e.g. SCIS, JPI UE Booklet, PED EU NET other references from outside EU) were considered and inspired by to fix the main aspects to build upon (Bossi, Gollner and Theierling 2020).
  Two dedicated papers were published that describe in more detail the data collection framework, the data collection template, as well as demo cases (Alpagut et al. 2023; Civiero et al. 2024). Participants

from Subtasks A, B, C supported the template process creation making sure that the template collects relevant info to carry out the Subtask A, B, C activities.
Data Collection started in 2022 and remains ongoing process. There was a twofold purpose for this (Alpagut et al. 2023):

1. Identifying relevant demo cases among the Annex partners and supporters to document demonstration activities at district levels relevant to the Annex. These are related to PED Labs, PED cases and PED relevant cases. Subtask D leaders were overseeing as PED editors the different entries and ensured the quality of the input data.
2. Establishing a knowledge base for the entire Annex83 initiative.

Using the database template, a collection of informative demo cases was created (database) that allows to showcase best practices, learnings about the definition, archetype and stakeholders involvement (for subtask A activities) as well as data availability of PED technologies (for Subtask B activities) and learnings about the evaluation framework and KPIs experience (for Subtask C activities).

- In the second section (Chapter 3) the PED guidelines are discussed.

- In the third section (Chapter 4) the dissemination activities are reported.

2. PED Database with demonstration cases

The subtask D1.1 kick-started with the Scoping Phase with the aim of creating a framework for data collection from demo cases. All the Annex participants contributed to the Scoping Phase outlining all the necessary domains and notions that are needed to collect to carry out the Subtask A, B, C activities. References from other initiatives (e.g. SCIS, JPI UE Booklet, PED EU NET other references from outside EU) were thereby considered to take inspiration for creating the data collection framework collaborative process to fix the main aspects to build upon.

The data collection framework was elaborated into a template, structured to collect relevant info from demo cases. Data collection was an ongoing activity throughout the Annex. This activity has a twofold purpose:
First, identifying relevant demo cases among the Annex partners and supporters to identify demonstration activities at district levels relevant to the Annex. These can be related to PED Labs, PED cases and PED relevant cases. Subtask D leaders oversaw as PED editors the different entries and ensured thereby quality of the input data.
Secondly, the purpose was to create a knowledge mass for the whole Annex83.

Demo cases were collected in a database to gather best practices, learnings about the definition, archetype and stakeholders' involvement (for subtask A activities) as well as data availability of PED technologies (for Subtask B activities) and learnings about the evaluation framework and KPIs experience (for Subtask C activities).
In the framework of the PED-Database development, a core aspect was the subdivision of the development process into a series of phases (also referred to as the database development life cycle (DDLC)). The database development moved through this life cycle starting with the Scoping Phase of establishing requirements expressed as a statement of requirements with the aim to create a framework for data collection from demo cases.
The next step was the Implementation Phase, based on an online template structured to collect the relevant info. Close cooperation among the three involved initiatives and their working groups was ensured by iteratively refining the template.
Then, a well-structured data collection was conducted. This task required external assistance from PED developers who are in charge and responsible for the gathered information (e.g., researchers, energy vendors, DSOs, TSOs, aggregators, technology providers, etc.), auditors (e.g., technical architects in charge, energy audit company, consulting expert) or any other actors within a public–private partnership who are actively involved in the projects.
Finally, the Testing Phase was initiated as the last step of the DDLC, ensuring the quality and consistency of the collected data.

2.1 Scope of the database

The main scope of PED-Database was to provide data on the state-of-the-art development in PED model to devise methods to characterise these districts, but also recommend concepts, solutions, strategies, and best practices for their effective grounding in different geographical contexts and according to multiple stakeholders' needs and expectations.
The PED EU NET Database is the result of collaboration of many researchers and practitioners in the PED field. The parameters included are designed to characterise the PED concept in a comprehensive way and to

support the learning process by the PED community. The database structure consists of two main blocks divided into six strictly interrelated sections (Figure 1).

- A central nucleus that collects information about PED/PED-relevant case studies and PED Labs. This part is structured in the following three sections:
    - 'Section A' (*i.e.,* A1. Global Characteristics, A2. Technological Aspects and A3. Non-technological Aspects);
    - 'Section B' (*i.e.* B1. PED Case studies in detail and B2. PED Labs in detail) and
    - 'Section C' (*i.e.,* C1. Drivers and barriers).

  Currently, a total of 109 parameters and 455 options are collected in this block and implemented in the online platform.
- A supporting nucleus of information related to PED concept is structured in three complementary sections:
    - 'Section D' on General Projects/Initiatives,
    - 'Section E' on National Policies and Strategies and
    - 'Section F' on Technological and Non-technological related Solutions/Innovations.
    - 'Section D' has been fully developed and integrated into the online platform, consisting of 16 parameters and 7 options.

  As regards 'Sections E' and 'Section F' are under development, and further sections may be added in the future, following the logic of modularity and ability of implementation of the database.

2.2 PED characteristics

Based on the characteristics of the existing PEDs and PED Labs as well as the available bibliography, a first selection of the entries that should be collected by the database was made. This selection was expanded and agreed upon by the different working groups of the initiatives involved, resulting in a list of variables required in different sections of a survey to characterise each case study. To validate these entries, the list was shared with external groups that managed real PED cases but were not involved in the PED-Database development. These groups assessed the questions in each section of the survey and provided their comments, identifying missing elements and redundant information. This review process led to a refinement of the survey, in each of its sections through much more precise and specific questions. As a result, the PED-Database was structured to extract the maximum possible information from each case, following the section framework established in the Scoping Phase. See Figure 1 for details.

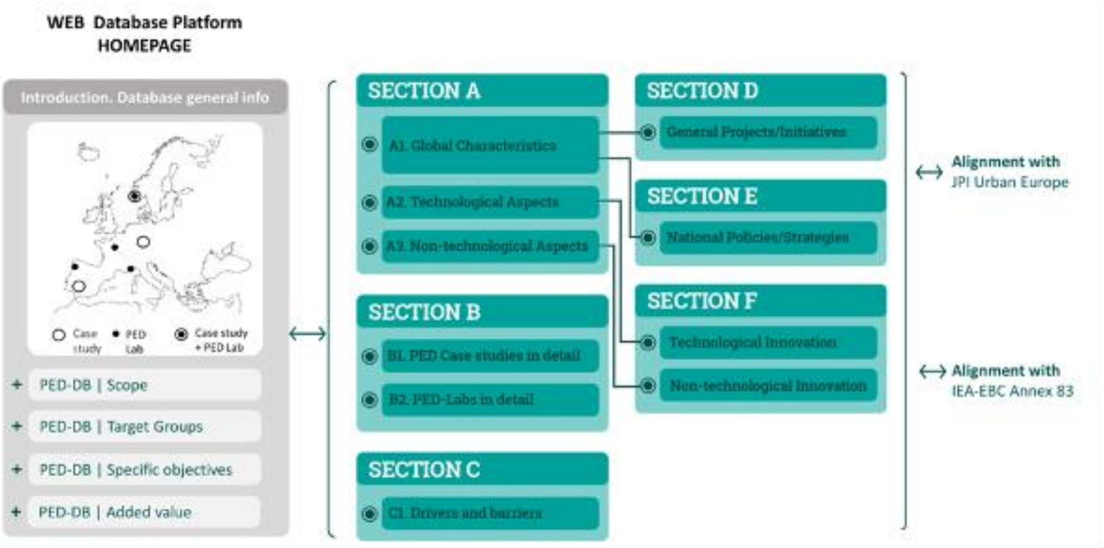


Figure 1: Sections of the PED database

2.3 Data Collection and testing

Data collection is the process of gathering information for use in strategic planning, research, and decision-making. In this case, it is a crucial step to comprehensively characterise the PED concept. Effective data collection provides the necessary information to answer key questions, analyse performance, evaluate outcomes, and predict future trends, actions, and scenarios. The data collection process is carried out in three main stages.

- **In the first stage**, a data collection plan is created, specific database (DB) guidelines are developed, and the main actors are identified. Two main collaborative roles are involved: the PED Database Editor and the Input Form Editor. The DB Editor is responsible for establishing effective communication with key PED/PED Lab case study contact persons to encourage their participation as input editors in the PED database. At this stage, the DB Editor invites Input Editors via web links to complete PED project and case study forms. Before issuing an invitation, the DB Editors can check in the DB backend which Input Editor has already been invited. The DB Editors' register is then updated with a record of the projects and case studies assigned to each DB Editor.
- **In the second stage**, appropriate data sources are identified, and Input Form Editors fill in the required information through online forms. The DB Editor provides advice to the input editors as needed. When the input form is submitted, the project/case status changes from draft to pending. A standard has been developed for entering individual entries into the PED database.
- **In the third stage**, completed information is evaluated prior to publication on the PED-EU-NET website. The DB Editor checks the completeness and accuracy of the information filled in the different input forms (case studies & projects). Major changes and clarifications are discussed between the DB Editor and the Input Form Editor before authorising the publication of the PED projects/cases in the database. The status changes from pending to published in the DB backend. Once published, the information is accessible through the front-end design of the PED Database. The home page allows users to view the maps and tables of the PED cases and associated projects without requiring registration (Turci et al. 2022).

In the Testing Phase, the necessary tests were conducted to verify that the database reflects the entered data and ensure that no errors occur in relation to the applications and tools that other users will be using.
To begin with, it was important to have a group of people with independent responsibilities: one group responsible for entering the data (Editors) and another group with verifying that the entered data had been successfully stored and used in accordance with the technical specifications of the database [9].
Prior to testing, there was a preparatory phase focused on gathering case study data to be entered into the database. These data, provided by other users and database collaborators, constitutes the core of this web tool.

The next step involved the database editors entering all received case studies while maintaining constant coordination with the individuals that had provided those case studies.
Finally, this phase of testing was done, once again, in coordination with the partners who submitted their case studies. A verification process was conducted to ensure that the database editors had correctly entered the case study in coordination with the partner who submitted it. This partner, acting as a external user, confirmed that all data had been entered accurately and was accessible for everyone interested in making free queries in this database. Each PED case study has been validated separately ensuring that the PED database was thoroughly tested (Koutra et al. 2023). In this phase, the fundamental objective was to conduct necessary tests to verify that the database accurately reflects the entered data, and to ensure that there are no errors with respect to the applications and tools that other users will be using.
The platform is fully operational, and a first round of data collection was conducted in 2023 and the first half of 2024 at both, the case study and project levels. Since summer 2024, the platform has expanded considerably, reaching **110 PED cases** by **March 2025**.

The PED-Database introduces definitions and insights that will guide cities' stakeholders in capacity building at different levels as well as by defining core capabilities. The developed framework provides an understanding of PED concepts, planning values, and functionality criteria to create a learning environment for capacity building and, at the same time, to establish a vision for future districts.

Dedicated Database Editors constantly review the data collection process assuring their consistency and transformed the information into a clear, standardised language displayed on the platform. The sustainability of the Database is crucial for ongoing contributions and research. For this reason, the three initiatives - COST Action PED EU NET, IEA EBC Annex 83 and JPI UE - have planned to maintain the Database beyond project duration, as it will be adopted by another host that works closely with the Action group. The DDLC will be repeatedly revisited.

The structure developed for this database has generated an interface that presents the stored results in a differentiated manner, offering both map and table views. Each of the stored PED developments can be assessed in detail or even compared with other cases, facilitating the identification of common or differentiating elements.
Another key feature of this web platform is its ability to provide quick access to general project information, while also linking the PED cases with their respective projects.

2.4 Demo cases and projects

In the database there are (status: March 2025) **110 PEDs** included. They stem from 35 projects from 24 countries. This connection, between PED cases and projects is illustrated in Figure 2 below.

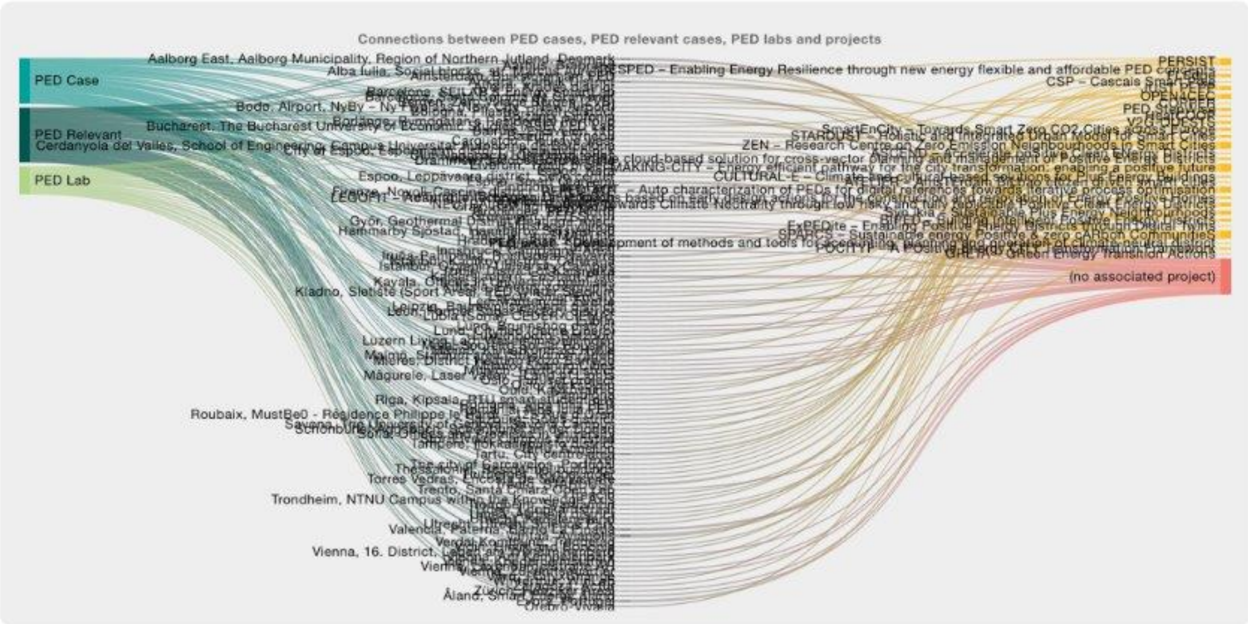


Figure 2: Overview of PED cases in the database and connection to projects

The following figure illustrates the number of PED case studies per country, highlighting the leadership of the Nordic countries and a high implementation rate in Southern countries such as Spain, Italy, and Portugal.

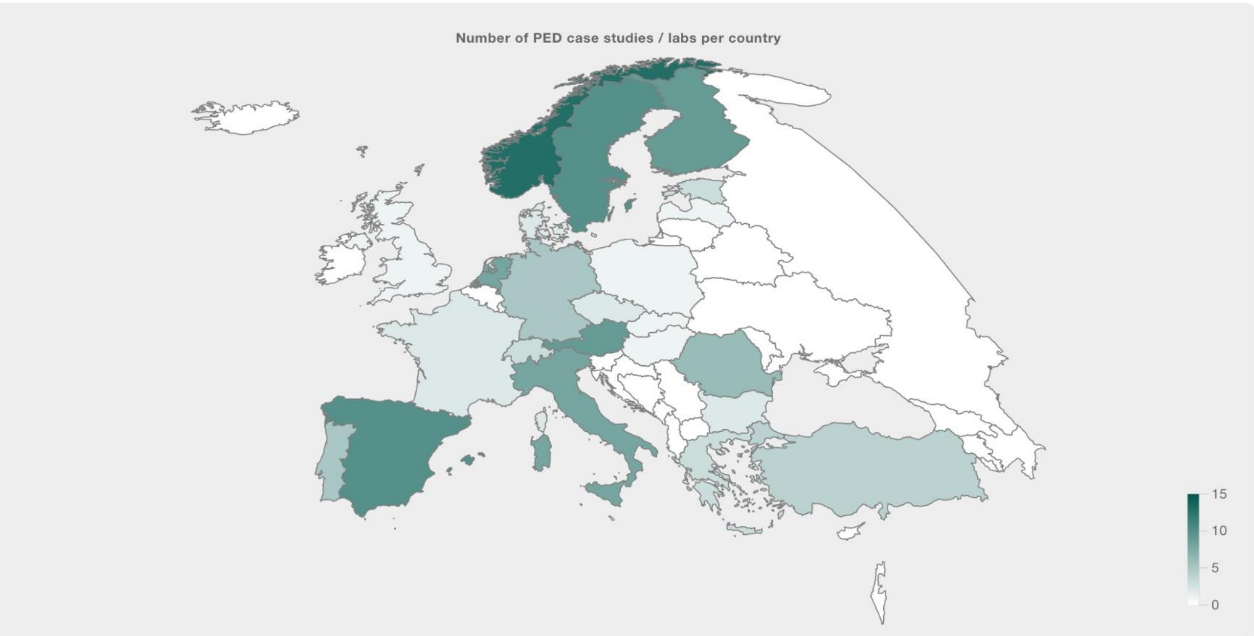


Figure 3: Overview of PED cases in the database per country

Figure 4 shows the targets of PED cases and the phases of PED cases. To demonstrate how the database can be used, it was decided to report on three demo cases. In this context, the framework developed by

Haase et al. (2025) was employed to analyse the PEDs, considering technological, social, financial, and regulatory perspectives. The KPI categories are linked to these aspects in various ways. In this regard, mapping the key stakeholders, as well as identifying the scale and phase at which decisions are made, is part of the analysis. As a result, the proposed framework establishes a relationship between the four key aspects:

- Technological
- Social
- Financial
- Regulatory

And the three dimensions:

- Stakeholders
- Life-cycle phase
- Scale

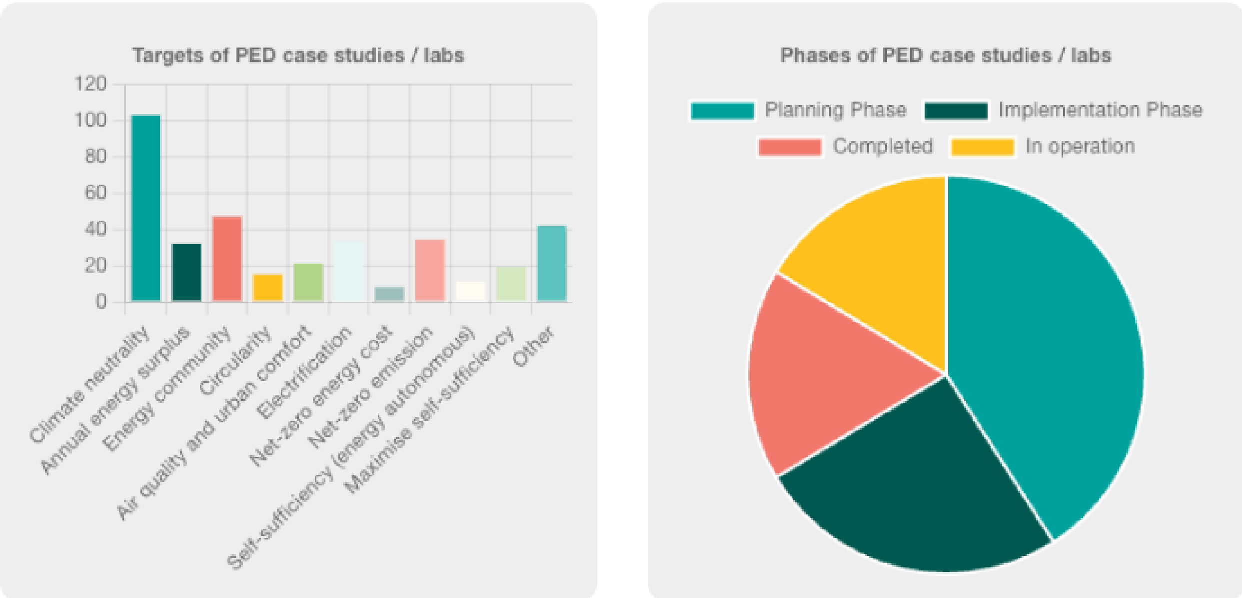


Figure 4: Targets of PED case studies / Labs (left) and phases of PED case studies / Labs in the PED database

2.4.1 PED projects

The PED cases in the database come from 35 projects. They are listed in Table 1 with project name, DB-ID and start and end date.

Table 1: PED projects with project name, DB-ID and start and end date

Project Name	Project Code	Start Date	End Date
RESPED - Enabling Energy Resilience through new energy flexible and affordable PED concepts		Jan 25	Jan 27
CSP - Cascais Smart Pole	01_Call#4_CascaisSmartPole-byNovaSBE	Jan 20	Jan 24
PERSIST	F-DUT-2022-0064	Jan 24	Jan 27
HeatCOOP	F-DUT-2022-0156	Jan 23	Jan 26
DigiTwins4PEDs	F-DUT-2022-0210	Jan 23	Jan 26
JUST PEPP	F-DUT-2022-0360	Jan 23	Jan 26
COPPER	F-DUT-2022-0352	Jan 24	Jan 26
CO2PED	F-DUT-2022-0327	Jan 24	Jan 26
FLEdge	F-DUT-2022-0337	Jan 24	Jan 26
OPEN4CEC	F-DUT-2022-0070	Jan 24	Jan 27
PED StepWise	F-DUT-2022-0419	Jan 23	Jan 26
V2G-QUESTS	F-DUT-2022-0241	Jan 23	Jan 26
London/Ontario Living Lab		Jan 26	
ASCEND - Accelerate poSitive Clean ENergy Districts	3251924	Jan 23	Jan 27
ENERGY4ALL	F-DUT-2022-0114	Jan 24	Jan 26
CULTURAL-E - Climate and cultural-based solutions for Plus Energy Buildings	870072	Jan 19	Jan 25
LEGOFIT - Adaptable technological solutions based on early design actions for the construction and renovation of Energy Positive Homes	101104058	Jan 23	Jan 27
InterPED - INTERoperable cloud-based solution for cross-vector planning and management of Positive Energy Districts	Grant Agreement number 101138047	Jan 24	Jan 26
PEDvolution - Interoperable solutions to streamline PED evolution and cross-sectoral integration	101138472	Jan 24	Jan 26
ATELIER - AmsTErdam BiLbao cItizen drivEn smaRt cities	864374	Jan 19	Jan 25
BIPED - Building Intelligent Positive Energy Districts	101139060	Jan 24	Jan 26

NEUTRALPATH - Pathway towards Climate-Neutrality through low risky and fully replicable Positive Clean Energy Districts	ID: 101096753	Jan 23	Jan 27
ExPEDite - Enabling Positive Energy Districts through Digital Twins	Grant Agreement No. 101139527	Jan 24	Jan 26
PED urban - Development of methods and tools for accounting, planning and operation of climate-neutral district	03EN3048A	Jan 21	Jan 24
PED-ACT - Auto characterisation of PEDs for digital references towards iterative process optimisation	43927229	Jan 22	Jan 25
CIEMAT-CEDER			
STARDUST - Holistic and Integrated Urban Model for Smart Cities	ID: 774094	Jan 17	Jan 24
ZEN - Research Centre on Zero Emission Neighbourhoods in Smart Cities		Jan 17	Jan 24
RESPONSE - Integrated Solutions for Positive Energy and Resilient Cities	ID: 957751	Jan 20	Jan 25
POCITYF - A POsitive Energy CITY Transformation Framework	ID: 864400	Jan 19	Jan 24
MAKING-CITY - Energy efficient pathway for the city transformation: enabling a positive future	ID: 824418	Jan 18	Jan 23
SPARCS - Sustainable energy Positive & zero cARbon CommunitieS	ID: 864242	Jan 19	Jan 24
Syn.ikia - Sustainable Plus Energy Neighbourhoods	ID: 869918	Jan 20	Jan 24
SmartEnCity - Towards Smart Zero CO2 Cities across Europe	ID: 691883	Jan 16	Jan 22
GRETA - GReen Energy Transition Actions	ID:101022317	Jan 21	Jan 23

But also the PED cases can be analysed by comparing different PEDs in the database directly, by listing them and by exporting the tables. An example is shown Figure 5 for four different PEDs (2 PED cases and 2 PED Labs:

- Lippulaiva Block in Espoonlahti in Espoo, Finland.
- Baumwollspinnerei (Intelligent Micro Grid) in Leipzig, Germany.
- Maia Sobreiro social housing.
- Lubia CEDER-CIEMAT PED Lab.

In the following sections the PEDs are described in more detail and in summarising tables (Table 2 to Table 5).

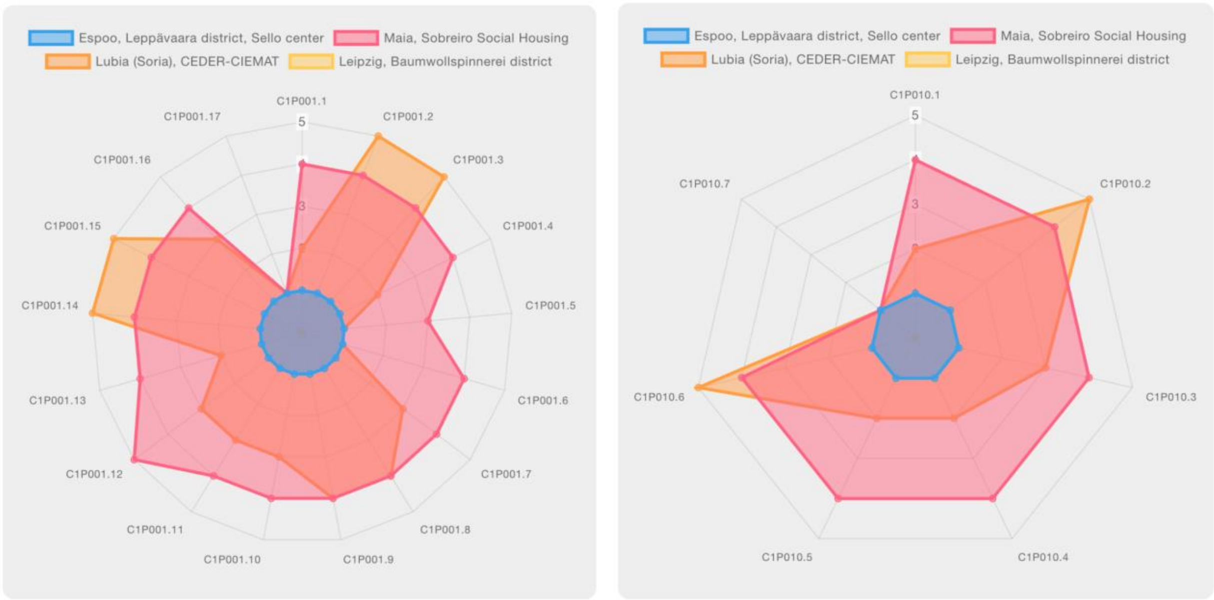


Figure 5: Possible comparisons of unlocking factors (left) and financial barriers (right) for four PEDs (Lippulaiva, Baumwollspinnerei, Maia, and Lubia); For labels, please refer to Table 2.

Table 2: labels for Figure 5

Factor	Label (left)	Factor	Label (right)
C1P001.1	Recent technological improvements for on-site RES production	**C1P010.1**	Hidden costs
C1P001.2	Innovative, integrated, prefabricated packages for buildings envelope / Energy efficiency of building stock	**C1P010.2**	Insufficient external financial support and funding for project activities
C1P001.3	Energy Communities, P2P, Prosumers concepts	**C1P010.3**	Economic crisis
C1P001.4	Storage systems and E-mobility market penetration	**C1P010.4**	Risk and uncertainty
C1P001.5	Decreasing costs of innovative materials	**C1P010.5**	Lack of consolidated and tested business models
C1P001.6	Financial mechanisms to reduce costs and maximise benefits	**C1P010.6**	Limited access to capital and cost disincentives
C1P001.7	The ability to predict Multiple Benefits	**C1P010.7**	Any other Financial BARRIER
C1P001.8	The ability to predict the distribution of benefits and impacts		
C1P001.9	Citizens improved awareness and engagement on sustainable energy issues (bottom-up)		
C1P001.10	Social acceptance (top-down)		
C1P001.11	Improved local and national policy frameworks (i.e. incentives, laws etc.)		
C1P001.12	Presence of integrated urban strategies and plans		
C1P001.13	Multidisciplinary approaches available for systemic integration		
C1P001.14	Availability of grants (from EC or other donors) to finance the PED Lab projects		
C1P001.15	Availability of RES on site (Local RES)		
C1P001.16	Ongoing or established collaboration on Public Private Partnership among key stakeholders		
C1P001.17	Any other UNLOCKING FACTORS		

2.4.2 PED case study, Lippulaiva Block in Espoonlahti in Espoo, Finland

PED solutions in the central block of Lippulaiva in Espoo, Finland, were demonstrated in EU funded SPARCS project[1]. The PED solutions include integrated renewable energy solutions, incorporating solar panels 690 kWp in buildings roofs and facade, geothermal heat pumps, and waste heat recovery. The energy system of the block is optimised with smart building energy management systems and energy storage, which implement the strategies for trading electricity with Fingrid at the energy flexibility markets. Additional activities involved EV charging integration and fostering e-mobility and optimisation and encouraging community involvement in sustainable urban development. The nearly Zero Energy Building (nZEB) block leverage a large regenerative commercial Ground Source Heat Pump (GSHP) system in Finland (4MW, with 50 km of heat collection pipelines), fulfilling over 90% of its heating and cooling needs (cutting CO_2 emissions by 95%) for the Lippulaiva area (Figure 6). The excess heat recovered from the building block during summer time is recovered from the cooling of the building and the thermal energy is stored into ground. The interventions to demonstrate, test and validate integrated energy solutions for PEDs in Lippulaiva block in SPARCS.[2] (see Figure 6).

Figure 6: PED case Lippulaiva block in Espoo, Finland, SPARCS.

[1] SPARCS https://sparcs.info/en/ 2019-2024, funded by European Commission under grant agreement 864242

[2] Hukkalainen, M., & Kazi, A. S. (2024). Towards Smart, Sustainable, Energy Positive, and Zero Carbon Communities: Challenges, Solutions and Impacts. https://doi.org/10.32040/2024.978-951-38-8837-4

Table 3: Overview of Lippulaiva Block PED dimensions, Espoo, SPARCS

Dimension	Technological	Social	Financial	Regulatory
Stakeholders	- Research organisation (VTT) -Local energy service provider (ADVEN) -Building owner (Citycon) -Building energy management system operator -Grid operators for energy flexibility	- City of Espoo - Local residents - Consumers visiting at the block - Users of sustainable transport solutions - Youth community and buddy classes at local school - Facility owner - KONE (researchers for urban mobility)	- Facility owner, with investors -SPARCS project partners	-National level, city and district level energy and transportation regulations
Life-cycle Phase	-Design phase: study of energy needs for electric buses, taxis, waste collection and delivery vehicles, and other service fleets, with consideration of their effects on the electrical grid -Implementation: all the integrated energy solutions of the block: the integration of renewable energy and storage systems as well as the e-charging infrastructure have been fully implemented.	-Design phase: *Community participation in sustainability efforts: collaboration with young consumers to co-create a shopping centre that meets their needs -Implementation: *Adoption of energy-efficient behaviours *Promotion of e-mobility uptake *User-driven design and innovation. These actions have been implemented and the evaluation of their impact done	Implementation: *Financial viability studies *Investment and funding strategies *Business model co-creation -Validation of the predictability of energy costs and the financial viability of the nZEB model, setting the stage for broader application. -Evaluation of financial impact of energy solutions	-Guidelines for integration of renewable energy systems in urban areas -Regulation of energy systems and grid stability -Urban mobility planning - Support for green business models
Scale	-Improve the NZEB energy system by integrating renewable energy sources and a Virtual power plant with big data analytics for predictive control. The system uses ground storage for thermal energy, supplying heat and cooling to Lippulaiva, with surplus energy shared with the district heating network. -Increase the self-sufficiency of adjacent blocks by exporting heat from	-Targeting local community (Lippulaiva residents) -Espoonlahti district level (community behaviour) -Youth-centric community design -Motivation for a shift in daily transportation habits, focusing on optimising energy use and user satisfaction	- Local business scale (e.g., energy-positive business models) -City-wide infrastructure development (e.g., e-mobility charging networks)	-National level energy and transportation regulations -Local government policies for sustainable energy and mobility solutions - Develop an automated steering system to enhance the building automation and HVAC efficiency linked to geothermal production, including adaptable system controls, air management, demand response, and weather prediction integration—with Lippulaiva as a pilot project.

Dimension	Technological	Social	Financial	Regulatory
	the ground source heat pump via the local district heating network -City-scale integration of e-mobility (140 charging stations, with the grid currently capable of accommodating a maximum of 400 EVs). Sustainability strategy for sustainable transportation modes to the Metro and Lippulaiva, turning Lippulaiva into a hub for shared electric vehicles.			

2.4.3 PED case study in Baumwollspinnerei (Intelligent Micro Grid) in Leipzig, Germany

The Baumwollspinnerei, a heritage-protected former cotton mill built in 1884, spans approximately 17,000 m^2 with brick structures that have been partially refurbished. It serves as a model for transforming old industrial sites into cultural hubs, incorporating a StartUpLab under the theme 'from cotton to culture'. Since its re-establishment, Baumwollspinnerei aims to evolve into an innovative energy-smart district with advanced management of heat and power. The SPARCS project demonstrated in Baumwollspinnerei to integrate additional renewable energy sources and power storage within the district grid; manage energy bidirectionally by syncing the local Microgrid with public networks; and devise financial models for district power systems, including fair tariffs and policies. The inclusion of 2nd generation electric vehicle charging stations supports the grid's energy flexibility, and tests vehicle-to-grid as a new storage unit. Table 4 provides an overview of the different dimensions in the Baumwollspinnerei PED.

Figure 7: SPARCS PED Solutions for Baumwollspinnerei, Leipzig

Table 4: Overview of Baumwollspinnerei Block PED dimensions (summary from3)

Dimension	Technological	Social	Financial	Regulatory
Stakehold-ers	-Local energy system manager (Cenero) -Local energy company (Leipgziger stadtwerke) -Vehicle-to-grid technology providers -Research partner (FHG)	City of Leipzig with other SPARCS partners and building users	The start-up Accelerator SpinLab and HHL Business school are based at the site, and helped to develop business models	City, PED partners
Life-cycle Phase	Installation of equipment for intelligent balancing of PV, CHP, and user demand control implemented. Demonstration of a two-way electric vehicle charging system to enable parked cars to act as additional energy storage resources. eV car fleet sharing.	Implemented: Integration of RES in the local micro electricity grid; in coordination with the user consumption patterns. Offering an interface to users showcasing air quality data and implicit demand management, expecting to reduce demand through live feedback, consumption insights, and behaviour recommendations for occupants.	Implemented: Bidirectional charging for electrical vehicles. Managing microgrid equilibrium relative to a city-wide virtual power plant by selling surplus energy or purchasing additional energy when needed; integrated with blockchain-based business frameworks.	Implemented intelligent heating demand control: Aligning heating requirements with the load profiles of the microgrid, considering the unique thermal properties of historic buildings used as thermal mass.
Scale	Local micro-grid balancing: Building & Block of buildings; connection to local district heating. Evaluation and incorporation of large-scale battery energy storage systems to maintain balance between energy output and demand within the microgrid.	Community engagement through SpinLab and HHL Business School	Financial incentives for energy savings and demand control and optimisation for the district energy system.	Compliance with energy regulations and standards at city, regional and national level

[3] SPARCS deliverable D4.3 Implemented demonstrations of solutions for energy positive blocks in Leipzig, https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5f21f4d36&appId=PPGMS

2.4.4 PED Lab Maia Sobreiro social housing

One of SPARCS' partner cities is located in the municipality of Maia, Portugal. This city is preparing for the adoption of PED solutions and has selected two priority districts as potential replication areas: Tecmaia and Sobreiro. To these districts must be added individual building operations in the city. The first district, Tecmaia, is a science and technology park located in the heart of the main commercial and industrial area close to the city centre, while the second, Sobreiro, is a city centre district consisting of social housing blocks. In this neighbourhood, 48 buildings are undergoing urban renewal as part of the Action Plan for the Rehabilitation of the Area. These actions, involving not only the buildings but also the surrounding areas (a total of approximately 46,632 m²), could extend to 242 social housing blocks in the centre of Maia and interventions in 22 buildings in Maia I and II, bringing the total to 364 social housing blocks (Figure 8).

Figure 8: PED case Maia, Portugal

The Maia districts are designed to focus on social aspects and the creation of virtual PEDs, in which energy production (and storage?) takes place outside the boundaries of the districts themselves. This fellow city drew up a detailed plan to implement the PED, integrating an energy community with the digitisation of the city. The process included goal setting, consultation with market players, in-depth evaluation, investment planning and management of the procurement and implementation phases. Maia focused on five strategic areas (Urban Sustainability, Energy Transition, Mobility, Smart City and Urban Inclusion and Integration) and developed a medium- and long-term plan. Continuous data collection enabled real-time changes to be made to renovation measures and operational strategies, ensuring key performance indicators (KPIs) were achieved. Renewable energy installations and renovations were cost-effective, with short payback periods. The Sobreiro energy community has a payback period of 4.4 years and a particularly favourable return on investment of 490%.

Therefore, the emphasis on future scalability, social inclusion, and enhanced environmental and economic impact shapes the vision of the 'Maia Positive City'. This includes the potential for establishing a Virtual Power Plant (VPP) in the future, although it is not currently a goal of the project. More details are available through the SPARCS website (www.sparcs.info) and Maia's result deliverable[4].

Table 5 provides an overview of the Maia PED Lab dimensions.

[4] Implementation plan Maia, SPARCS project https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5021e1088&appId=PPGMS

Table 5: Overview of Maia PED Lab dimensions

Dimension	Technological	Social	Financial	Regulatory
Stakeholders	Municipality of Maia. Feasibility studies, assessments, and integration tools are provided by the technical partners, including AdEPorto, EDP NEW R&D, and the University of Maia.	In the social sphere, the population, particularly those from the social housing district of Sobreiro, was actively engaged in the co-design and formation of RECs, resulting in a positive impact on comfort and quality of life.	The municipality and the Espaço Municipal derive benefits from a reduction in energy costs, while industries, such as Sonae, achieve gains through improved sustainability and greater environmental efficiency.	The municipality is responsible for developing policies and coordinating with national agencies to implement the REC model effectively, ensuring adherence to applicable regulations and standards.
Life-cycle Phase	Extensive and careful technological planning was carried out, with feasibility studies outlining retrofit measures (such as photovoltaic systems and the installation of smart meters), all monitored through a functional energy management platform.	There is community involvement at every stage of the project, starting from the planning phase with public consultations and extensive workshops, including those with children, ensuring everyone could contribute valuable insights. This continues through to the implementation and operational stages.	Investment decisions (such as performance-based contracts) are made during the planning phase. Operational savings are accumulated to achieve a quick return on investment. Advanced financial decisions remain focused on social aspects, considering that the energy surplus will be used to reduce utility costs for social housing.	During the planning phase, authorisations are drawn up and policies established, while ongoing compliance monitoring is conducted systematically during the operational phase.
Scale	Interventions are made from building to district scales, involving PED and Energy Communities. The virtual nature of the district and city transformation efforts could also involve the urban scale. The different energy production and consumption patterns can lead to create a Virtual Power Plant (VPP) in future with a "Maia Positive City" perspective.	Social involvement operates at multiple scales, from changes at the building (or individual dwelling) level to the neighbourhood/district scale. The replicability of the social actions taken could already generate interest in applying them at the urban scale.	Funding and financing are provided at both the regional and national levels through public funding programmes, as well as investments from private individuals	This PED Lab operates within a regional and national regulatory framework, which facilitates its replication in different urban areas.

2.4.5 CEDER-CIEMAT PED Lab

The Centre for the Development of Renewable Energy (CEDER) [http://www.ceder.es/redes-inteligentes] is placed in the middle-north region of Spain (Soria) and it is specialised in applied research, development and promotion of renewable energy. This PED Lab is located in the CIEMAT facilities (Spanish public research centre) and operates as an energy district, covering an area of 640 hectares (Figure 9).

Figure 9: Aerial image of the CEDER-CIEMAT Lab facilities [Source: CEDER website]

The district consists of six office buildings and two energy networks, one electrical (operational) and one thermal (under implementation). The electrical network integrates a 50 kW wind turbine, eight photovoltaic systems with a total generation capacity of 116 kW, a 100 kVA engine generator, a reversible hydraulic system and storage systems through batteries and flexible loads. The thermal network currently consists of two 300 kW biomass boilers and 90 kWh water tanks for thermal storage. However, this network is being expanded through the incorporation of a low temperature ring (90°C) and a high temperature ring (150°-250° C), both interconnected through an oil/water heat exchanger. Several thermal storage systems are also being incorporated through boreholes, phase change materials, geothermal exchange or the use of zeolites (Figure 10).

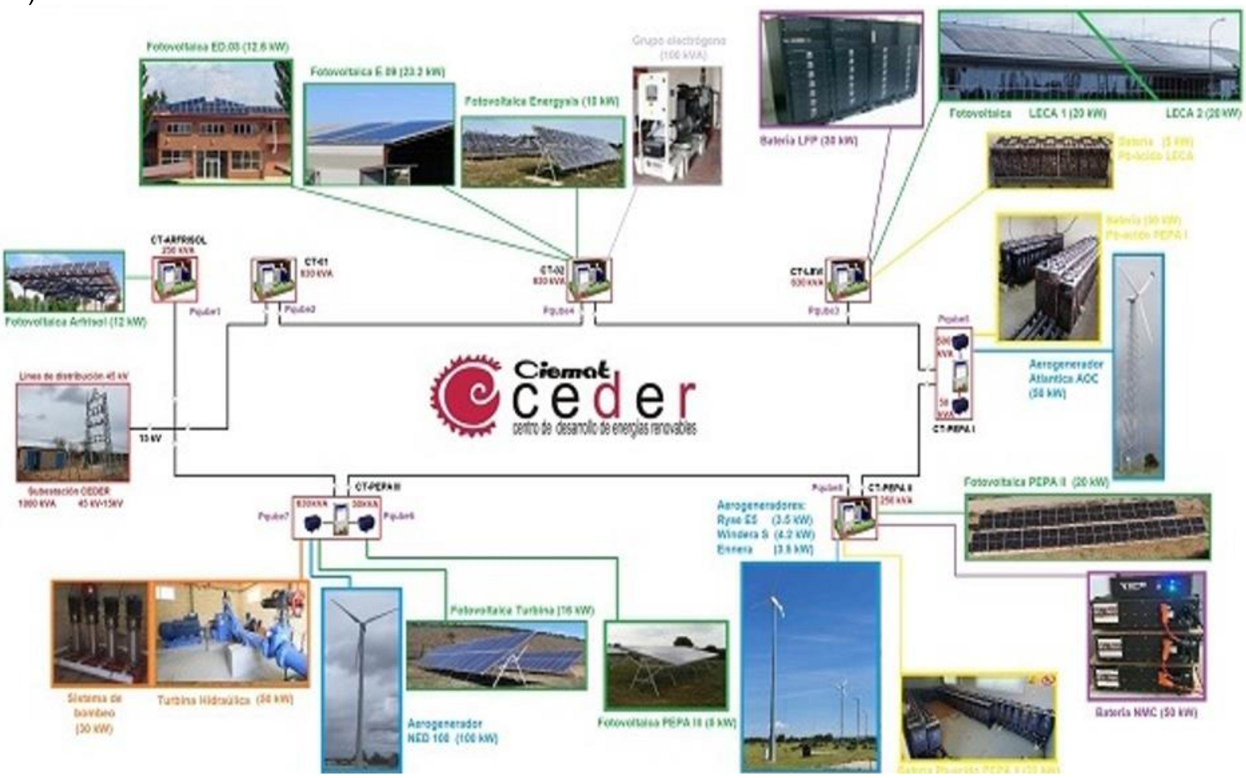


Figure 10: Diagram of electric network elements installed in CEDER-CIEMAT Lab [Source: CEDER website]

The main actor of this PED Lab is CIEMAT, since it is the owner and responsible for the implementation and operation, achieving a flexible facility that produces renewable energy and enhances efficiency through energy networks and adapted buildings. However, the engagement of technical and industrial companies, suppliers and governmental and political actors is crucial to the decision-making and financial processes. In addition, it is essential to involve the local community both to identify its energy behaviour (determining user profiles) and to achieve its acceptance in these urban solutions.

This laboratory measures climatic, building and network values, generating datasets processed by a central control system that makes it possible to design and test strategies and solutions or perform virtual analysis related to building and district scale. Although being a laboratory, the change to real urban scale still poses technical and logistical challenges.

Therefore, among the main challenges faced by this laboratory are the need for investment in technology and innovation, cooperation between stakeholders balancing their interests and processing of the monitored data to be translated into results applicable in industrial applications and urban planning. Table 6 provides an overview of the CEDER-CIEMAT PED Lab dimensions.

Table 6: Overview of CEDER-CIEMAT PED Lab dimensions

Dimension	Technological	Social	Financial	Regulatory
Stakeholders	CIEMAT, Universities from Castilla y Leon (Spain), Suppliers, Technological Companies (e.g. Geoter, Gaptek), Technological centres (e.g. CARTIF Foundation)	CEDER-CIEMAT Staff, Spanish Technological Platforms	CIEMAT, Spanish Ministry of Science and Technology, Spanish Centre for the Development of Industrial Technology (CDTI), National and international projects	National Government of Spain, Regional Government of Castilla y Leon, municipality of Soria
Life-cycle Phase	Building retrofit measures and electrical network are defined in the planning phase. Thermal network characteristics are proposed in the implementation and operation phases.	Occupants' behaviour patterns start in the planning phase but are modelled during the operation phase	As a Public Research Body facility, it requires funding at all stages of the process and throughout its life-cycle to keep it in operation.	Aligning the lab's innovations with evolving energy policies at the local, national and European levels requires constant adaptation at all phases
Scale	Interventions are executed at building and district scales. The implementation of IoT systems and smart meter sensors will enable the future development of a virtual PED Lab.	CIEMAT staff engagement occurs at the building scale. The future virtual PED Lab plans to expand this participation at district level in CEDER	In a public Body, funding and savings obtained are not accounted for in economic terms, but are considered in energy terms	This public PED Lab operates within regional and national regulatory frameworks, allowing for replication across different urban zones

2.5 Conclusions

As explained above, the PED DB is focused on creating a structured digital repository of information and data, aiming at driving urban transformations across the whole complexity of urban challenges, empowering the creation of capacity and community building as key aspects of the decision-making process, implementation, and replication of PEDs. Therefore, gathering data and addressing the systematisation of enabling factors, stakeholders and lessons learnt by mapping PEDs experiences abroad, is the necessary first step to support the entire process and/or promote replication by an advanced database.
Each input collected in the DB questionnaires is a key PED indicator that will be individually shown in the web platform and that can be also adopted for the further calculation of the different KPIs according to multiple purposes and needs - e.g., UBEM, Digital Twins, interactive planning tool, simulation software, etc.
Therefore, the PED DB adopts a user-centred, tailored approach that allows for the selection of relevant parameters according to four main stakeholder categories: public sector, private sector, research sector and citizens & civil society. These categories and their associated needs were identified during DB presentations and workshops (see Table 7).

Table 7: PED DB target stakeholder and main emerged needs [Source: Civiero et al. 2024]

Target Stakeholders	Main emerged needs
Public Sector (Pu) ***e.g.,* government, municipalities, policymakers, public technicians, *etc.***	• Gain expertise/knowledge on PEDs; • Identify similar/twin projects to get inspiration; • Find available funding; • Understand the strategic city/district vision beyond PED; • Recognise regulations/laws gaps and barriers; • Identify the most suitable areas/dimension to implement PEDs; • Identify main stakeholders to be involved; • Identify key factors of governance models; • Identify land uses and owners to develop mechanisms for implementing public-private partnerships.
Private Sector (Pr) ***e.g.,* practitioners (architects, engineers, urban planners, etc.), developers, real estate, construction companies, energy companies, SMEs, *etc.***	• Identify available funding; • Compare technical and non-technical solutions; • Understand economic leverages and costs; • Quantify energy production, energy flexibility and consumptions; • Understand process management; • Verify technical feasibility.
Research Sector (Re) ***e.g.,* academia, R&I centres, EU Commission, DGs, *etc.***	• Compare technical/quantitative data/info; • Identify adopted KPIs; • Test innovative solutions/approaches in real-world environment; • Identify recurrent patterns (type of PEDs, geographical distributions, district boundaries, *etc.*); • Identify unlocking factors, driving factors and barriers and match them with appropriate tools and strategies; • Identify circular economy measures and processes; • Theoretical frameworks develop to model urban areas; • Monitoring and control devices installed.
Citizens & civil society (Ct) ***e.g.,* inhabitants, local communities, city users, local associations, *etc.***	• Surf innovative approaches towards a more sustainable way of living; • Learn about participatory approaches and engagement strategies; • Exchange good practices; • Peer-to-peer learning.

Thanks to the achieved outcome of the PED DB and according to the above-mentioned stakeholder-tailored and user-centred perspective, a multiple outlook is provided for the Database to be considered as next steps of the implementation process, namely:

1. **Decision making support tools** - intended as a data-driven system, where PED information serves as the primary material for informed decision-making at the district level through computerised systems. This approach significantly enhances the effectiveness and efficiency of the decision-making process in PEDs, decreasing technical, spatial, and socioeconomic barriers in district energy planning, while also providing flexibility to tailor reports, roadmaps and presentations to meet the specific requirements of decision makers.

2. **Advanced learning tool** - consisting of certain technologies, such as Artificial Intelligence, Machine Learning, Blockchain, Big Data, Internet of Things, Augmented Reality, Cloud Computing, *etc*., that have revolutionised traditional database systems. Machine learning, with its advanced learning algorithms, stands out as a ground-breaking technology with significant implications for the future. It can provide accurate predictions based on past experiences, making its integration into the PED Database a valuable tool for stakeholders to develop more effective strategies from current conditions to urban transition.

3. **Database Query** - allowing to enhance the data management capabilities within the PED database through adaptive and approximate query processing. This approach emphasises the use of runtime feedback to modify query processing, aiming to achieve better response times and more efficient CPU utilisation, as opposed to the traditional 'optimise-then-execute' approach.

4. **Import and export updatable Database** - support practical methods for backing up critical PED data or transferring these metadata between various versions. These methods provide self-service restoration capability from system-generated backups, ensuring consistently faster, interoperable and predictable import/export performance without causing throttling by the database service. Running client applications from a Virtual Machine in the same region as the PED database helps avoid performance issues related to network latency.

To sum up, the overall workflow involved collaborative efforts to define the PED Database, starting from the framework and categories design to the partnership agreements, towards parameters alignment and final definition, case studies' storytelling and data exportation according to priorities and perspectives of different targeted stakeholders.

Table 8: Contents framework of the DB sections [Source: CA 'PED-EU-NET'].

ID	Parameter title	Glossary	Type of answers	Answers	Target
Section [**A1, A2, A3, B1, B2, C1, D1**] + N. of the parameter [*e.g.,* **P001**, **P002**, *etc.*]	Name of the specific parameter. (*) indicates mandatory parameters.	Text description about content of each specific parameter (when needed) - see Annex A	Open [**O**] insert free text, image or numbers; Close single [**Cs**] choose one option; Close multiple [**Cm**] choose one or more options; Automatic [**A**] generated/calculated from previous inputs.	In case of [O] or [A], specify the type of answer - i.e., free text [**txt**], image [**img**], number [**nr**]. In case of [Cs] or [Cm], list the related answer options	Public sector [**Pu**] Privat sector [**Pr**] Research sector [**Re**] Citizens & civil society [**Ct**]

Further structured information as detailed in Table 9 can be found in the Annex II (Section A1 'Global characteristics'), Annex III (Section A2 'Technological aspects'), Annex IV (Section A3 'Non-Technological aspects'), Annex V (Section B1 'PED Case studies in detail'), Annex VI (Section B2 'PED Lab in detail'), Annex VII (Section C1 'Drivers and Barriers'), and Annex VIII (Section D1 'General Projects/Initiatives').

The information gathered in the PED database can be used to assess the effectiveness of the strategies and of any solution adopted in the mapped case studies. Additionally, the data can be dynamically updated to incorporate new data sources and ontologies, ensuring its continued relevance and usefulness as the projects progress. It can also be used to generate archetypes or "library concepts" to evaluate each scenario.

3. Planning and implementation methodology, PED Guidelines

This section presents the methodological framework used to develop the PED Guidelines. It explains how the guidelines were structured, how existing knowledge and references were reviewed, how stakeholder inputs were collected and integrated, and how the resulting content was refined to improve its practical relevance for cities.

3.1 Good Practice

The development of the PED Guidelines is grounded in a rigorous and structured methodological framework, which builds upon the initial approach proposed by Neumann et al. (2022)[5] and expands it through deeper analytical steps, a more inclusive stakeholder engagement process, and a stronger emphasis on practical applicability for cities. The methodology consists of five sequential steps:

Step 1: Collection of Existing Guidelines.

The process began with a comprehensive **inventory of existing guideline documents** relevant to Positive Energy Districts and adjacent concepts such as smart cities, climate-neutral districts, eco-districts, and sustainable urban development.

- Data sources included targeted desk research, academic and grey literature reviews, as well as structured online surveys disseminated to project consortia and city networks.
- By early 2024, a total of 85 guidelines and reference documents were collected and subjected to a preliminary categorisation.
- Categorisation parameters included thematic scope (e.g. energy systems, mobility, urban planning, governance), geographical coverage (national, European, international), and relevance to district-scale energy transformation.

This broad initial mapping ensured that the review would reflect the diversity of approaches in PED-related domains while enabling a consolidated synthesis of best practices and conceptual gaps.

Step 2: Two-Stage Analytical Process.

To ensure analytical depth and methodological rigor, a **two-stage evaluation approach** was applied to the collected material.

2.1 Brief Characterisation

Each guideline was classified according to:

- **Spatial scale**: Building, block, neighbourhood, district, or city-wide.
- **Target audience**: Local governments, planners, policymakers, investors, communities.
- **Content focus**: Technical specifications, spatial planning, legal and regulatory frameworks, financial models, stakeholder engagement, or assessment methodologies.

This classification enabled an initial thematic mapping of the corpus and helped to identify overlapping areas and thematic imbalances.

2.2 In-Depth Analysis.

A more detailed and mixed-methods analytical approach was then employed:

[5] Neumann, H.-M., Garayo, S.D., Gaitani, N., Vettorato, D., Aelenei, L., Borsboom, J., Etminan, G., Kozlowska, A., Reda, F., Rose, J., Tuominen, P., 2022. Qualitative Assessment Methodology for Positive Energy District Planning Guidelines, in: Littlewood, J.R., Howlett, R.J., Jain, L.C. (Eds.), Sustainability in Energy and Buildings 2021, Smart Innovation, Systems and Technologies. Springer Nature, Singapore, pp. 507–517. https://doi.org/10.1007/978-981-16-6269-0_42

- **Text mining and clustering** were performed using the **NVIVO software platform** to identify dominant keywords, conceptual clusters, and semantic trends.
- **Discourse analysis** was used to interpret the narrative framing of PEDs across documents, assessing how different guidelines conceptualise energy transitions, co-benefits, and stakeholder roles.
- **Manual qualitative analysis** enabled critical review of the guidelines in relation to:
    - Their alignment with PED lifecycle stages (e.g., planning, implementation, operation).
    - Tools proposed for citizen engagement, co-design, and governance.
    - Degree of integration with spatial planning practices.

Step 3: Expert Consultation and Gap Identification.
To strengthen relevance and operational value, the project team undertook a dedicated consultation process involving experts and practitioners.

- Inputs were gathered through tools developed within IEA EBC Annex 83 Subtask D, including Miro boards, thematic meetings, and structured feedback sessions.
- A specific effort was made to involve urban planners and municipal officers, whose operational needs and constraints were often underrepresented in earlier technical or policy-driven guidelines.
- The consultation process allowed for the identification of key methodological and practical gaps, such as:
    - Lack of integration between PED approaches and formal spatial planning instruments
    - Limited attention to legal, institutional, and governance frameworks
    - Insufficient emphasis on co-benefits, socio-economic synergies, and system interdependencies (e.g., between energy, housing, and mobility)

These insights were instrumental in shaping a more context-sensitive and action-oriented guideline structure.

3.2 Draft Guidelines

The drafting of the PED Guidelines was led by an editorial board composed of Subtask leaders and thematic experts from IEA EBC Annex 83, supported by practitioners and academic contributors The process was designed as a modular, iterative, and user-oriented framework to reflect the diversity of PED contexts and users. Its modular structure allows different stakeholders to access the most relevant sections according to their needs; its iterative nature reflects the fact that PED planning evolves over time; and its user-oriented focus ensures that complex concepts are turned into practical guidance for cities and practitioners. A key foundational step in this phase was the development of the Table of Contents (ToC), which served as the backbone for the structure, scope, and logic of the guidelines. To ensure its relevance and comprehensiveness, the ToC was created through a collaborative process involving multiple expert focus groups:

- The process began with a **proposal of initial thematic clusters**, derived from prior analyses of the 85 key reference guidelines and project documents.
- These clusters were then reviewed and refined during structured focus group sessions with members of Annex 83 Subtask D and external stakeholders, including urban planners, researchers, municipal officers, and domain-specific professionals.
- The focus groups helped prioritise topics, identify knowledge gaps, and suggest cross-cutting dimensions such as governance, social equity, ESG integration, and the role of PEDs in broader urban sustainability agendas.
- Feedback loops and multiple iterations led to the consolidation of the ToC, ensuring it was not only technically robust but also practical and accessible for diverse user profiles.

The resulting final structure of the Guidelines consists of **10 chapters**, each addressing a key dimension of PED planning and implementation:

Final Table of Contents

10.3 Relation to Nearly Zero-Energy Buildings (NZEBs)
10.4 PEDs, ESG, and the New European Bauhaus
10.5 PEDs and Energy Communities
11. **Conclusions and Recommendations**
12. **References**

3.3 Validated Guidelines

The final phase of the methodological process focused on the validation and refinement of the guidelines, ensuring their operational relevance, coherence with project outcomes, and practical applicability across different urban contexts. This step was designed as both a technical review and a strategic alignment exercise. The process involved the following key activities:

- **Final refinement of the reference corpus:**
  Building on the analytical process from Step 2, this stage culminated in a refinement of the reference document base. From the original pool of 85 collected guidelines and strategic references, 57 documents were retained for integration into the final synthesis. Selection criteria included relevance to PED development stages, practical usability for city planners, geographic and thematic coverage, and strategic alignment with EU policy frameworks.
- **Peer review and stakeholder consultation:**
  Preliminary drafts of the guidelines were shared with a targeted group of practitioners and experts, including urban planners affiliated with the International Society of City and Regional Planners (ISOCARP), representatives from the Institute for Urban Excellence, and technical staff from municipalities and energy agencies. Their feedback was collected through structured interviews, written inputs, and validation workshops.
- **Cross-validation with Annex 83 Subtasks:**
  To ensure internal consistency and reflect the full breadth of insights generated within the IEA EBC Annex 83 framework, the near-final content of the guidelines was systematically reviewed in collaboration with the reference leads of each Subtask (A–D). This process allowed:
  - The incorporation of latest results and outputs from thematic working groups (e.g. on energy balance methodologies, stakeholder engagement, technological integration, assessment tools).
  - The alignment of terminology, concepts, and recommendations with the most up-to-date deliverables produced within each Subtask.
  - The identification and closure of potential knowledge gaps, ensuring that the guidelines reflect both research-based evidence and practical implementation insights.

Through this coordinated review effort, the final version of the guidelines was validated not only by external stakeholders but also by the internal expert network of Annex 83.
The validated guidelines developed through the methodological process described in this report are included as an Annex to the present document. They are intended to serve not only as a supporting component of this report but also as a standalone publication, with a clearly defined structure, authorship, and editorial identity.
Conceived as a practical and accessible resource for city planners, policymakers, and technical stakeholders, the guidelines have been designed to be distributable independently, enabling their use across different dissemination channels, policy contexts, and project implementations—regardless of their direct association with the full technical report. This modular format ensures that the guidelines can retain their own visibility, usability, and strategic coherence as a reference tool within and beyond the Annex 83 community.
Annex IX provides a detailed analysis.

4. Dissemination

4.1 Communication and dissemination plan

In this chapter are listed all Annex 83 working meetings, summer schools organised by Annex 83, events and conferences that Annex 83 participated or co-organised between 2021 and 2025. There is also a full list of publications which were written by Annex 83 members, with Annex 83 acknowledgement.

4.1.1 Annex 83 Working meetings

There were 10 Annex 83 working meetings organised till March 2025. The list is presented in the Table 9 below. More details about the meetings can be found online, here: https://annex83.iea-ebc.org/meetings.

Table 9: Annex 83 working meetings (2021-2025)

No.	Date	Location
1	January 28-29, 2021	Online
2	April 21-22, 2021	Online
3	September 23-24, 2021	Online
4	April 28-29, 2022	Online
5	September 14-16, 2022	VTT, Espoo, Finland
6	April 12-14, 2023	University of Palermo, Palermo, Italy
7	September 11-12, 2023	Lausanne, Switzerland
8	February 26-29, 2024	CENER Headquarters, Pamplona, Spain
9	September 23-25, 2024	Concordia University, Montreal, Canada
10	March 13-14, 2025	Dalarna University, Borlänge, Sweden

4.1.2 Summer Schools

Every year Annex 83 is organising a summer school for PhD students. The list of the organised and planned summer schools is shown in the Table 10. In the first year of Annex 83 there was no summer school as it was pandemic period. More details about the summer schools can be found online, here: https://annex83.iea-ebc.org/meetings and https://annex83.iea-ebc.org/news .

Table 10: Annex 83 summer schools (2022-2025)

No.	Date	Location
1	July 1-8, 2022	Montreal, Canada
2	June 12-16, 2023	Catania, Italy
3	July 8-13, 2024	Graz, Austria
4	June 16-20, 2025	Palermo, Italy
5	April 20, 2023	Trondheim, Norway
6	November 18 and 24, 2023	Stockholm and Lund, Sweden
7	April 28 2024	Carleton University, Canada

4.1.3 Events and conferences

Members of Annex 83 participated in several conferences and workshops between 2022 and 2024 (Table 11).

Table 11: Events and conferences where Annex 83 was present (2022-2024)

No.	Name of the event	Date	Location
1	First Nordic Conference on Zero Emission and Plus Energy Buildings	November 6 – 8 2019	Norway
2	3rd International Conference on “Smart and Sustainable Planning for Cities and Regions (SSPCR)	December 9 – 12 2019	Bolzano, Italy
3	ASHRAE winter meeting Presentation and ad-hoc workshop on PEDs	February 1 – 5 2020	USA
4	Colloqueimu2020 Presentation and ad-hoc workshop on PEDs	March 11 – 13 2020	France
5	EUSEW Workshop	June 22 – 26 2020	Brussels, Belgium
6	Nordic Edge Presentation and ad-hoc Workshop on PEDs	September 22-24 2020	Stavanger, Norway
7	World summit on digital built environment	September 24 – 25 2020	Online
8	BuildSim-Nordic2020 Conference Organisation	October 13 – 14 2020	Norway
9	First Nordic Conference on Zero Emission and Plus Energy Buildings	November 6 – 8 2020	Norway
10	Smart City Expo World Congress	November 17 – 19 2020	Barcelona, Spain
11	ASim2020, IBPSA-Asia Conference	December 7 – 9 2020	Osaka, Japan
12	Workshop on PED definitions	April 22nd 2021	Online
13	CAE Roadmap 2030 Conference	June 14th 2021	Canada (Online)
14	IEA EBC Annex 83: Library workshop for Urban Platform: Use of data libraries and catalogue concepts for energy systems, occupancy, green roofs and other urban domain	July 12th 2021	Online
15	Building simulation conference	September 1 – 3 2021	Hybrid
16	International Conference on Sustainability in Energy and Buildings (SEB-21)	September 16 – 17 2021	Online
17	EERA JPSC: Workshop of PED initiatives on preliminary results: Towards a European PED definition	September 17th 2021	Online
18	NZEB conference	November 5th 2021	
19	PED Database Joint Workshop	March 8th 2022	Online
20	PED Conference on ‘Tools and Guidance for the Interdisciplinary Approach to Positive Energy Districts’	June 23rd 2022	Amsterdam, Netherlands
21	Smart and Sustainable Planning for Cities and Regions (SSPCR) 2022 Conference	July 19-22, 2022	Bolzano, Italy
22	Seminar title: “Sustainability Assessment of Positive Energy Districts: Methodologies, Indicators and Future Perspectives.”	August 23rd 2022	Phoenix, USA
23	Fall school, September 6-22 - 2022, "Planning solar Neighbourhoods: strategies, tools	September 6 – 8 2022	Online

	and perspectives" organised by IEA SHC Task 63". Two lectures titled " Positive Energy Districts" and "Environmental sustainability of Positive Energy Districts"		
24	Joint Workshop PED database with COST Action PED-EU-NET	September 14th 2022	Online
25	Annex83 - STD - PED Guidelines Workshop	January 26th 2023	Online
26	Positive Energy Districts Essential Components for "Net Zero" City	February 2nd 2023	Online
27	Annex 83 participated in the Sustainable Built Environment event organised by Architectural Institute of Japan	February 15th 2023	Japan (Online)
28	Annex 83 participated in the BT-Seminar Research Sparkles from the World organised by Department of Civil and environmental Engineering and Zero Emission Neighbourhoods, Norwegian University of Science and Technology (NTNU)	March 28th 2023	Norway
29	IEA EBC Annex 83: Subtask B Workshop	April 11th 2023	Palermo, Italy
30	Building simulation 2023 conference	September 4-6, 2023	Shanghai, China
31	CISBAT 2024 Conference and Workshop	September 13-15, 2023	Lausanne, Switzerland
32	ISHVAC Conference 2023	November 14-16, 2023	Beijing, China
33	Wiener Kongress für zukunftsfähiges Bauen	April 16, 2024	Vienna, Austria
34	eSim 2024 conference	June 5-7, 2024	Alberta, Canada
35	Sustainability Research + Innovation Congress 2024 in collaboration with Sustainability Science Days	June 10-14, 2024	Espoo, Finland
36	Joint Workshop IEA SHC Task 66 and IEA EBC Annex 83	October 10, 2023	Graz, Austria

At the Smart and Sustainable Planning for Cities and Regions (SSPCR) Conference 2022 in Bolzano, Annex 83 had a dedicated session planned for one of the days of the conference. The members of Annex 83 organised a workshop in a form of World Café. The results of this workshop were presented in the paper “Positive Energy Districts: Fundamentals, Assessment Methodologies, Modelling and Research Gaps” (Kozlowska et al., 2024).

At the CISBAT 2023 Conference in Lausanne, Annex 83 had a dedicated session planned for one of the days of the conference. 9 papers and posters with PED topic and reference to Annex83 were presented. The members of Annex 83 organised a workshop in a form of World Café for the four Subtasks A, B, C, D.

At the Building Simulation Conference 2023 ((BS2023) in Shanghai, Annex 83 had a dedicated session with PED related paper presentations for one of the days of the conference.

As part of the “Wiener Kongress für zukunftsfähiges Bauen”, Workshop 6: Plus-Energy Districts – From Planning to Implementation was held under the leadership of Shokufeh Zamini (AIT Austrian Institute of Technology GmbH), represented by Gerhard Zucker (AIT) 16 April 2024.
Key Topics Covered:

- Introduction to Plus-Energy Districts (IEA Annex83) – Shokufeh Zamini (AIT), presented by Gerhard Zucker (AIT).
- Klima: aktiv Plus-Energy District Standard – Simon Schneider (FH Technikum): A method for quantitatively proving future decarbonisation and local renewable energy supply requirements.

- PEQ Concepts and Archetypes – Fabian Ochs (UIBK): Analysis of different Plus-Energy Districts' load curves, energy demand, and production.
- Implementation Use Cases – Klara Maggauer (AIT): Economic risk assessment of two financing models for energy communities using Monte Carlo simulations.
- Replication Strategies – Andreas Türk (Joanneum Research, H2020 EXCESS Project): Technical and political conditions for scaling Plus-Energy Districts in Austria and Europe.

4.1.4 Annex 83 Newsletter

The Annex 83 newsletter is distributed monthly, providing updates on PED-related news within the Annex 83 members. Each issue begins with updates on individual subtasks, followed by information on upcoming group meetings and conferences involving Annex 83 participants. It also highlights new Annex 83 publications and concludes with a reminder of the open special issues on PEDs listed on the Annex 83 webpage. The newsletter is distributed to nearly 300 contacts. Besides the email form of newsletter, its content is also published directly on the Annex 83 website: https://annex83.iea-ebc.org/news .

4.1.5 Annex 83 Publications

All the publications that were submitted within Annex 83 are listed in the table below (Table 12). These publications are also listed on the Annex 83 website (https://annex83.iea-ebc.org/publications).

Table 12: Annex 83 publications.

Title	Authors	Year	Type	DOI
Energy and Emission Implications of Electric Vehicles Integration with Nearly and Net Zero Energy Buildings	Hassam ur Rehman; Jan Diriken; Ala Hasan; Stijn Verbeke; Francesco Reda	2021	J	https://doi.org/10.3390/en14216990
A techno-economic analysis of an optimal self-sufficient district	Ari Laitinen, Oscar Lindholm, Ala Hasan, Francesco Reda, Åsa Hedman	2021	J	https://doi.org/10.1016/j.enconman.2021.114041
IEA EBC Annex83 Positive Energy Districts	Åsa Hedman; Hassam Ur Rehman; Andrea Gabaldón; Adriano Bisello; Vicky Albert-Seifried; Xingxing Zhang; Francesco Guarino; Steinar Grynning; Ursula Eicker; Hans-Martin Neumann; Pekka Tuominen; Francesco Reda	2021	J	https:// doi.org/10.3390/buildings11030130
Economic and emission reduction potential of renewable based energy systems in an apartment building in cold climatic conditions	Hassam ur Rehman, Ala Hasan, Francesco Reda	2021	P	https://doi.org/10.26868/25222708.2021.30189
Qualitative Assessment Methodology for Positive Energy District Planning Guidelines	Hans-Martin Neumann; Sergio Díaz Garayo; Niki Gaitani; Daniele Vettorato; Laura Aelenei; Judith Borsboom; Ghazal Etminan; Anna Kozlowska; Francesco Reda; Jørgen Rose; Pekka Tuominen	2021	P	https://doi.org/10.1007/978-981-16-6269-0_42
State of the Art on Sustainability Assessment of Positive Energy Districts: Methodologies, Indicators and Future Perspectives	Francesco Guarino, Adriano Bisello, Dorian Frieden, Joana Bastos, Alberto Brunetti, Maurizio Cellura, Marco Ferraro, Alberto Fichera, Emanuela Giancola, Matthias Haase, Julia Kantorovitch, Camilla Neumann, Rose Mankaa, Ivan Luque Segura, Marzia Traverso, Giovanni Tumminia, Rosaria Volpe & Xiaojin Zhang	2021	P	https://doi.org/10.1007/978-981-16-6269-0_40

Title	Authors	Year	Type	DOI
Sustainable Development Goals and Performance Measurement of Positive Energy District: A Methodological Approach	Maurizio Cellura, Alberto Fichera, Francesco Guarino, Rosaria Volpe	2021	P	https://doi.org/10.1007/978-981-16-6269-0_43
Local Production and Storage in Positive Energy Districts: The Energy Sharing Perspective	Alberto Fichera, Alessandro Pluchino, Rosaria Volpe	2021	J	https://doi.org/10.3389/frsc.2021.690927
Towards energy efficient planning of Danish cities and neighbourhoods	Barbara Kristin Holmsund Jepsen, Tom Walther Haut, Muhyiddine Jradi	2021	P	https://www.proceedings.com/062738-0039.html
Challenges in reaching positive energy building level in apartment buildings in the Nordic climate: A techno-economic analysis.	Hassam ur Rehman; Ala Hasan; Francesco Reda	2022	J	https://doi.org/10.1016/j.enbuild.2022.111991
Optimal design and operation of distributed electrical generation for Italian positive energy districts with biomass district heating	Rosaria Volpe, Maria Gonzalez Alriols, Nesly Martelo Schmalbach, Alberto Fichera	2022	J	https://doi.org/10.1016/j.enconman.2022.115937
Reviewing Challenges and Limitations of Energy Modelling Software in the Assessment of PEDs Using Case Studies	Alberto Belda, Emanuela Giancola, Karen Williams, Sanam Dabirian, Muhyiddine Jradi, Rosaria Volpe, Soroush Samareh Abolhassani, Alberto Fichera, Ursula Eicker	2022	P	https://doi.org/10.1007/978-981-16-6269-0_39
A holistic energy planning tool for Danish cities and districts	Mhyiddine Jradi	2022	P	https://nottingham-repository.worktribe.com/search/all/outputs?criteria=set2022
Economic and emission reduction potential of renewable based energy systems in an apartment building in cold climatic conditions	Hassam ur Rehman, Ala Hasan, Francesco Reda	2022	P	10.26868/25222708.2021.30189
Design, Modelling and Performance Evaluation of a Positive Energy District in a Danish Island	Barbara Kristin Holmsund Jepsen, Tom Walther Haut, Muhyiddine Jradi	2022	J	DOI: 10.5334/fce.146
Lessons Learned from Positive Energy District (PED) Projects: Cataloguing and Analysing Technology Solutions in Different Geographical Areas in Europe	Leone, Federica, Francesco Reda, Ala Hasan, Hassam ur Rehman, Fausto Carmelo Nigrelli, Francesco Nocera, and Vincenzo Costanzo	2022	J	https://doi.org/10.3390/en16010356

Title	Authors	Year	Type	DOI
The Sense and Non-Sense of PEDs—Feeding Back Practical Experiences of Positive Energy District Demonstrators into the European PED Framework Definition Development Process	Vandevyvere, Han, Dirk Ahlers, and Annemie Wyckmans	2022	J	https://doi.org/10.3390/en15124491
Exploring tools and indicators to support collaborative planning, design, implementation, operation, and evaluation of Positive Energy Districts	Maria-Beatrice Andreucci, Marco Delli Paoli, Matthias Haase	2023	J	10.1088/1742-6596/2600/8/082001
Modelling uncertainty in positive energy districts through a non-probabilistic approach	Mohammad Haris Shamsi, Amin Kouti, Yixiao Ma, Lukas Engelen, Mohsen Sharifi	2023	J	10.1088/1742-6596/2600/8/082007
Optimizing positive energy districts	Matthias Haase	2023	J	10.1088/1742-6596/2600/8/082012
Assessing pathways to carbon neutrality in a neighbourhood study in Germany	Miaomiao He, Isabell Nemeth, Astrid von Blumenthal, Thomas Haupt, Jochen Stopper, Johannes Jungwirth	2023	J	10.1088/1742-6596/2600/8/082010
Economic and environmental benefits of decentralized multi-energy systems for energy communities	Xavier Jobard, Massimiliano Capezzalli, Neha Dimri, Alexis Duret, Marten Fesefeldt, Mija Frossard, Vincent Jacquot, Sebastien Lasvaux	2023	J	10.1088/1742-6596/2600/8/082011
The more the better? Archetype segmentation in urban building energy modelling	Zoe Le Hong, Zachary Berzolla, Christoph Reinhart	2023	J	10.1088/1742-6596/2600/8/082004
Towards the implementation of Positive Energy Districts in industrial districts: an Italian case study	Elisa Marrasso, Chiara Martone, Giovanna Pallotta, Carlo Roselli, Maurizio Sasso	2023	J	10.1088/1742-6596/2600/8/082039
Towards positive energy islands - a Danish case study	Muhyiddine Jradi	2023	J	10.1088/1742-6596/2600/8/082017
A database for positive energy districts (PED)	Beril Alpagut, Silvia Bossi, Paolo Civiero, Sergio Diaz de Garayo, Christoph Gollner, Matthias Haase, Michal Kuzmic, Nuria Sanchez, Oscar Secco, Silvia Soutullo Castro, Giulia Turci, Shokufeh Zamini	2023	J	10.1088/1742-6596/2600/8/082018
Development of an early design tool for the sustainability assessment of positive energy districts: methodology, implementation and case-studies	Alberto Brunetti, Salvatore Cellura, Francesco Guarino, Sonia Longo, Marina Mistretta, Francesco Reda, Roberta Rincione	2023	J	10.1088/1742-6596/2600/8/082020

Title	Authors	Year	Type	DOI
Review of natural language processing techniques for characterizing positive energy districts	Mengjie Han, Juveria Shah, Xingxing Zhang	2023	J	10.1088/1742-6596/2600/8/082024
“oPEN Lab” project as an underpin innovation for Positive Energy District solutions in Pamplona	Alicia Kalms, Iñaki Cornago Santos, Mikel EzquerMayo, Sergio Diaz de Garayo Balsategui, Alba Juncal Arias Royo, Luis Torres Cardona, Daniel San Emeterio Carciandia, M. Olatz Irulegui Garmendia, Faisal Bouchotrouch, Maarten De Groote	2023	J	10.1088/1742-6596/2600/8/082029
Energy Flexibility and towards Resilience in New and Old Residential Houses in Cold Climates: A Techno-Economic Analysis	Hassam ur Rehman, Ala Hasan	2023	J	https://doi.org/10.3390/en16145506
A Comprehensive Technical Analysis of Retrofitting a Danish Residential Area into a Positive Energy District, Future Cities and Environment.	Muhyiddine Jradi, Emil Wang Nielsen, Mads Lund	2023	J	DOI: 10.5334/fce.200
Supporting Cities towards Carbon Neutral Transition through Territorial Acupuncture	Leone, Federica, Ala Hasan, Francesco Reda, Hassam ur Rehman, Fausto Carmelo Nigrelli, Francesco Nocera, and Vincenzo Costanzo	2023	J	https://doi.org/10.3390/su15054046
Energy flexibility and resiliency analysis of old and new single family buildings in Nordic climate	Hassam ur Rehman, Ala Hasan	2024	P	10.26868/25222708.2023.1171
A novel methodology and a tool for supporting the transition of districts and communities in Positive Energy Districts	Elisa Marrasso, Chiara Martone, Giovanna Pallotta, Carlo Roselli, Maurizio Sasso	2024	J	https://doi.org/10.1016/j.enbuild.2024.114435
Towards Extensive Definition and Planning of Energy Resilience in Buildings in Cold Climate	Hassam ur Rehman, Mohamed Hamdy, Ala Hasan	2024	J	https://doi.org/10.3390/buildings14051453
Quantifying and Rating the Energy Resilience Performance of Buildings Integrated with Renewables in the Nordics under Typical and Extreme Climatic Conditions	Hassam ur Rehman,Vahid M. Nik, Rakesh, Ramesh, Mia Ala-Juusela	2024	J	https://doi.org/10.3390/buildings14092821
Lessons learned from analysing PED case studies	Matthias Haase, Ursula Eicker, Caroline Hachem-Vermette; Genku Kayo, Hassam ur Rehman	2024	P	10.2760/716916

Title	Authors	Year	Type	DOI
Co-ordinations of ocean energy supported energy sharing between zero-emission cross-harbour buildings in the Greater Bay Area	Shijie Zhou, Sunliang Cao	2024	J	https://doi.org/10.1016/j.apen-ergy.2024.122718
Development of integrated energy sharing systems between neighboring zero-energy buildings via mi-cro-grid and local electric vehicles with energy trad-ing business models	Suijie Liu, Sunliang Cao	2024	J	https://doi.org/10.1016/j.apen-ergy.2024.124952
Positive Energy Districts: Fundamentals, Assess-ment Methodologies, Modelling and Research Gaps	Kozlowska, Anna, Francesco Guarino, Rosaria Volpe, Adriano Bisello, Andrea Gabaldòn, Abolfazl Rezaei, Vicky Albert-Seifried, Beril Alpagut, Han Vandevyvere, Fran-cesco Reda, and et al.	2024	J	https://doi.org/10.3390/en17174425
Design and Operational Indicators to Foster the Transition of Existing Renewable Energy Communi-ties towards Positive Energy Districts	Rosaria Volpe, Emanuele Cutore, Alberto Fichera	2024	J	https://doi.org/10.13044/j.sdewes.d12.0513
Exploring Multiple Benefits of Urban and Energy Re-generation Projects: A Stakeholder-Centred Meth-odological Approach	Irene Bertolami, Adriano Bisello, Marco Volpatti, Marta Carla Bottero	2024	J	https://doi.org/10.3390/en17122862
Toward a certification protocol for Positive Energy Districts (PED). A methodological proposal	Marco Volpatti, Elena Mazzola, Adriano Bisello, Marta Carla Bottero	2024	J	https://doi.org/10.6093/1970-9870/10301
The Role of Positive Energy Districts through the Lens of Urban Sustainability Protocols in the Case Studies of Salzburg and Tampere	Marco Volpatti, Elena Mazzola, Adriano Bisello, Marta Carla Bottero	2024	J	https://doi.org/10.3390/buildings14010007
Ten questions on tools and methods for positive en-ergy districts	Jonathan Natanian, Francesco Guarino, Naga Manapra-gada, Abel Magyari, Emanuele Naboni, Francesco De Luca, Salvatore Cellura, Alberto Brunetti, Andras Reith	2024	J	https://doi.org/10.1016/j.buildenv.2024.111429
Validation of an early design tool for Positive Energy Districts: the case study of Bucharest	Giuseppina Ciulla, Alberto Brunetti, Maurizio Cellura, So-nia Longo, Francesco Guarino, Elahe Moazzen, Ana Dra-gomir, Codrut Papina, Emilio Sessa	2024	P	

Title	Authors	Year	Type	DOI
Investigating the energy resilience performance of the old and new buildings integrated with solar photovoltaic and storage under extreme Nordic conditions	Hassam ur Rehman, Vahid M. Nik, Rakesh Ramesh, Ala Hasan	2024	P	https://publications.ibpsa.org/conference/paper/?id=esim2024_5
Uno strumento per il supporto alla progettazione preliminare eco-orientata di "Positive Energy Districts"	Alberto Brunetti., Maurizio Cellura, Giuseppina Ciulla, Francesco Guarino, Sonia Longo	2024	P	
Leveraging Positive Energy Districts Surplus for the Achievement of the Sustainable Development Goals	Cellura, Maurizio, Alberto Fichera, Francesco Guarino, and Rosaria Volpe	2025	J	https://doi.org/10.3390/en18030506
Linking environmental impact assessment and Positive Energy Districts: A literature review	Rosaria Volpe, Adriano Bisello, Andreas Tuerk, Francesco Guarino, Emanuela Giancola, Maria Nuria Sanchez, Giovanni Tumminia, Elisa Marrasso, Giovanna Pallotta, Emanuele Cutore, Maurizio Cellura, Alberto Fichera, Sonia Longo, Carlo Roselli, Maurizio Sasso, Xiaojin Zhang, Ilaria Marotta, Alberto Brunetti, Roberta Rincione, Francesco Reda	2025	J	https://doi.org/10.1016/j.cesys.2025.100264
Towards positive energy district assessment: The case study of Bucharest	Emilio Sessa, Alberto Bruneti, Ciulla Giuseppina, Francesco Guarino, Sonia Longo, Maurizio Cellura, Ana-Maria Dragomir, Codruț Papina	2025	P	https://doi.org/10.1016/j.energy.2025.136208
A simplified tool for early-stage planning of positive energy districts	Alberto Brunetti, Francesco Guarino, Giuseppina Ciulla, Maurizio Cellura, Sergio Diaz de Garayo, Sonia Longo	2025	P	https://doi.org/10.1016/j.egyr.2025.04.059

4.2 Collaboration with other networks, projects and IEA Tasks

The project collaborated with the following projects in terms of funding some of the Annex83 research activities, summer schools, publications and discussion with the stakeholders. The data was also used from these projects for various deliverables and publications. These activities are listed in the Table 13.

Table 13: List of collaborations.

No.	Name of the Project	Date	Location	Form of Collaboration	Organisation
1	ATELIER Smart Cities & Communities	2019 - 2024	Netherlands	Synergies in ST A-D	City of Amsterdam
2	COST Action 19126	2020	Germany	Synergies in ST A-D	Fraunhofer
3	COST Action 19126 WG1	2020	Czech	Synergies in ST A & C (definitions, KPIs)	CVUT
4	COST Action 19126 WG1	2020	Turkey	Synergies in ST D (database)	Demir Energy
5	syn.ikia H2020	2020	Norway	Synergies in ST A-D	NTNU, SINTEF
6	EXCESS H2020	2020	Austria	Synergies in ST A-D	Joanneum Research
7	cultural-e H2020	2020		Synergies in ST A-D	
8	CityxChange Smart Cities & Communities	2020	Norway	Synergies in ST A-D	NTNU, Trondheim Municipality
9	MAKING-CITY Smart Cities & Communities	2020	Spain	Synergies in ST A-D	CARTIF Technology Centre
10	SPARCs Smart Cities & Communities	2020	Finland	Synergies in ST A-D	VTT
11	POCITYF Smart Cities & Communities	2020	Portugal	Synergies in ST A-D	LABELEC - ESTUDOS, DESENVOLVIMENTO E ACTIVIDADES LABORATORIALS SA
12	Norwegian Research Centre on Zero Emission Neighbourhoods in Smart Cities	2020	Norway	Synergies in ST A-D	NTNU, SINTEF
13	NTRANS - Norwegian Centre for Energy Transition Strategies	2020	Norway	Synergies in ST A	NTNU
14	ZERO-PLUS H2020	2020	Greece and Australia	Synergies in ST A-D	NKUA

15	Schoonschip floating neighbourhood project in Amsterdam	2020	Norway	Synergies in ST A-D	NTNU
16	STARDUST Smart Cities & Communities	2020 - 2024	Spain	Synergies in ST A-D	CENER
17	oPEN Lab H2020	2021 - 2026	Belgium	Synergies in ST A-D	VITO
18	ARV	2022 - 2025	Norway, Italy	Synergies in STA, C and D	NTNU, SINTEF, EURAC
19	RESPONSE Smart Cities and Communities	2022 - 2025	Finland		VTT
20	KINETIC	2022 - 2025	Italy	Synergies with STA, C and D	UNIPA, EURAC

FleXible user-CEntric Energy poSitive houseS (**EXCESS**), H2020 project 2019-2024, Decision number: 870157 (https://positive-energy-buildings.eu/)

Energy Resilience in Buildings in Extreme Cold Weather Conditions in Finland (**FinERB**), Research Council of Finland project 2022-2025, Decision number: 348060 (https://cris.vtt.fi/en/projects/energy-resilience-in-buildings-in-extreme-cold-weather-conditions).

Integration of building flexibility into future energy systems (**FlexiB**), Research Council of Finland project 2020-2024, Decision number: 333364 (https://cris.vtt.fi/en/projects/integration-of-building-flexibility-into-future-energy-systems).

Sustainable energy Positive & zero cARbon CommunitieS (**SPARCS**) H2020 project 2019-2024, Decision number: 864242 (https://sparcs.info/en/).

On 2. Feb. 2023 a **stakeholder workshop on PEDS**, POSITIVE ENERGY DISTRICTS essential components for “Net Zero” Cities took place with Austrian stakeholders. Attendees from industry and research discussed about this topic. After an overview about Annex83 by Shokufeh Zamini (AIT, Austria, STD), Christoph Gollner (FFG, Austria), Ali Hainun (AIT, Austria), Carsten Wemhöner (OST, Switzerland), Fabian Ochs und Georgios Dermentzis (UIBK, Austria, STD), Andreas Türk (Joanneum Research, Austria, STC), presented PEDs from different points of view. The presentations are published in https://drc.ait.ac.at/sites/annex83austria/activities/#:~:text=EventID%3D8343.-,Stakeholders%2DWorkshop,-Wir%20organisieren%20einen

A **joint workshop with IEA SHC Task 66** took place on 10 October 2023 in Graz, Austria. The workshop focused on the SYSPEQ project, the Austrian certification of climate-neutral positive energy neighbourhoods, the Campagne demonstration project and the cost-optimal analysis of EXCESS. Furthermore, topics such as solar power communities, cold neighbourhoods in Austria and buildings without CO_2 emissions in China was discussed. Further details are available at https://annex83.iea-ebc.org/event?EventID=8583 , as well as https://drc.ait.ac.at/sites/annex83austria/activities/ and https://task66.iea-shc.org/.

4.3 Website and Presence in Social Media

4.3.1 Website

Annex 83 has its own website (https://annex83.iea-ebc.org/). There are separate sections: News, Meetings, Publications, Special Issues, Videos and About page. The About page describes the structure and goals of

Annex 83, the members of the Annex 83, as well as it presents in more details the activities of all Annex 83 subtasks (STA, STB, STC, STD). The News page is updated every month with information about the current activities that took place within each of the Subtasks. All of the publications that acknowledged Annex 83 are listed in the Publication section. Special Issues are also listed, in Special Issues section.

For collecting the statistics about the Annex 83 website, Google Analytics was set up. As there was a switch between the systems, we only have access to the analytics from October 2022, and the current reporting is focusing on the entire period from the start (i.e. Oct 2022) till the time of finalising this report (Mar 2025). The analytics focuses mostly on users activity, new users, and the locations from where the users log in while using the website. The Google Analytics interface allows to examine the user activity over time, checking the specific period and checking in details any date one wishes. Below are presented graphs which show the use of the Annex 83 website over the period October 2022 – March 2025.

Entire period (October 2022 – March 2025)

For the entire available period, from October 2022 till March 2025, it is reported that there were in total approximately 4.8 thousand active users visiting Annex 83 website. The activity distribution over the entire period is shown in Figure 11 and Figure 12. Whilst first presents the raw data, with visible peaks for certain dates, the second is an aggregated data showing the users activity in certain days (past 30 days, past 7 days, and a day). The closer look at the possible patterns and explanation of the peaks in user activities is described in the next section. We also looked at the spatial distribution of the active users (Figure 12). The map shows from where the users are logging in while using the Annex 83 website. The darker shade of blue the higher number of active users logging in from that country. Colour grey shows no active users for that location. The countries from where the most active users logged in are listed next to the map. The top countries are: Italy, US, Austria, the Netherlands, Finland, Spain, and Sweden.

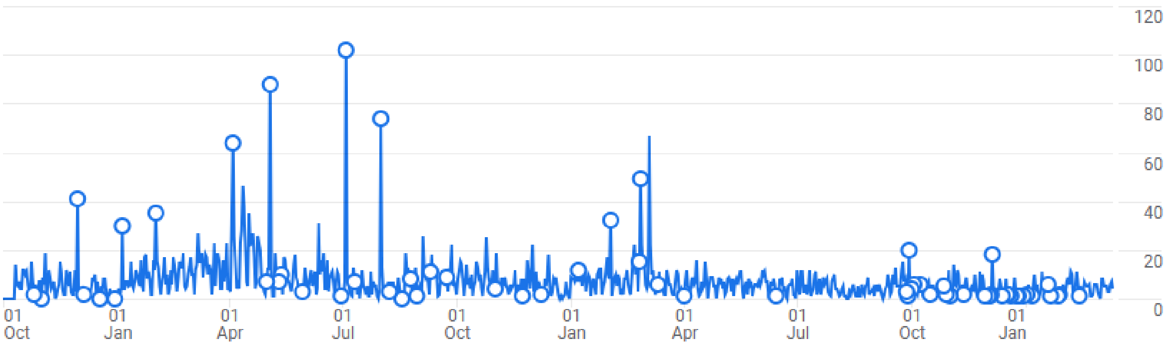


Figure 11: Website: active users. Period: 10/2022-03/2025

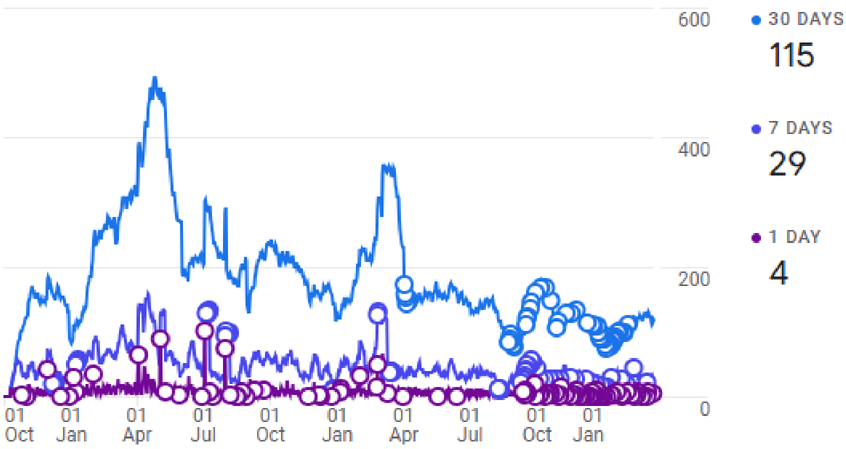
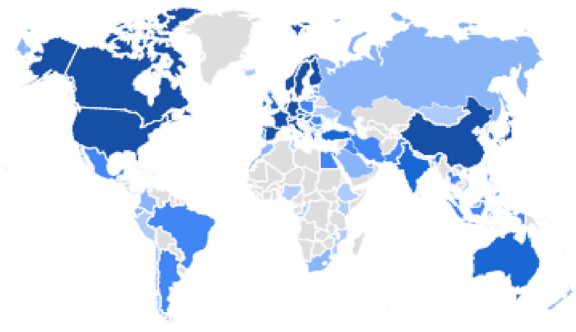


Figure 12: Website: user activity over time. Period: 10/2022-03/2025



COUNTRY	ACTIVE USERS
Italy	557
United States	404
Austria	369
Netherlands	346
Finland	316
Spain	314
Sweden	260

Figure 13: Website: active users per country. Period: 10/2022-03/2025.

Separate periods

A more detailed analysis of user activities is presented in the following section, with the figures (Figure 14, Figure 15, Figure 16 and Figure 17) illustrating the activity per year. The initial period from the available data (10/2022-12/2022) documented approximately 370 active users during this time. The second period (01/2023-12/2023) saw an approximate increase to 2500 active users over the course of the year, and the third period (01/2024-12/2024) registered 1600 active users over the same period. The final period analysed (01/2025-03/2025) recorded approximately 250 active users.

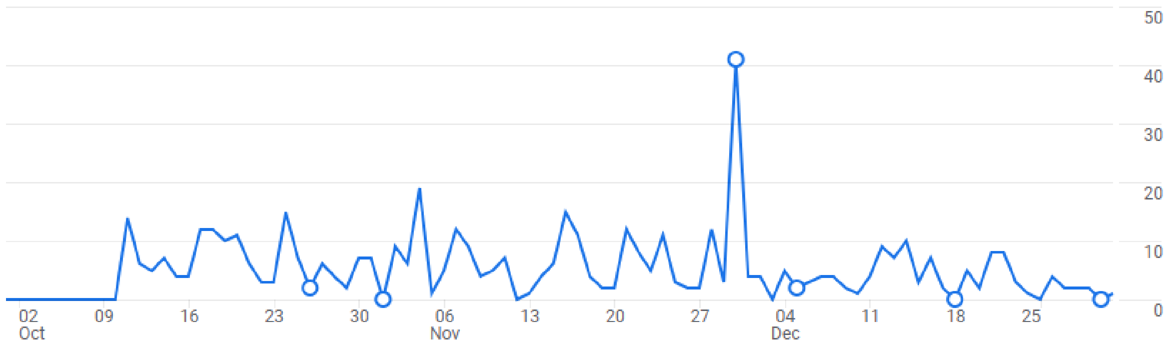


Figure 14: Website: active users. Period: 10/2022-12/2022

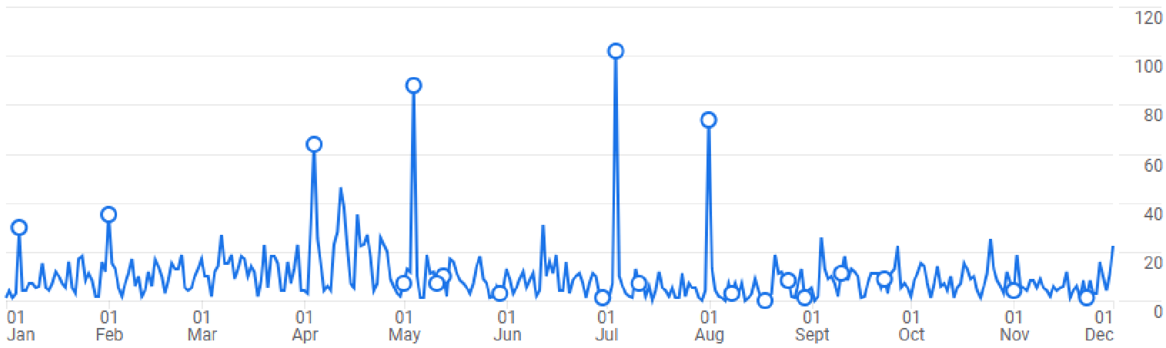


Figure 15: Website: active users. Period: 01/2023-12/2023

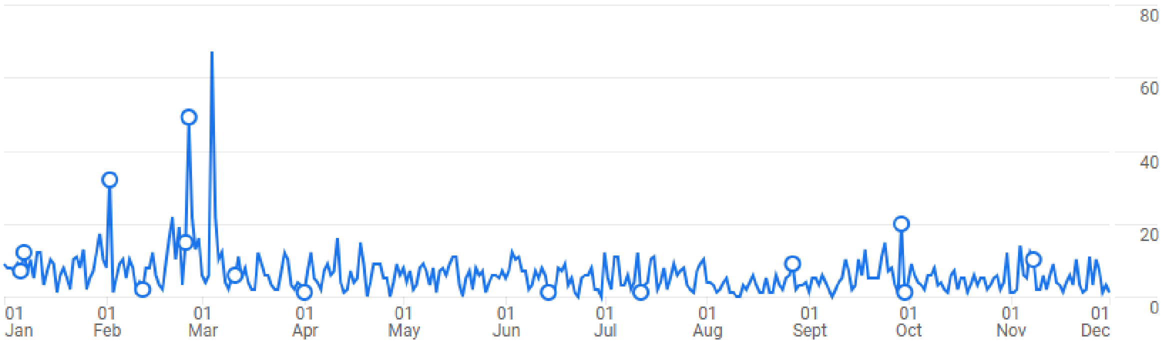


Figure 16: Website: active users. Period: 01/2024-12/2024

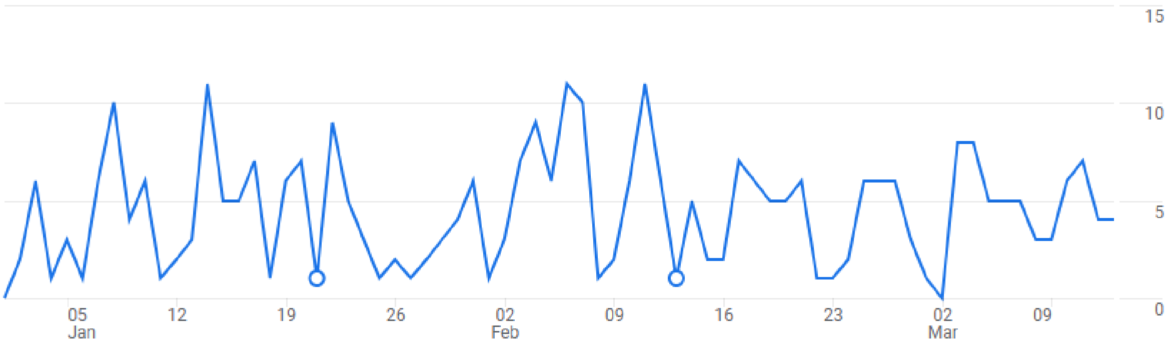


Figure 17: Website: active users. Period: 01/2025-03/2025

4.3.2 Presence on Social Media

LinkedIn

Annex 83 has a LinkedIn page from the start: https://www.linkedin.com/company/iea-ebc-annex-83-ped/. The page has currently 560 followers. On that profile we share our activities, inform about upcoming events and new publications, report on the project meetings and share call for abstracts or other topics and activities related to Annex 83. The engagement on LinkedIn is the strongest around the Annex 83 project meetings and the conferences that Annex 83 members are participating to.

Twitter / X

At the beginning, next to LinkedIn and website, we had also a Twitter / X account for Annex 83. However, after some time, we came to a conclusion that this is not the right platform for us to report on our activities. It was found out that our activities reaching out many more users on LinkedIn platform in comparison to Twitter platform. Therefore, we focused on establishing the Annex 83 profile solely on LinkedIn.

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Annex I

Table 1. Comparative/alignment table: PED Booklet vs PED DB (in grey the direct correspondences among Booklet and DB) [Source: CA ‘PED-EU-NET’]

PED Booklet [23]			**PED DB** [12]		
section*	**n.**	**parameters**	**Section****	**n.**	**parameters**
GI	001	City	A1	P011	Geographic coordinates
			A1	P012	Country
			A1	P013	City
			A1	P014	Climate Zone - Köppen Geiger classification
			A1	P015	District boundary
GI	002	Project name	A1	P001	Name of the PED case study / PED Lab
			A1	P002	Map, aerial view, photos, graphic details, leaflet
			A1	P003	Categorisation of the PED site
GI	003	Project status	A1	P005	Phase of the PED case study / PED Lab
GI	004	Project start – end	A1	P006	Start Date
			A1	P007	End Date
GI	005	Contact	A1	P026	Contact person for general enquiries - name
			A1	P027	Contact person for general enquir-ies - organisation
			A1	P028	Contact person for general enquir-ies – affiliation
			A1	P029	Contact person for general enquir-ies - e-mail

	A1	P030	Contact person for other special topics - name			
	A1	P031	Contact person for other special topics - e-mail			
GI		006	Project website	A1	P008	Reference Project
	D1	P001	Name of the project			
	D1	P002	Project assigned code			
	D1	P003	Start date			
	D1	P004	Operator of the installation			
	D1	P005	Ongoing project			
	D1	P006	Funding programme/financing model			
	D1	P007	Estimated project costs			
	D1	P008	Description of project objec-tives/concepts			
	D1	P009	Description of project upscaling strategies			
	D1	P010	Number of PED case studies in the project			
	D1	P011	Case Study			
	D1	P012	Description of project expected im-pact			
	D1	P013	Standardisation efforts			
	D1	P014	Project Sources			
	D1	P015	Contact person regarding the PED project			
	A1	P009	Data availability			
	A1	P010	Case study/lab sources			
GI		007	Size of project area	A1	P018	Number of buildings in PED
	A1	P019	Conditioned space			
	A1	P020	Total ground area			
	A1	P021	Floor area ratio: conditioned space/total ground area			

	B1	P007	District population before intervention - Residential				
	B1	P008	District population after intervention - Residential				
	B1	P009	District population before intervention - Non-residential				
	B1	P010	District population after intervention - Non-residential				
	B1	P011	Population density before intervention				
	B1	P012	Population density after intervention				
GI			008	Building structure	B1	P003	Environment of the case study area
	B1	P004	Type of district				
	B1	P005	Case Study Context				
	B1	P006	Year of construction				
GI			009	Land use (%)	A1	P016	Ownership of the case study/PED Lab
	A1	P017	Ownership of the land / physical infrastructure				
	B1	P013	Building and Land Use before intervention				
	B1	P014	Building and Land Use after intervention				
GI			010	Financing	A1	P022	Financial schemes
	A1	P023	Economic Targets				
	A1	P024	More comment				
	A1	P025	Estimated PED case study / PED LAB costs				
OV			011	Overview description of the project	B1	P001	PED/PED relevant concept definition

	B1	P002	Motivation behind PED project development			
ST		012	Goals/ambition	A1	P004	Targets of the PED case study / PED Lab
ST		013	Indicators	A2	P022	KPIs related to the PED case study / PED Lab
ST		014	Overall strategies of municipality connected with the project	A3	P001	Relevant city /national strategy
	A3	P002	Quantitative targets in the city/national strategy			
	A3	P003	Strategies towards decarbonisation of the gas grid			
	A3	P004	Identification of needs and priorities			
ST		015	Which factors have been included in implementation strategies?	A2	P005	Mobility included in the energy balance
	A2	P006	Description of how mobility is included (or not)			
	A2	P026	Technological Solutions / Innovations - Mobility			
	A2	P027	Mobility strategies - Additional notes			
	A3	P005	Sustainable behaviour			
	A3	P006	Economic strategies			
	A3	P008	Integrated urban strategies			
	A3	P009	Environmental strategies			
	A3	P010	Legal / Regulatory aspects			
ST		016	Innovative stakeholder involvement strategies	A3	P007	Social models
	B2	P001	Scale of action of the PED Lab			

	B2	P001	Motivation for developing the PED Lab				
	B2	P001	Lead partner that manages the PED Lab				
	B2	P001	Collaborative partners that participate in the PED Lab				
	B2	P001	Incubation capacities of the PED Lab				
	B2	P001	Available facilities to test configurations in PED Lab				
	B2	P001	Synergies between facilities in the PED Lab				
	B2	P001	Available tools				
	B2	P001	Monitoring capabilities				
	B2	P001	Any accredited laboratory services?				
	B2	P001	Replication and scalability framework in the PED Lab				
	B2	P001	Stakeholders accessing the facilities				
	B2	P001	Stakeholders' accessibility framework to facilities				
ST		017	Typology of energy supply		A2	P001	Fields of application
	A2	P002	Tools/strategies/methods applied				
	A2	P003	Application of ISO52000				
	A2	P004	Appliances included in the energy balance				
	A2	P007	Annual energy demand in buildings / Thermal				
	A2	P008	Annual energy demand in buildings / Electric				
	A2	P009	Annual energy demand for e-mobility				

	A2	P010	Annual energy demand for infrastructure				
	A2	P011	Annual renewable electricity production on-site/year				
	A2	P012	Annual renewable thermal production on-site/year				
	A2	P013	Renewable resources on-site - Additional notes				
	A2	P014	Annual energy use				
	A2	P015	Annual energy delivered				
	A2	P016	Annual non-renewable electricity production on-site/year				
	A2	P017	Annual non-renewable thermal production on-site/year				
	A2	P018	Annual renewable electricity imports from outside/year				
	A2	P019	Annual renewable thermal imports from outside/year				
	A2	P020	Share of RES on-site / RES outside the boundary				
	A2	P021	GHG-balance calculated for the PED				
	A2	P023	Technological Solutions - Energy Generation				
	A2	P024	Technological Solutions - Energy Flexibility				
	A2	P025	Technological Solutions - Energy Efficiency				
	A2	P028	Energy efficiency certificates				
	A2	P029	Any other building / district certificates				
SCB		018	Success factors	C1	P001	Unlocking Factors	
	C1	P002	Driving Factors				

SCB	019	Challenges/Barriers	C1	P003	Administrative barriers
			C1	P004	Policy barriers
			C1	P005	Legal and Regulatory barriers
			C1	P006	Technical barriers
			C1	P007	Environmental barriers
			C1	P008	Social and Cultural barriers
			C1	P009	Information and Awareness barriers
			C1	P010	Financial barriers
			C1	P011	Market barriers
			C1	P012	Stakeholders involved

* PED Booklet: Global Information (GI), Overview (OV). Strategies (ST) and Success factors, challenges and barriers (SCB).

** PED Database: Global Characteristics (A1), Technological aspects (A2), Non-Technological aspects (A3), Case studies in detail (B1), PED LABs in detail (B2), Drivers and Barriers (C1), General Projects/Initiatives (D1).

Annex II

Table 1. Section A1 ‘Global characteristics’ [Source: CA ‘PED-EU-NET’]

ID	Parameter title	Type of answer				Answers	Target			
		O	**Cs**	**Cm**	**A**		**Pu**	**Pr**	**Re**	**Ct**
A1 P001	Name of the PED case study / PED Lab (*)	•				[txt]	•	•	•	•
A1 P002	Map/aerial view/photos /graphic details/leaflet (*)	•				[img]	•	•	•	•
A1 P003	Categorisation of the PED site (*)			•		•PED case study; •PED relevant case study; •PED Lab.	•	•	•	•
A1 P004	Targets of the PED case study / PED Lab (*)			•		•Air quality and urban comfort; •Circularity; •Climate neutrality; •Electrification; •Energy Community; •Net-zero emission; •Net zero energy cost; •Annual energy surplus; •Self-sufficiency (energy autonomous); •Maximise self-sufficiency.	•	•	•	•
A1 P005	Phase of the PED case study / PED Lab (*)		•			•Planning stage; •Implementation stage; •Completed; •In operation.	•	•	•	•
A1 P006	Start Date	•				[nr]	•	•		
A1 P007	End Date	•				[nr]	•	•		
A1 P008	Reference Project	•				[txt]	•	•	•	
A1 P009	Data availability			•		•Monitoring data available within the districts; •Open data city platform; •Meteorological open data; •General statistical dataset; •GIS open datasets; •Vehicle registration datasets.	•		•	
A1 P010	Sources	•				[txt]	•	•	•	
A1 P011	Geographic coordinates (*)	•				[nr]	•	•	•	•
A1 P012	Country (*)	•				[txt]	•	•	•	•
A1 P013	City (*)	•				[txt]	•	•	•	•
A1 P014	Climate Zone - Köppen Geiger classification (*)		•			•Af; •Am; •As; •Aw; •BSh; •BSk; •BWh; •BWk; •Cfa; •Csa; •Csb; •Csc; •Cwa; •Cwb; •Cwc; •Dfa; •Dfb; •Dfc; •Dfd; •Dsa; •Dsb; •Dsc; •Dwa; •Dwb; •Dwc; •Dwd; •EF; •ET	•	•	•	•

A1 P015	District boundary		•		•Functional; •Geographic; •Off-Grid; •Virtual; •Other - specify	•		•	
A1 P016	Ownership of the case study/PED Lab (*)		•		•Private; • Public; •Mixed	•	•	•	•
A1 P017	Ownership of the land / physical infrastructure (*)		•		•Single Owners; •Multiple Owners	•	•	•	•
A1 P018	Number of buildings in PED	•			[nr]	•	•		
A1 P019	Conditioned space	•			[nr]	•	•		
A1 P020	Total ground area	•			[nr]	•	•		
A1 P021	Floor area ratio: conditioned space / total ground area	•			[nr]	•		•	
A1 P022	Financial schemes (*)			•	•Private, Real estate; •Private, ESCO scheme; •Private, Other, please specify; •Public, EU structural funding; •Public, National funding; •Public, Regional funding; •Public, Municipal funding; •Public, Other, please specify; •Research funding, EU; •Research funding, National; •Research funding, Local/regional; •Research funding, Other, please specify. - Add the value in €, if available	•	•	•	•
A1 P023	Economic Targets			•	•Job creation; Positive externalities; •Boosting local businesses; •Boosting Local and sustainable production; •Boosting consumption of local and sustainable products; •Other, please specify.	•	•		
A1 P024	More comment	•			[txt]	•	•	•	•
A1 P025	Estimated PED case study / PED LAB costs	•			[nr]	•	•	•	•
A1 P026	Contact person for general enquiries – name (*)	•			[txt]	•	•	•	•
A1 P027	Contact person for general enquiries – organisation (*)	•			[txt]	•	•	•	•
A1 P028	Contact person for general enquiries – affiliation (*)		•		•Research Center/University; •Municipality/Public Bodies; •SME/Industry; •Other, please specify	•	•	•	•
A1 P029	Contact person for general enquiries - e-mail (*)	•			[txt]	•	•	•	•
A1 P030	Contact person for other special topics - name	•			[txt]	•	•	•	•
A1 P031	Contact person for other special topics - e-mail	•			[txt]	•	•	•	•

Annex III

Table 1. Section A2 ‘Technological aspects’ [Source: CA ‘PED-EU-NET’]

ID	Parameter title	Type of answer				Answers	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
A2 P001	Fields of application			•		•Energy efficiency; •Energy flexibility; •Energy production; •E-mobility; •Urban management; •Urban comfort and air quality; •Digital technologies; •Water use; •Waste management; •Air quality; •Construction materials; •Other, please specify	•		•	
A2 P002	Tools/strategies/methods applied	•				[txt]	•		•	
A2 P003	Application of ISO52000		•			•Yes; •No	•		•	
A2 P004	Appliances included in the calculation of the energy balance		•			•Yes; •No	•	•	•	
A2 P005	Mobility included in the calculation of the energy balance		•			•Yes; •No	•		•	
A2 P006	Description of how mobility is included (or not included) in the calculation	•				[txt]	•		•	
A2 P007	Annual energy demand in buildings / Thermal demand	•				[nr]		•	•	
A2 P008	Annual energy demand in buildings / Electric demand	•				[nr]		•	•	
A2 P009	Annual energy demand for e-mobility	•				[nr]		•	•	
A2 P010	Annual energy demand for infrastructure	•				[nr]		•	•	
A2 P011	Annual renewable electricity production on-site during target year			•		•PV; •Wind; •Hydro; •Biomass_el; •Biomass_peat_el; •PVT_el; •Other, please specify. - Add the value in GWh/y, if available-	•	•	•	
A2 P012	Annual renewable thermal production on-site during target year			•		•Geothermal; •Solar Thermal; •Biomass_heat; •Waste heat+HP; •Biomass_peat_heat; •PVT_th, •Biomass_firewood_th, •Other,	•	•	•	

					please specify. - Add the value in GWh/y, if available				
A2 P013	Renewable resources on-site - Additional notes	•			[txt]	•	•	•	
A2 P014	Annual energy use	•			[nr]		•	•	
A2 P015	Annual energy delivered	•			[nr]		•	•	
A2 P016	Annual non-renewable electricity production on-site during target year	•			[nr]		•	•	
A2 P017	Annual non-renewable thermal production on-site during target year		•		•Gas; •Coal; •Oil; •Other, please specify - Add the value in GWh/y, if available -		•	•	
A2 P018	Annual renewable electricity imports from outside the boundary during target year		•		•PV; •Wind; •Hydro; •Biomass_el; •Biomass_peat_el; •PVT_el; •Other, please specify. - Add the value in GWh/y, if available -		•	•	
A2 P019	Annual renewable thermal imports from outside the boundary during target year		•		•Geothermal; •Solar Thermal; •Biomass_heat; •Waste heat+HP; •Biomass_peat_heat; •PVT_th; •Biomass_firewood_th; •Other, please specify.- Add the value in GWh/y, if available		•	•	
A2 P020	Share of RES on-site / RES outside the boundary			•	[nr]		•	•	
A2 P021	GHG-balance calculated for the PED	•			[nr]	•		•	
A2 P022	KPIs related to the PED case study / PED Lab		•		•Safety & Security; •Health; •Education; •Mobility; •Energy; •Water; •Waste; •Economic development; •Housing and Community - Specify the associated KPIs	•		•	
A2 P023	Technological Solutions / Innovations - Energy Generation		•		•Photovoltaics; •Wind turbines; •Solar thermal collectors; •Geothermal energy system; •Waste heat recovery; •Waste to energy; •Polygeneration; •Co-generation; •Heat Pump; •Hydrogen; •Hydropower plant; •Biomass; •Biogas; •Other, please specify	•	•	•	•
A2 P024	Technological Solutions / Innovations - Energy Flexibility		•		•Information and Communication; •Technologies (ICT); •Energy management system; •Demand-side management; •Smart electricity grid; •Thermal Storage; •Electric Storage; •District Heating and Cooling; •Smart metering	•	•	•	•

					and demand-responsive control systems; •P2P – buildings; •Other, please specify				
A2 P025	Technological Solutions / Innovations - Energy Efficiency			•	•Deep Retrofitting; •Energy efficiency measures in historic buildings; •High-performance new buildings; •Smart Public infrastructure (e.g., smart lighting); •Urban data platforms; •Mobile applications for citizens; •Building services (HVAC & Lighting); •Smart irrigation; •Digital tracking for waste disposal; •Smart surveillance; •Other, please specify	•	•	•	•
A2 P026	Technological Solutions / Innovations - Mobility			•	•Efficiency of vehicles (public and/or private); •Measures to reduce traffic; •e-Mobility; •Soft mobility infrastructures and last mile solutions; •Car-free area; •Other, please specify	•	•	•	•
A2 P027	Mobility strategies - Additional notes	•			[txt]	•			•
A2 P028	Energy efficiency certificates		•		•Yes; •No	•	•		
A2 P029	Any other building / district certificates		•		•Yes; •No	•	•		

Annex IV

Table 1. Section A3 ‘Non-Technological aspects’ [Source: CA ‘PED-EU-NET’]

ID	Parameter title	Type of answer				Answers	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
A3 P001	Relevant city/national strategy			•		•Smart cities strategies; •Urban Renewal Strategies; •Energy master planning (SECAP, etc.); •New development strategies; •Promotion of energy communities; •Climate change adaptation plan/strategy; •National / international city networks addressing sustainable urban development and climate neutrality	•			•
A3 P002	Quantitative targets included in the city / national strategy	•				[txt]	•		X	
A3 P003	Strategies towards decarbonisation of the gas grid			•		•Electrification of Heating System based on Heat Pumps; •Electrification of Cooking Methods; •Biogas; •Hydrogen; •Other, please specify	•	•		
A3 P004	Identification of needs and priorities	•				[txt]	•			•
A3 P005	Sustainable behaviour	•				[txt]	•			•
A3 P006	Economic strategies			•		•Open data business models; •Innovative business models; •Life Cycle Cost; •Circular economy models; •Blockchain; •Demand management; •Living Lab; •Local trading; •Existing incentives; •Other, please specify	•	•	•	•
A3 P007	Social models			•		•Strategies towards (local) community-building; •Co-creation / Citizen engagement strategies; •Behavioural Change / End-users engagement; •Citizen Social Research; •Policy Forums; •Social incentives; •Quality of Life; •Strategies towards social mix; •Affordability; •Prevention of energy poverty; •Digital Inclusion; •Citizen/owner; •Involvement in planning and maintenance; •Educational activities and trainings; •Other, please specify	•		•	•
A3 P008	Integrated urban strategies			•		•Strategic urban planning; •Digital twinning and visual 3D models; •District Energy plans; •City Vision 2050; •SECAP	•		•	

				Updates; •Building / district Certification; •Other, please specify				
A3 P009	Environmental strategies		•	•Energy Neutral; •Low Emission Zone; •Net zero carbon footprint; •Carbon-free; •Life Cycle approach; •Pollutants reduction; •Greening strategies; •Sustainable Urban drainage systems (SUDS); •Cool Materials; •Nature Based Solutions (NBS); •Other, please specify	•		•	
A3 P010	Legal / Regulatory aspects	•		[txt]	•	•		•

Annex V

Table 1. Section B1 ‘PED Case studies in detail’ [Source: CA ‘PED-EU-NET’]

ID	Parameter title	Type of answer				Answer options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
B1 P001	PED/PED relevant concept definition	•				[txt]	•		•	•
B1 P002	Motivation behind PED/PED relevant project development	•				[txt]	•			•
B1 P003	Environment of the case study area			•		•Rural; •Rurban; •Suburban area; •Urban area	•	•	•	•
B1 P004	Type of district			•		•New construction; •Renovation	•	•	•	•
B1 P005	Case Study Context		•			•Re-use Transformation Area; •New Development; •Retrofitting Area; •Preservation Area	•	•	•	•
B1 P006	Year of construction	•				[nr]	•	X		
B1 P007	District population before intervention – Residential	•				[nr]	•			
B1 P008	District population after intervention – Residential	•				[nr]	•			
B1 P009	District population before intervention - Non-residential	•				[nr]	•			
B1 P010	District population after intervention - Non-residential	•				[nr]	•			
B1 P011	Population density before intervention				•	[nr]	•			
B1 P012	Population density after intervention				•	[nr]	•			
B1 P013	Building and Land Use before intervention			•		•Residential; •Office; •Industry and utility; •Commercial; •Institutional; •Natural areas; •Recreational; •Dismissed areas; •Other, please specify - Add the value in m^2, if available	•	•	•	•
B1 P014	Building and Land Use after intervention			•		•Residential; •Office; •Industry and Utility; •Commercial; •Institutional; •Natural areas; •Recreational; •Dismissed areas; •Other, please specify - Add the value in m^2, if available	•	•	•	•

Annex VI

Table 1. Section B2 'PED Lab in detail' [Source: CA 'PED-EU-NET']

ID	Parameter title	Type of answer				Answer options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
B2 P001	Scale of action		•			•Building; •City; •District; •Campus; •Virtual; •Semi-virtual	•	•	•	•
B2 P002	Motivation for developing the PED Lab			•		•Strategic; •Private; •Civic; •Grassroots; •Other, please specify	•		•	•
B2 P003	Lead partner that manages the PED Lab		•			•Research centre / University; •Municipality; •Industry / Company; •Other, please specify	•	•	•	
B2 P004	Collaborative partners that participate in the PED Lab			•		•Academia; •Private; •Industrial; •Citizens, •Public, •NGO; •Other, please specify	•	•	•	
B2 P005	Incubation capacities of the PED Lab			•		•Monitoring and evaluation infrastructure; •Pivoting and risk-mitigating measures; •Tools for prototyping and modelling; •Tools, spaces, events for testing and validation; •Other, please specify	•	•	•	•
B2 P006	Available facilities to test urban configurations in PED Lab			•		•Buildings; •Demand-side management; •Prosumers/P2P; •Renewable generation; •Non-renewable generation; •Energy storage; •Energy networks; •Efficiency measures; •Waste management; •Water treatment; •Lighting; •E-mobility; •Green areas; •User interaction/participation; •Information and Communication Technologies (ICT); •Ambient measures; •Social interactions; •Sustainability processes; •Blockchain; •Business models; •Financial models; •Circular economy models; •Other, please specify	•	•	•	•
B2 P007	Synergies between facilities in the PED Lab	•				[txt]		•	•	
B2 P008	Available tools			•		•Energy modelling; •Social models; •Business and financial models; •Sustainable models; •Decision making models; •Fundraising	•	•	•	•

					and accessing resources; •Matching actors; •Other, please specify;				
B2 P009	Monitoring capabilities			•	•Execution plan; •Available data; •Type of measured data; •Equipment; •Restricted access to facilities; •Other, please specify	•	•	•	
B2 P010	Any accredited laboratory services?		•		•Yes; •No	•	•		•
B2 P011	Replication and scalability framework in the PED Lab	•			[txt]	•	•	•	
B2 P012	Stakeholders accessing the facilities			•	•Academy and students; •Industry; •Research; •Associations; • Other, please specify	•	•	•	•
B2 P013	Stakeholders' accessibility framework to facilities			•	•Under contract; •Collaborative project; •Internships allowed; •Other (open text)	•	•	•	•

Annex VII

Table 1. Section C1 ‘Drivers and Barriers’ [Source: CA ‘PED-EU-NET’]

ID	Parameter title	Type of answer				Answer options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
C1 P001	Unlocking Factors			•		•Recent technological improvements for on-site RES production; •Innovative, integrated, prefabricated packages for buildings envelope / Energy efficiency of building stock; •Energy Communities, P2P, Prosumers concepts; •Storage systems and E-mobility market penetration; •Decreasing costs of innovative materials; •Financial mechanisms to reduce costs and maximise benefits; •The ability to predict Multiple Benefits; •The ability to predict the distribution of benefits and impacts; •Citizens improved awareness and engagement on sustainable energy issues (bottom-up); •Social acceptance (top-down); •Improved local and national policy frameworks (i.e., incentives, laws etc.); •Presence of integrated urban strategies and plans; •Multidisciplinary approaches available for systemic integration; •Availability of grants (from EC or other donors) to finance the PED Lab projects; •Availability of RES on site (Local RES); •Ongoing or established collaboration on Public Private Partnership among key stakeholders; •Any other UNLOCKING FACTORS – please specify - rank on the scale (1-5)	•			
C1 P002	Driving Factors			•		•Climate Change mitigation need •Climate Change mitigation need (local RES production and efficiency); •Climate Change adaptation need; •Rapid urbanisation trend and need of urban expansions; •Urban re-development of existing built environment; •Economic growth need; •Territorial and market attractiveness; •Improved local environmental quality (air, noise, aesthetics, etc.); Energy autonomy/independence; • Any other DRIVING FACTOR - please specify - rank on the scale (1-5)	•			
C1 P003	Administrative barriers			•		•Difficulty in the coordination of high number of partners and authorities; •Lack of good cooperation and acceptance among	•			

			partners; •Lack of public participation; •Lack of institutions/mechanisms to disseminate information; •Long and complex procedures for authorisation of project activities; •Time consuming requirements by EC or other donors concerning reporting and accountancy; •Complicated and non-comprehensive public procurement; •Fragmented and or complex ownership structure; •City administration & cross-sectoral attitude/approaches (silos); •Lack of internal capacities to support energy transition; •Any other Administrative BARRIER - please specify - rank on the scale (1-5)				
C1 P004	Policy barriers	•	•Lack of long-term and consistent energy plans and policies; •Lacking or fragmented local political commitment and support on the long term; •Lack of Cooperation & support between national-regional-local entities; •Any other Political BARRIER - please specify - rank on the scale (1-5)	•			
C1 P005	Legal and Regulatory barriers	•	•Inadequate regulations for new technologies; •Regulatory instability; •Non-effective regulations; •Unfavorable local regulations for innovative technologies; •Building code and land-use planning hindering innovative technologies; •Insufficient or insecure financial incentives; •Unresolved privacy concerns and limiting nature of privacy protection regulation; •Shortage of proven and tested solutions and examples; •Any other Legal and Regulatory BARRIER - please specify - rank on the scale (1-5)	•	•		
C1 P006	Technical barriers	•	•Lack of skilled and trained personnel; •Deficient planning; •Lack of well-defined process; •Retrofitting work in dwellings in occupied state; •Inaccuracy in energy modelling and simulation; •Lack/cost of computational scalability; •Grid congestion, grid instability; •Negative effects of project intervention on the natural environment; •Energy retrofitting work in dense and/or historical urban environment; •Difficult definition of system boundaries; •Any other Technical BARRIER - please specify - rank on the scale (1-5)	•	•	•	
C1 P007	Environmental barriers	•	•Yes + [txt]; •No	•		•	
C1 P008	Social and Cultural barriers	•	•Inertia; •Lack of values and interest in energy optimisation measurements; •Low acceptance of new projects and technologies; •Difficulty of finding and engaging relevant	•		•	•

			actors; •Lack of trust beyond social network; •Rebound effect; •Hostile or passive attitude towards environmentalism; •Hostile or passive attitude towards energy collaboration; •Exclusion of socially disadvantaged groups; •Non-energy issues are more important and urgent for actors; •Any other Social BARRIER - please specify - rank on the scale (1-5)				
C1 P009	Information and Awareness barriers	•	•Insufficient information on the part of potential users and consumers; •Lack of awareness among authorities; •Perception of interventions as complicated and expensive, with negative socio-economic or environmental impacts; •Information asymmetry causing power asymmetry of established actors; •High costs of design, material, construction, and installation; •Any other Information and Awareness BARRIER - please specify - rank on the scale (1-5)	•			•
C1 P010	Financial barriers	•	•Hidden costs; •Insufficient external financial support and funding for project activities; •Limited access to capital and cost disincentives; •Economic crisis; •Risk and uncertainty; •Lack of consolidated and tested business models; •Any other Financial BARRIER - please specify - rank on the scale (1-5)	•	•		•
C1 P011	Market barriers	•	•Split incentives; •Energy price distortion; •Energy market concentration, gatekeeper actors (DSOs); •Any other Market BARRIER - please specify - rank on the scale (1-5)	•	•		•
C1 P012	Stakeholders involved	•	•Government/Public Authorities; •Research & Innovation; •Financial/Funding; •Analyst, ICT and Big Data; •Business process management; •Urban Services providers; •Real Estate developers; •Design/Construction companies; •End-users/Occupants/Energy Citizens; •Social/Civil Society/NGOs; •Industry/SME/eCommerce; •Other - please specify - Choose options (1-5)	•	•	•	•

Annex VIII

Table 1. Section D1 ‘General Projects/Initiatives’ [Source: CA ‘PED-EU-NET’]

ID	Parameter title	Type of answer				Answer options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
D1 P001	Name of the project (*)	•				[txt]	•	•	•	•
D1 P002	Project assigned code	•				[nr]			•	
D1 P003	Start date	•				[nr]	•		•	
D1 P004	End date	•				[nr]	•		•	
D1 P005	Ongoing project		•			•Yes; •No	•	•	•	
D1 P006	Funding programme/financing model		•			•FP7/H2020/HEU; •Inter-reg; •National funding; •Public-Private Partner-ship; •Other, please specify - Specify the call, If available.	•	•	•	
D1 P007	Estimated project costs	•				[nr]	•	•	•	
D1 P008	Description of project objectives/con-cepts	•				[txt]	•		•	•
D1 P009	Description of project upscaling strat-egies	•				[txt]	•		•	
D1 P010	Number of PED case studies in the project	•				[nr]			•	
D1 P011	Case Study	•				[txt]	•	•	•	•
D1 P012	Description of project expected im-pact	•				[txt]	•		•	
D1 P013	Standardisation efforts	•				[txt]			•	
D1 P014	Sources	•				[txt]	•	•	•	•
D1 P015	Contact person within PED project (*)	•				[txt]	•	•	•	•

ANNEX 83

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Technology Collaboration Programme

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ANNEX 83

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Annex IX

International Energy Agency

Comprehensive PED Guidelines for City planners

Positive Energy Districts (Annex 83)

Energy in Buildings and Communities Technology Collaboration Programme

June 2026

International Energy Agency 83

Comprehensive PED Guidelines for City planners

Positive Energy Districts (Annex 83)

Energy in Buildings and Communities Technology Collaboration Programme

June 2026

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.)

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives - The strategic objectives of the EBC TCP are as follows:

– reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
– improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
– the creation of 'low tech', robust and affordable technologies;
– the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible;
– the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means - The strategic objectives of the EBC TCP will be achieved by the means listed below:

– the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
– benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
– improving smart control of building services technical installations, including occupant and operator interfaces;
– addressing data issues in buildings, including non-intrusive and secure data collection;
– the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: ☼ Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: ☼ Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)
Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)
Annex 62: Ventilative Cooling (*)
Annex 63: Implementation of Energy Strategies in Communities (*)
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)
Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)
Annex 67: Energy Flexible Buildings (*)
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Resilient Public Communities
Annex 74: Competition and Living Lab Platform
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables
Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO_2 Emissions
Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting
Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications
Annex 79: Occupant-Centric Building Design and Operation
Annex 80: Resilient Cooling
Annex 81: Data-Driven Smart Buildings
Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems
Annex 83: Positive Energy Districts
Annex 84: Demand Management of Buildings in Thermal Networks
Annex 85: Indirect Evaporative Cooling
Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - HVAC Energy Calculation Methodologies for Non-residential Buildings (*)
Working Group - Cities and Communities
Working Group - Building Energy Codes

Summary

This document provides comprehensive guidelines for city planners on the implementation, management, and integration of **Positive Energy Districts (PEDs)** as part of the broader urban energy transition in cities. PEDs are defined as urban districts that produce more renewable energy than they consume annually, enabling sustainable, climate-neutral cities. The guidelines aim to accelerate the adoption and integration of PEDs in cities while addressing challenges related to energy, governance, social, and economic aspects.

PEDs are a crucial concept in the transition towards sustainable urban energy systems, representing a shift from individual building-centric approaches to a district-scale perspective for integrated, efficient, and sustainable urban development. Identified as a strategic priority by the European Commission (EC), the PED concept has evolved from Net Zero Energy Districts (NZEDs) and Positive Energy Blocks (PEBs), emphasising the systemic integration of renewable energy, smart grids, and energy sharing at the urban level. The EC actively supports PED development through funding pilot projects under Horizon 2020.

Various definitions of PEDs exist across organisations and initiatives, though a single universally accepted definition remains elusive, posing challenges for project comparison due to varying baseline assumptions. Key definitions highlight aspects such as achieving net-zero energy imports and CO_2 emissions annually with a local renewable energy surplus, being energy-efficient and flexible urban areas with net-zero greenhouse gas emissions and a renewable energy surplus integrating energy, mobility, and ICT, actively regulating energy exchanges to maintain a positive annual energy balance by maximising renewable production and efficiency, comprising multiple buildings actively managing energy usage for an annual positive balance within the city's energy system, and maintaining net-zero energy imports and CO_2 emissions while working towards a renewable energy surplus, integrated with regional energy systems and active energy flow management.

Despite differing definitions, **common principles underpin the PED concept**: **energy efficiency and flexibility** of interconnected buildings and urban areas to optimise energy use; the active management of an **annual surplus of locally or regionally produced renewable energy** with net-zero GHG emissions; the **integrated nature of urban systems**, including buildings, mobility, energy, and ICT; prioritising **social, economic, and environmental sustainability** with secure energy supply and inclusivity; **integration within urban and regional energy networks** supplied by renewables; and often incorporating **net-zero direct carbon emissions**.

Key topics covered in the document include:

Definitions and Frameworks: PEDs are defined within the context of sustainable urban energy transitions, emphasising their role in achieving net zero energy imports and CO_2 emissions. Frameworks for holistic energy planning and the systemic integration of renewable energy, smart grids, and energy-sharing mechanisms are discussed.

Energy Balance Methodologies: Various calculation methods and tools are provided to assess energy production, demand, and balance at the district level. These include dynamic modelling approaches, GIS-based tools, and standardised frameworks like ISO 52000-1.

Technological Solutions: The document explores energy efficiency technologies, renewable energy production systems, energy flexibility tools, and the integration of ICT solutions, e-mobility, and smart infrastructure. Emphasis is placed on optimised integrated designs and advanced energy systems.

Monitoring and Evaluation: A systematic approach to monitoring, assessment, certification, and evaluation is outlined, including the use of Key Performance Indicators (KPIs). The importance of data collection, visualisation, and governance frameworks is emphasised.

Social Aspects: The transformation to PEDs requires stakeholder engagement and inclusive planning. Strategies like urban living labs, co-creation platforms, and justice assessments ensure citizen participation and equitable energy access.

Financial and Business Models: Financing strategies for PEDs include public-private partnerships, risk mitigation measures and regulatory support. The document highlights innovative funding mechanisms and streamlined regulatory frameworks to overcome financial barriers.

Urban Planning and Integration: PEDs must be embedded into urban master plans for effective spatial integration. Land use evaluations, regulatory alignment and synergy between energy and urban planning are essential for successful implementation.

Governance and Legal Aspects: Collaborative governance models, policy frameworks, and systems thinking approaches are critical for overcoming institutional silos and regulatory barriers. Multi-stakeholder coordination and quadruple helix models are recommended to align PEDs with broader urban strategies.

Implementation Processes: Structured methodologies like the **Smart City Guidance Package (SCGP)** and **PED-LAB** model are proposed, focusing on adaptive, step-by-step approaches for PED deployment. Feedback loops and stakeholder-driven processes ensure continuous improvement.

Alignment with Urban Sustainability Initiatives: PEDs are positioned as integral elements of climate-neutral and smart cities, aligning with initiatives like the European Climate Neutral Cities program, Nearly Zero-Energy Buildings (NZEBs), Nature-Based Solutions (NBS), New European Bauhaus (NEB) and others. Their contribution to achieving EU climate goals is highlighted.

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Abbreviations

Abbreviations	Meaning
4P model	Public-Private-People-Planet model
AI	Artificial Intelligence
BEMS	Building Energy Management Systems
BIM	Building Information Modelling
BREAM	Building Research Establishment Environmental Assessment Method
CEA	Community Energy Analyst
CHPs	Combined Heat and Power
City BES	City Building Energy Simulation
COMIS	Multi Zone Air Flow Modelling
COP21	21st Conference of the Parties
DSM	Demand-Side Management
DHC	District Heating and Cooling
EC	European Commission
EBC	Energy in Buildings and Communities
EEA JPSC	EERA Joint Programme Smart Cities
EES	Electrical Energy Storage
EIP-SCC	European Innovation Partnership on Smart Cities and Communities
EnERGo	Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings
EPNs	Energy-Positive Neighbourhoods
EPs	Electric Vehicles
ERNA	International Renewable Energy Agency
ESCos	Energy Service Company
EU	European Union
EVs	Electric Vehicles
FBF	Future Buildings Forum
FC+COGEN-SIM	The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GIS	Geographic Information Systems
HVAC	Heating, Ventilation, and Air Conditioning
HYBVENT	Hybrid Ventilation
ICT	Information and Communication Technology

IEA	International Energy Agency
IEA EBC	IEA Energy in Buildings and Communities
IoT	Internet of Things
IRENA	International Renewable Energy Agency
JPI Urban Europe	Joint Programme Initiative Urban Europe
KPIs	Key Performance Indicators
LCA	Life Cycle Analysis
LEED	Leadership in Energy and Environmental Design
LowEx	Low Exergy Systems for Heating and Cooling of Buildings
MIT UBEM	Massachusetts Institute of Technology Urban Building Energy Model
MOIST-ENG	Whole Building Heat, Air and Moisture Response
NBS	Nature-Based Solutions
NGOs	Non-Governmental Organisations
NSGE	Near Surface Geothermal Energy
NZEBs	Nearly Zero-Energy Buildings
NZEDs	Net Zero Energy Districts
PEBs	Positive Energy Blocks
PED	Positive Energy District
PPPs	Public-Private Partnerships
PV	Photovoltaics
PVgis	Photovoltaic Geographical Information System
PVsyst	PV system simulation software
QMS	Quality Management Systems
RAP-RETRO	Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost
R&D	Research and Development
RES	Renewable Energy Sources
SCGP	Smart City Guidance Package
SCIS	Smart Cities Information System
SEC	Smart Energy City
SET-Plan	Strategic Energy Technology Plan
SMEs	Small and Medium Enterprises
SPECs	Solution Cards
TCP	Technology Collaboration Programme
TES	Thermal Energy Storage
TRNSYS	Transient System Simulation Program
UBEM	Urban Building Energy Modelling
UMI	Urban Modelling Interface
V2G	Vehicle-to-Grid
VPPs	Virtual Power Plants
WAsP	Wind Atlas Analysis and Application Program

ZEN	Zero Emission Neighbourhood

Definitions

Blended Finance
A financial strategy combining public and private capital to reduce investment risk and support PED development.
Building Design
The strategic planning and construction of buildings aimed at optimising energy efficiency through compact structures, optimal orientation, passive climate control, and solar shading.
Co-benefits
Secondary benefits of PEDs, including improved air quality, public health, property value, and urban liveability.
District Heating and Cooling (DHC)
Centralised systems distributing thermal energy (heating/cooling) to buildings in a district, often linked to renewables.
Energy Balance
The comparison between total energy consumed and renewable energy generated within a district, typically on an annual basis.
Energy-Conscious User Behaviour:
Daily practices and behavioural patterns that reduce energy consumption, supported by tools such as real-time feedback systems, smart meters, and adaptive controls.
Energy Efficiency
The reduction of energy use while maintaining equivalent service levels, achieved through technology, design, and behaviour.
Energy Flexibility
The capacity of systems to adapt energy consumption and generation dynamically, using storage, smart control, and demand-response.
Energy Management System (EMS)
Digital systems used to monitor, control, and optimise energy flows within buildings or districts.
Integrated Urban Systems
The coordinated operation of buildings, energy, mobility, and ICT systems within a PED to optimise sustainability and performance.
Key Performance Indicators (KPIs)
Quantitative and qualitative metrics used to evaluate PED performance in terms of energy, environment, economy, and social aspects.
Living Lab
A real-life testing environment where innovative PED solutions are co-developed and evaluated with local stakeholders.
Optimised Construction:
Energy-efficient construction techniques that ensure airtightness, eliminate thermal bridges, and improve the overall thermal performance of buildings.
PED Lab
A type of Living Lab focused specifically on experimenting with Positive Energy District concepts and solutions at the city level.
Positive Energy Block (PEB)
A group of buildings that manage their energy consumption and generation to achieve a net-positive energy balance.

Positive Energy Community (PEC)
A broader community-driven concept applying PED principles within participatory and decentralised frameworks.
Positive Energy District (PED)
An urban district with a net-zero annual energy import and CO_2 emissions, producing a surplus of renewable energy and promoting holistic sustainability.
Primary Energy Balance
An assessment of PED energy performance using conversion factors to express energy use in terms of primary energy.
Public-Private-People Partnership (4P)
A collaborative governance model involving public institutions, private stakeholders, and citizens in PED planning and operation.
Regulatory Sandbox
A legal framework allowing temporary regulatory flexibility for testing innovative PED-related technologies or business models.
Renewable Energy Surplus
The condition in which renewable energy production exceeds total energy consumption in a PED on an annual basis.
Smart Appliances
Energy-efficient devices integrated with sensors and automation that adjust their operation based on user behaviour and real-time energy demand.
Smart Grid
An ICT-enhanced electrical grid that enables real-time communication and optimisation of energy production, storage, and use.
Stakeholder Mapping
A method for identifying and analysing the roles, interests, and influence of different actors involved in a PED project.
Thermal Insulation:
Materials and methods used to reduce heat transfer through the building envelope, minimising energy loss and enhancing indoor temperature stability.
Urban Energy Planning
The integration of energy systems and sustainability goals into urban land use, infrastructure, and development strategies.
Virtual Boundary
A conceptual extension of a PED's geographic limits to include off-site renewable energy sources through contracts or agreements.
Zero Emission Neighbourhood (ZEN)
A district-scale concept aligned with PEDs, focused on achieving net-zero carbon emissions through integrated planning.

1. Introduction

1.1 Objective and methodology of the Guidelines

The objective of these guidelines is to provide city planners, policymakers and stakeholders with a comprehensive and practical framework to design, implement, and scale Positive Energy Districts (PEDs) as a core strategy for sustainable urban energy transitions. The guidelines aim to support cities in achieving climate neutrality by helping them produce more renewable energy than they consume, while also ensuring social inclusion, economic viability, and environmental resilience. By addressing key challenges across technical, regulatory, financial, and social dimensions, the guidelines serve as a roadmap to foster adaptable, and citizen-centred PED solutions that are integrated in the cities. They promote collaborative governance, innovation, and cross-sectoral alignment, ultimately empowering urban areas to become frontrunners in the energy transition.
The guidelines have been developed in the framework of the **International Energy Agency (IEA)** - **Energy in Buildings and Communities (EBC) Technology Collaboration Programme**,

The methodology has been developed under Subtask D of IEA Annex 83 to collect, assess, and synthesise existing guidelines related to Positive Energy Districts, with the aim of producing **integrated planning guidelines** that support professionals, city planners, and municipal stakeholders in all phases of PED implementation. The methodology serves multiple strategic goals:

- **Map and analyse existing PED guidelines** across technologies, governance, planning, and implementation dimensions.
- **Identify gaps** in current practices and address stakeholder needs.
- **Produce structured, targeted, and usable guidelines** for city-level implementation, grounded in cross-domain best practices.
- **Support the PED value chain** from planning and construction to operation, verification, and maintenance, across urban, suburban, and rural contexts.

Methodological Framework

The updated methodology builds on an approach published in 2022 [1], *expanding it with additional steps and broader stakeholder involvement:*

Step 1: Collection of Existing Guidelines

- *Guidelines were gathered through a combination of **online surveys** and **desk research**, covering materials relevant to PEDs, smart cities, climate-neutral districts, eco-districts, and sustainable urban development.*
- *As of early 2024, **85 guidelines and relevant documents** had been collected and preliminarily categorised.*

Step 2: Two-Stage Analysis Process

1. ***Brief Characterisation**: Classification by spatial scale (building, block, district, city), audience (local, national, international), and content (technical, planning, legal, financial, etc.).*
2. ***In-depth Analysis**:*

- *__Text mining and clustering__ to identify dominant keywords, concepts, and thematic groupings using NVIVO software platform.*
- *__Discourse analysis__ to understand narrative patterns and interpretive frameworks used in different guidelines.*
- *__Manual qualitative analysis__ to assess objectives, stakeholder engagement tools, and alignment with PED planning stages.*
- *__Selection of the most relevant contributions__ reducing the number of reference documents used to compile this guideline from 85 to 57.*

Step 3: Experts consultation and Gap Identification

- *Experts opinions were collected via dedicated tools within the Annex 83 (e.g. Miro boards, dedicated meetings of SubTask D for expert consultations).*
- *Special attention was paid to __urban planners and municipal officers__, whose needs were often underrepresented in previous guidelines.*
- *Gaps identified include: lack of integration in spatial planning practices, limited emphasis on legal/governance aspects, and insufficient attention to co-benefits and systemic interdependencies.*

Step 4: Drafting the New Guidelines

- *An __editorial board__ composed of Subtask leaders and domain experts oversaw the creation of the new guidelines.*
- *The guidelines aim to be modular, focused, and easily accessible and they have been structured into __11 core chapters__.*
- *Drafting was iterative, incorporating expert feedback and preliminary validation through direct consultation with the target audience.*

Step 5: Validation and Review

- *Intermediate drafts have been shared shared with professionals, planners (Members of the International Society of City and Regional Planners - Isocarp - and Institute for Urban Excellence) in order to ensure relevance and completeness before final draft.*
- *Online database and research tool (e.g., hyperlinked guideline repositories with link to case studies) supporting dissemination and accessibility possibly connect the PED Database (COST Action PED-EU-NET) is foreseen as further development and is highly desirable.*

1.2 Positive Energy Districts (PEDs) definition evolution in the Sustainable Urban Energy Transition context

The **Positive Energy District** is emerging as a fundamental concept in the shift toward a sustainable urban energy transition and has been identified as a strategic priority by the European Commission through its endorsement of the Strategic Energy Technology Plan (SET-Plan Action 3.2) [2]. Unlike traditional approaches focused on individual buildings, PEDs adopt a district-scale perspective, enabling energy transformation at a larger scale and promoting more integrated, efficient, and sustainable urban development [3].

The concept of Positive Energy Districts has undergone a significant evolution over the past decade, shaped by diverse institutional frameworks and advancing urban sustainability goals. Initially focused on achieving a local energy surplus, the definition of PEDs has expanded to embrace flexibility, integration, and systemic value creation at the district and city scale.

1. Early Definitions (Pre-2018): From Energy Surplus to District-Scale Thinking.
PEDs emerged from the idea of scaling up net-zero energy buildings to the district level. In these early interpretations, the emphasis was on producing more renewable energy annually than consumed, largely without considering energy system interactions or temporal dynamics. Energy assessments were typically static and annual, with little focus on flexibility, resilience, or urban integration.

2. Structuring the Concept: JPI Urban Europe (2018–2020).
The JPI Urban Europe PED Programme introduced a structured definition that broadened the scope to include:
“Energy-efficient and energy-flexible urban areas or groups of interconnected buildings that produce net zero greenhouse gas emissions while managing a local or regional annual surplus of renewable energy.”
This marked a turning point in conceptualising PEDs not only as energy producers, but also as enablers of climate neutrality, energy flexibility, and urban resilience. It acknowledged the importance of integrating systems such as mobility and ICT, and balancing economic, social, and environmental sustainability.
This definition also laid the foundation for further refinement by initiatives such as the Driving Urban Transitions (DUT) Partnership [59], which simplified the JPI framework [41] for practical implementation.

3. Expansion and Systemic Framing (2021–Present).
Recent EU-funded projects such as MAKING-CITY [6], SPARCS [60], and syn.ikia [61] have accelerated the shift from a narrow energy balance to a broader systemic approach, where PEDs are conceived as active components of the wider urban energy transition.
Emerging trends and key updates include:

- **From net-positive to system-positive**: PEDs are no longer seen merely as exporters of energy, but as nodes that enhance grid stability, demand flexibility and urban sustainability.
- **Temporal granularity**: The use of hourly or sub-hourly data is now seen as essential to evaluate performance under real conditions.
- **Multi-dimensional KPIs**: Evaluation frameworks increasingly incorporate energy, emissions, flexibility, mobility and social equity indicators.
- **Inclusivity and adaptability**: PEDs should be replicable across different urban contexts—dense cities, suburban areas, or rural zones—through contextual optimisation.
- **Integration into climate-neutral strategies**: PEDs are now strongly linked with broader urban missions, including climate neutrality, nature-based solutions, and energy communities.

4. Institutional Definitions: A Converging Landscape.
Multiple European and international initiatives have proposed definitions that converge around common principles and must be considered as the result of a collaborative effort while reflecting institutional priorities:

- **SET-Plan Action 3.2** defines PEDs as urban districts that achieve **net zero energy imports and CO_2 emissions**, aiming to generate a **local renewable energy surplus** and maintain **affordable living conditions** [3], [4].
- **Horizon 2020 and Horizon Europe** define PEDs as **clusters of new, retrofitted, or mixed buildings** that self-regulate energy consumption and exchange via **renewables, smart grids, storage, and advanced EMS**. The term “**Positive Clean Energy Districts**” **(PCED)** is also used interchangeably in this context, emphasising **scalability** and **integration into clean energy infrastructures** [3].
- **European Innovation Partnership on Smart Cities and Communities (EIP-SCC)** presents PEDs as districts comprising multiple buildings that **actively manage energy use and interactions**, contributing to **environmental, economic, and social sustainability** [5].

- **EERA Joint Programme Smart Cities (JPSC)** emphasises **integration with regional energy systems** and **active energy management**, aiming for **net-zero energy imports and CO_2 emissions** [6].
- The **DUT PED Framework 3.0** describes PEDs as: "Energy efficient and energy flexible urban neighbourhoods or areas of connected buildings and facilities that produce local renewable energy, achieve net zero greenhouse gas emissions, and actively contribute to overall climate neutrality."

Finally, the International Energy Agency (IEA) EBC Annex 83 builds on earlier definitions (especially SET-Plan and EERA JPSC), but adds emphasis on:
"Energy-efficient districts with net zero greenhouse gas emissions and an annual positive energy balance, prioritising local renewable energy and optimising interactions among buildings, users, mobility, energy, and ICT systems."
Annex 83 also highlights the expectation that PEDs generate **positive impacts not only within the district but across the wider energy system**, delivering **social, economic, and environmental co-benefits**.

According to [7] the concept of Positive Energy Districts and similar "Climate Friendly Neighbourhoods" (CFNs) remains largely Eurocentric in its documented discourse, with their systematic review acknowledging a limited inclusion of research projects and initiatives from other continents such as Asia, South America, Oceania, or Africa. This observation is corroborated by other sources, which explicitly state that the PED term is primarily European, while guidelines from other parts of the world, like the United States, may refer to similar concepts as "energy master planning" or "Zero Net Energy Community" [1].
Several initiatives and terminologies emerging globally share foundational elements with the PED vision, such as the emphasis on local energy generation, system integration, participatory governance, and climate neutrality. These alternative or complementary definitions provide valuable perspectives that may enrich the understanding and operationalisation of PEDs, especially when adapting them to diverse urban, socio-economic, or climatic contexts. Points of convergence can be identified with the approaches and terminologies used by the following scholars or initiatives:

Nearly Zero Energy Neighbourhood (nZEN), Positive Energy Block (PEB), Energy Positive Neighbourhood (EPN), Low Carbon District Heating (LCDH), Zero Energy Neighbourhood (ZEN), Plus Energy District (pED), Zero Energy District (ZED), Positive Energy Precinct, Zero Carbon District, Zero Carbon Neighbourhood, Smart City Eco District, Zero Energy Emission District, Zero Non-Renewable Energy Neighbourhood, - Plus Energy Neighbourhood, Nearly Zero Energy Settlement, Net Zero Exergy District, - Net Zero Carbon Emission District, Low or Zero Emission District Heating, Low Carbon Energy District, Low Carbon Local Energy Community, Net Positive Energy Neighbourhood, Energy Positive District, Smart Energy Community, Net Zero Energy Block, Nearly Zero Carbon Neighbourhood, Net Zero Energy Settlement, Net Zero Energy Campus, and Net Zero Energy Community [7].

1.3 Key Aspects of PED Definitions

Despite the fact that there is not a common European PED definition, the PED reference framework developed by JPI Urban Europe [41] and DUT [59] is well used in recent projects. Although the baseline assumptions vary among existing projects, several common principles have emerged:

- **Energy Efficiency and Flexibility:** PEDs consist of energy-efficient and energy-flexible urban areas or clusters of interconnected buildings, designed to optimise energy use and respond dynamically to fluctuations in energy demand and supply[3], [7].
- **Renewable Energy Surplus**: A frequently used criterion is the active management of an annual surplus of locally or regionally produced renewable energy, while ensuring net-zero greenhouse gas (GHG) emissions [3] [7],[8]. This means that local energy consumption must remain lower than the renewable energy generated within the district [[7], [6].
- **Integrated Urban Systems**: PEDs require the synergistic integration of multiple infrastructures, including buildings, mobility networks, energy systems, and Information and Communication Technol-

ogy (ICT) [3], [7]. This ensures the optimal interaction between energy demand, supply, and storage systems [3], [7].

- **Sustainability Considerations**: Beyond energy performance, PEDs prioritise social, economic, and environmental sustainability, ensuring secure energy supply, high-quality urban living and inclusivity [3], [7]. Citizen engagement and affordability are essential components of PED planning and governance [3].
- **Urban and Regional Energy System Integration:** PEDs should be embedded within urban and regional energy networks, ideally supplied by renewable energy sources (RES) [6], [9], [4]. This approach enhances both the reliability and flexibility of urban energy systems [6], [9]–[6].
- **Net-Zero Carbon Emissions:** Many PED initiatives incorporate net-zero direct carbon emissions as a key requirement, reinforcing the alignment of the PED concept with EU's climate-neutrality agenda. [3].

1.4 PED, PEB, PEC, PECs

The European Commission interchangeably used the terms **Positive Energy Blocks (PEBs)** and Positive Energy Districts (PEDs) in the Horizon 2020 Work Programme, defining them as "clusters of buildings that actively manage their energy consumption and the energy flow between them and the wider energy system". However the two concepts differ primarily in **scale, complexity, and systemic integration**. [6], [7], [10].

	Positive Energy Block (PEB)	**Positive Energy District (PED)**
Scale	Small-scale: typically, a **group of 3–5 adjacent buildings**	Larger-scale: **entire neighbourhoods or urban districts, preferably mixed use**
System Integration	Focused mainly on **building-level integration**	Involves **multi-system integration** (buildings, mobility, ICT, grids)
Governance Complexity	Simpler, often **project-based or single-owner**	More complex, involving **multiple stakeholders and public governance**
Planning Scope	Can be implemented as a **localised retrofit or new build**	Requires **urban planning integration** and alignment with city strategies

The term **Positive Energy City (PEC)** has been so far used only in a visionary and strategic sense, primarily within European innovation projects such as MAKING-CITY ("Positive Energy Cities are urban areas composed of multiple interconnected Positive Energy Districts that contribute to an annual positive energy balance at the city scale.") and SPARCS (cities such as Espoo (FI) and Leipzig (DE) have adopted the PEC concept as a strategic urban goal, using PEDs as a foundation. The project supports long-term visions of PECs through digitalisation, local renewable production, and citizen engagement.)
Curiously the Mission "100 Climate-Neutral and Smart Cities" itself does not use the term Positive Energy City but it promotes the scaling of PEDs as part of city-level climate neutrality plans, indirectly supporting the PEC vision.

In relation to the concept of Positive Energy Communities (PECs), to date, no consolidated academic or policy literature has succeeded in defining or modelling it as a conceptual or operational fusion of Renewable Energy Communities and PED paradigms. This represents a critical gap and an opportunity for future research.
According to (Vandevyvere et al., 2022) PEDs may, in the near future, revert to Local Energy Communities (LECs) for operationalising their energy systems and markets.

Finally **PED Lab** refers to a city-driven initiative or "living lab" focused on the development, testing, and refinement of PED concepts tailored to the specific needs and approaches of individual cities. These labs serve as experimental platforms where innovative solutions for energy efficiency, sustainability, and community engagement are co-created and evaluated in real-world urban settings. The insights and methodologies derived from PED Labs are intended to inform and facilitate the broader implementation and replication of Positive Energy Districts across various urban contexts [11].

1.5 Challenges in Defining PEDs

While there is growing uptake on the concept of Positive Energy Districts (PEDs), its interpretation varies as it is used by different stakeholders, in different contexts for different goals. As such, several challenges persist in developing a standardised and practical definition, that is achievable in the required contexts:

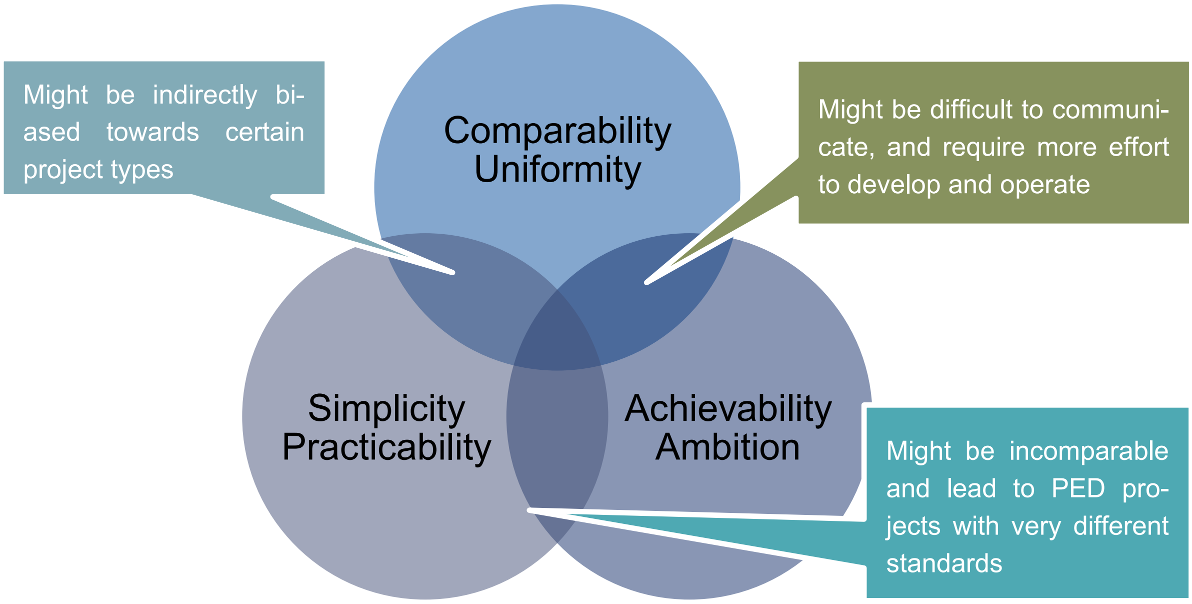

Figure 1: Challenges in Defining PEDs: Finding common ground at the intersection of three definition requirements: Simplicity (of Implementation, Practicability), Comparability (Standardisation) and Achievability (for different districts across Europe). Adapted from [13]

Establishing Clear District Boundaries: Defining the limits of a PED is a complex task, as boundaries must be determined for a number of domains, which can be grouped in different ways [3]:

- **Geographical:** Based on the physical limits of the district, such as administrative or infrastructural divisions [14], [6].
- **Functional:** Based on which energy functions are considered being part of the PED. Defined by energy grids and interconnections, considering the way energy flows between buildings and systems, [6] and which energy is considered, such as HVAC operation, Pug-loads, Mobility and embodied energy).
- **Virtual:** Extending beyond the physical district to include off-site renewable energy generation through contractual agreements[14], [6] or other balancing methods such as virtual context factors [15].

Establishing a Common Energy Balance Methodology: The development of a common framework can support the replication of PEDs, but there are major challenges including the clarification of district boundaries and incorporation of energy use for mobility [3].

- **Incorporating Carbon Emissions:** Addressing carbon emissions within the PED framework requires a consistent methodology ideally aligned with international GHG accounting standards, such as the three-scope emissions classification [3].

- **Balancing Energy and Non-Energy Criteria**: While energy performance is central, PEDs must also integrate social, economic, and environmental sustainability goals. However, there is a delicate balance as an overly broad definition could dilute the core PED concept [3].
- **Accounting for Local Diversity:** PED definitions must be flexible enough to accommodate diverse urban contexts, ensuring equitable implementation across European cities. A one-size-fits-all approach is unlikely to be effective given the variability in local resources, governance structures, and energy infrastructure [3], [13].

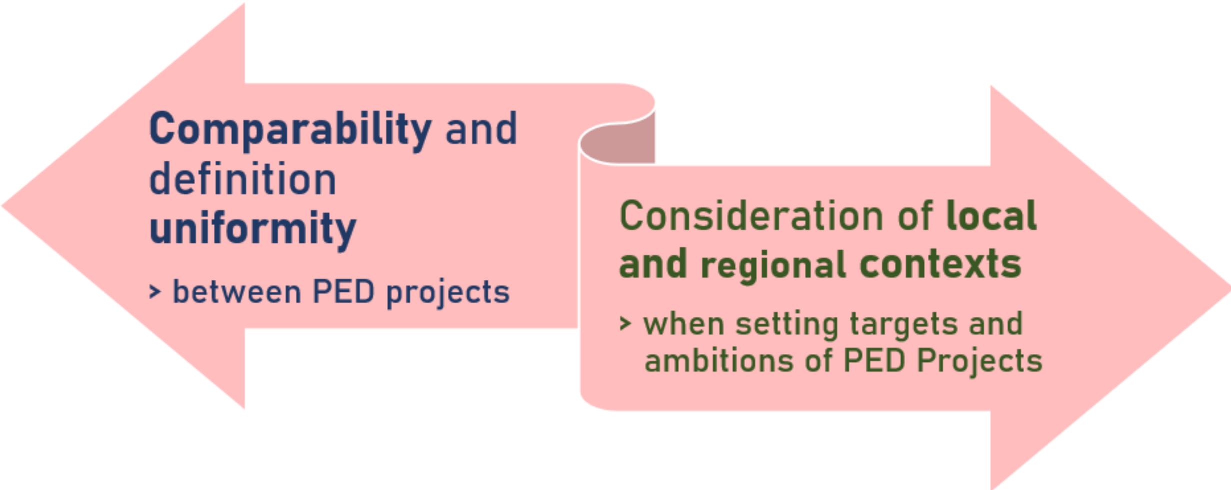

Figure 2: Two definition goals commonly diverge: Uniformity and Locality (based on Schneider, 2023)

Framing the PED definition as an academic question: Many of the above-mentioned considerations offer a choice in definition creation, that are not decidable from a scientific point of view but have implications on the feasibility of individual districts for PED. Since the PED concept is employed for different reasons, the definitions to measure the PED projects success must also reflect the reasons and goals behind them [5], [15].

1.6 Potential Solutions and Frameworks

To address these challenges, several approaches have been proposed:

- **Adaptive Frameworks:** Establishing a flexible definition of Positive Energy Districts (PEDs) allows for adaptation to diverse local conditions while upholding fundamental energy principles. This flexibility ensures that PEDs can be scaled and implemented across different urban environments without compromising their core objectives [3], [15].

- **Context-Based Approaches:** Integrating PED definitions with regional and national energy policies enhances contextual adaptability, making implementation strategies more aligned with specific regulatory and infrastructural landscapes [5], [15].

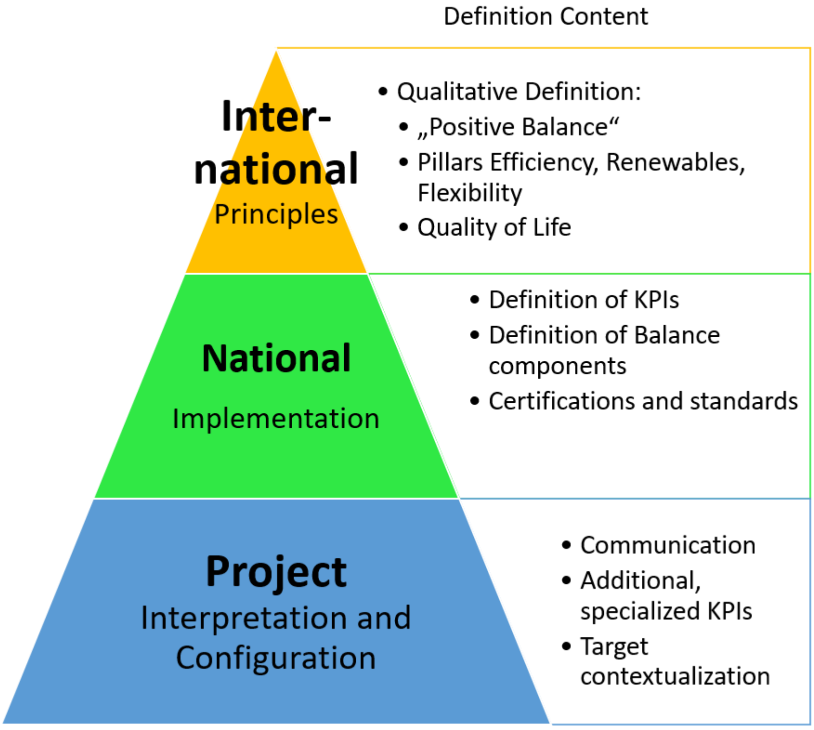

Figure 3: PED Definition aspects split three responsibility layers of regionality (adapted from [13])

- **Multidimensional Assessment**: A thorough evaluation of PED performance requires a robust set of Key Performance Indicators (KPIs), because the “positivity” of a district cannot be assessed through energy performance alone. KPIs should therefore cover multiple dimensions, including energy balance, carbon emissions, and social equity, to ensure a holistic measurement of a district's "positivity" [16].

2. Energy Balance at city scale

Several approaches and tools are available for calculating energy balances at the district scale, each with its own data requirements, geographical scales, and reference timeframes.

This chapter presents an overview of some methodologies and tools that can support city planners in evaluating energy balance, modelling energy demand, and designing effective strategies for Positive Energy Districts.
The methodologies outlined in this chapter cover a range of approaches, from high-level energy balance calculations to detailed methodologies and simulation tools.

2.1 Methodologies

Many programmes and projects created their own methods for calculating energy balance, though the approaches can vary [3]. A common methodology is needed for objectively evaluating Positive Energy Districts, but formulating a universal methodology applicable to different local contexts remains a challenge [3]. The annual energy balance is a key aspect for demonstrating a district's positivity and evaluating its energy surplus [6]. Energy flexibility can be evaluated by carrying out energy balances in shorter time periods or by time-dependent assessment of flexible energy flows in the energy balance, giving a better perspective on district performance at different times [15], [17].
A recent comparison [18] of three energy assessment methodologies - MAKING-CITY, Zukunftsquartier Wien (ZQW), and Zero Emission Neighbourhood (ZEN) - aimed to provide recommendations for a common, generalisable framework for assessing Positive Energy Districts (PEDs). It emphasises that PEDs should not be narrowly defined by a positive energy balance; rather, the framework should recognise diverse district conditions, aim for system-wide benefits, and balance technical robustness with applicability and fairness.

MAKING-CITY Methodology:

The MAKING-CITY project provides an eight-step methodology for calculating energy balances in Positive Energy Districts (PEDs). This methodology focuses on achieving an annual balance in primary energy terms (either total or non-renewable) and is described in [12]:

Key Steps:

1. Define PED boundaries (geographical, functional, or virtual).
2. Calculate energy needs (heating, cooling, domestic hot water, lighting, etc.).
3. Determine energy use (thermal and electric).
4. Quantify on-site renewable energy production.
5. Estimate energy delivered to the district.
6. Convert delivered energy into primary energy using factors.
7. Calculate the primary energy balance.
8. Visualise results with a Sankey Diagram.

Input Data: Requires data on energy demand, renewable energy production, system efficiencies and primary energy factors.
Geographical Scale: Applicable to districts with defined boundaries.
Reference Timeframe: Annual energy balance is the primary focus, but hourly or sub-hourly balances are recommended for flexibility analysis.

syn.ikia Methodology: Described in [19], this approach:

- Calculates balance over a one-year period.
- Uses site-to-source conversion factors (weighting factors).
- Considers all building operational energy uses (excluding household appliances).
- Follows EN ISO 52000-1:2017.
- Recommends hourly or sub-hourly calculation for a more accurate picture.

Input data: Building energy use, on-site production, conversion factors.
Geographical scale: Building to neighborhood.
Timeframe: Annual, with hourly/sub-hourly calculations recommended.

ISO 52000-1 Framework
ISO 52000-1 provides a general framework for assessing energy performance, focusing on primary energy balance and renewable energy contributions [20].
Key Features:
- Differentiates between energy needs, energy delivered, and energy exported.
- Includes weighting factors for primary energy and exported energy.

Input Data: Includes detailed energy use data (HVAC, lighting), renewable production, and grid interactions.
Geographical Scale: Typically applied at building or neighbourhood levels, but adaptable to districts.
Reference Timeframe: Calculates annual energy balances but supports hourly or sub-hourly assessments for exported and delivered energy.

2.2 Tools

Urban Building Energy Modelling (UBEM) Tools: Urban Building Energy Modelling (UBEM) can enable PEDs by providing evidence-based decision support. Reviews of UBEM tools applied to Energy Communities differentiate them regarding their approaches, such as top-down and bottom-up methods [21].

Various UBEM tools are available for district-scale energy modelling, as summarised in [21]. Some examples include:

- MIT UBEM: Physics-based dynamic model, integrated approach, hourly time step.
- City BES: Web-based, physics-based dynamic model, sub-hourly time step.
- UMI: Standalone desk-based, physics-based dynamic model, hourly time step.
- CEA: Engineering & statistical reduced-order method, integrated approach, hourly time step.

These tools vary in their approaches, time steps, and specific outputs, but generally aim to model building operational energy demand at a city or district scale.

Input data: Varies by tool, but generally includes building characteristics, climate data, occupancy patterns.
Geographical scale: City/District.
Timeframe: Varies (hourly to annual).

EnergyPLAN: EnergyPLAN is a freeware tool that can provide fast results. It's a deterministic simulation model that does partial optimisation of the energy system. It helps model and identify opportunities for flexibility in different energy grids [22]. This tool:

- Analyses complex renewable energy systems locally.

- Includes all potential components of the future energy system.
- Uses hour-by-hour analysis to understand energy system dynamics.
- Focuses on the sustainability of the Smart Energy System.

Input data: Detailed energy system components, hourly demand and production profiles.
Geographical scale: City/Region.
Timeframe: Hourly over a year.

ENERKAD: A GIS-based model such as ENERKAD® can model a district with high details, and different solutions can be analysed for specific buildings, calculating the corresponding hourly energy balances [12]. Described in [23], this GIS-based tool:

- Calculates annual and hourly energy demand and consumption at building, district, or city scale.
- Allows analysis and comparison of current and future scenarios.
- Can be used for detailed modelling of districts, including hourly energy balances.

Input data: Basic cartography, cadastral, and climatic information.
Geographical scale: Building to city.
Timeframe: Annual and hourly.

Other tools mentioned in literature include Mesap PlaNet, H2RES, and SimREN [22].

Finally the COMPASS tool, created by RWDI consultants, streamlines energy benchmarking and reporting [24].

Name	Description	Key Features	Input Data	Geograph-ical Scale	Timefram e
MIT UBEM	Physics-based dy-namic model with an integrated ap-proach and hourly time step.	Provides district-scale energy modelling with detailed physics-based approach.	Building characteristics, cli-mate data, occupancy pat-terns.	City/District	Hourly
City BES	Web-based, phys-ics-based dynamic model with sub-hourly time step.	Enables district-scale modelling with web-based access.	Building characteristics, cli-mate data, occupancy pat-terns.	City/District	Sub-hourly
UMI	Standalone desk-based, physics-based dynamic model with hourly time step.	Supports detailed en-ergy modelling at the building and district scale.	Building characteristics, cli-mate data, occupancy pat-terns.	City/District	Hourly
CEA	Engineering & sta-tistical reduced-or-der method, inte-grated approach, hourly time step.	Combines engineer-ing and statistical methods for reduced complexity.	Building characteristics, cli-mate data, occupancy pat-terns.	City/District	Hourly
Ener-gyPLAN	Deterministic simu-lation model for re-newable energy systems with hourly time step.	Analyses energy sys-tem dynamics at city/regional scale.	Detailed energy system components, hourly de-mand and production pro-files.	City/Region	Hourly over a year
ENER-KAD	GIS-based tool for modelling energy demand and con-sumption at multi-ple scales.	Supports scenario analysis and detailed hourly modelling.	Basic cartography, cadas-tral, and climatic infor-mation.	Building to city	Annual and hourly

2.3 Additional considerations

Data Considerations:

To effectively model a Positive Energy District, it is crucial to collect data on energy production processes, categorised by technology and fuel type, as well as energy demands across different economic sectors [23]. Comprehensive data libraries play a fundamental role in PED modelling. To enhance consistency and interoperability, a standardised framework is required for organising urban and district-level data models [25].

Weather conditions must also be factored in when estimating solar and wind energy production. Various software tools, such as PVsyst, PVgis, WAsP, and TRNSYS, can be utilised to accurately predict the potential energy output of these renewable systems [12].
Data is needed regarding also energy production processes per technology and fuel type, as well as energy demands by economic sector [23].

Data libraries are essential for modelling a PED, and a framework is needed to standardise libraries for urban/district data models [25].

Geographical boundaries and scales:

When defining PED boundaries, several factors should be taken into account, including the potential for renewable energy generation, existing land use patterns, the urban built environment, and the layout of infrastructure. The selection of PED boundaries should consider renewable energy potential, land use patterns, urban built form, and infrastructure layout. Moreover it should also capture political, economic, social, legal, and spatial barriers and enablers [3].

Defining district boundaries is one of the first challenges to tackle. These boundaries can be geographical, virtual, or functional [12], [25].

PED assessments can be conducted at building, district, and city scales [25].The appropriate scale depends on the research questions being addressed [22]

Reference Timeframes:

The annual energy balance is a common requirement for PED definition. However, shorter time periods can give a better perspective on district performance [17].

Conversely, longer timeframes over the life-cycle of buildings and districts allow more holistic assessments towards climate neutrality and zero emissions neighbourhoods. [26]

Concepts of Efficiency, Production, and Flexibility.

Efficiency: Energy efficiency measures can reduce energy demand, and in some cases, may be more cost-effective than developing new supply capacity [27]. Efficiency of the energy system can be determined based on resource inputs and total energy sector demands [22].

Production: PEDs rely on local Renewable Energy Source (RES) generation systems to cover their own needs and potentially supply surrounding areas [12]. Distributed energy resources, such as residential rooftop PVs or micro-CHPs, contribute to achieving a positive net balance [28].

Flexibility: Energy storage technologies play a key role in enhancing flexibility and resilience within Positive Energy Districts [29]. Effective flexibility management is essential for balancing energy flows both within the PED boundaries and in connection with external energy systems [25]. To achieve this, flexibility strategies should focus on optimising energy management, including the development of modular hybrid microgrids and the refinement of control algorithms for real-time energy vector management [6]. The potential for energy flexibility in PEDs is particularly significant when multiple technologies interact within district energy networks, enabling more efficient and integrated energy distribution [12].

3. Technological Solutions for PEDs

Developing a PED requires a comprehensive integration of diverse energy technologies, efficiency measures, and innovative management systems. This chapter explores key technological solutions that contribute to PEDs, including renewable energy sources such as solar photovoltaics (PV), wind, hydropower, and geothermal heat pumps. Energy efficiency technologies, such as deep building retrofitting and smart building systems, further enhance PED performance by reducing overall consumption.

Additionally, energy storage systems—ranging from thermal energy storage (TES) and electrical energy storage (EES) to hydrogen production—play a crucial role in maintaining energy balance. Information and Communication Technology (ICT) solutions, including smart grids, energy management systems, and distributed ledger technology, facilitate efficient energy distribution and optimisation. The integration of e-mobility solutions, including electric vehicles (EVs) and public transport electrification, further supports PED objectives by enhancing energy flexibility and reducing emissions.
It is important to remember that beyond technological advancements, PED success depends on social innovation, policy frameworks, financial models, and urban planning strategies that ensure stakeholder engagement and long-term sustainability.

3.1 Energy Efficiency Technologies

Energy efficiency is a fundamental pillar in PED design, aimed at reducing energy demand and minimising losses:

- **Building Design**: Energy-efficient structures incorporate compact layouts, optimal orientation, and passive climate control solutions, such as solar shading devices, to minimise energy needs [8].
- **Thermal Insulation and Deep Building Retrofitting**: High-performance insulation materials and windows enhance the building envelope, reducing heat loss and improving overall efficiency [8], [30].
- **Advanced Materials**: Innovative materials contribute to energy-efficient buildings and improved energy generation [6].
- **Optimised Construction**: Thermal bridge-free and airtight constructions further enhance energy performance [8].
- **Smart Appliances**: Intelligent and energy-efficient systems for heating, cooling, ventilation, and lighting contribute to overall energy savings [6].
- **Smart Building Systems**: These systems use sensors and controls to optimise energy use based on occupancy, weather conditions, and other factors [30]
- **Energy-Conscious User Behaviour**: Encouraging behavioural changes through real-time energy consumption visualisation, smart meters, and adaptive controls fosters energy-conscious habits [8].
- **High-Efficiency Appliances**: Using appliances with high energy efficiency ratings reduces overall energy demand [2].

3.2 Renewable Energy Production

To meet energy demands sustainably, PEDs can integrate a high variety of local renewable energy sources:

- **Solar Photovoltaics (PV), Photovoltaic-Thermal Hybrid Collectors (PVT), and Building-Integrated PV (BIPV)**: PV panels installed on rooftops, facades, and surrounding areas [8]. These technologies generate electricity from sunlight and can be integrated into buildings or as separate installations [25]They directly contribute to energy positivity by providing on-site renewable energy generation, reducing reliance on external energy sources [30] [31], [6].
- **Solar Thermal Collectors**: To support water heating, reducing dependency on conventional thermal energy sources [8].
- **Geothermal Energy**: in combination with district heating and heat pumps [6]**.** This technology uses the earth's constant temperature to provide heating and cooling, enhancing energy efficiency and reducing the need for conventional heating/cooling systems [25].
- **Wind and hydro Power**: Small-scale wind turbines or connections to nearby wind farms can provide a consistent renewable energy input [32]. Suitable as Virtual Power Plants (VPPs) located outside the district's geographical boundaries, these can supply renewable energy to the PED through virtual boundaries [33].
- **Waste Heat Recovery**: Capturing and repurposing waste heat from industrial processes and data centers contributes to overall energy efficiency [6] and circular economy.
- **Biogenic Fuels & Waste-to-Energy**: Biomass and other organic/inorganic materials can serve as renewable energy sources to supplement PED energy systems [8] preferably if in line with circular economy principles. Waste Digestion, converts organic waste into biogas [25].

3.3 Energy Flexibility & Integration Technologies

Energy flexibility is crucial for balancing supply and demand, ensuring reliability and efficiency in the PED systems:

- **Energy Storage**:
  - **Electrical Energy Storage (EES)**: Battery systems store excess energy from renewable sources for later use [33], [16], [2].
  - **Thermal Energy Storage (TES)**: It can include boreholes and seasonal storage tanks that store heat or cold for later use, improving energy efficiency [25].
  - **Seasonal Storage**: Technologies designed for long-term energy storage help maintain energy availability across different seasons [6].
  - **Hydrogen Production**: Hydrogen can be produced from excess renewable energy and stored for later use [2], [33].
  - **Pumped Hydro and Compressed Air Energy Storage (CAES)**: Large-scale energy storage solutions that can be implemented as Virtual Power Plants (VPPs) [33].
- **Smart Grids**: Digital and ICT-based grid solutions enable demand-response management, load balancing, and optimised renewable energy use [6].
- **District Heating and Cooling (DHC)**: Integrating low-temperature renewables in district heating and cooling networks enhances energy efficiency [27].
- **Electric Vehicle (EV) Integration**:

  - **Smart Charging**: Ensuring that EV charging aligns with grid capacity helps prevent imbalances [8].
  - **Vehicle-to-Grid (V2G)**: EVs function as mobile energy storage units, supplying power back to the grid when needed [6].
- **Microgrids**: Localised energy networks operate either independently or in coordination with the main grid, improving energy self-sufficiency and resilience [6].

3.4 Information and Communication Technologies (ICT)

ICT plays a key role in optimising PED operations by enabling intelligent energy management and data-driven decision-making:

- **Energy Management Systems**: Smart platforms help balance energy production, storage, and consumption efficiently. These systems control and optimise energy flows, balancing local demand and supply of RES, including EV charging infrastructure for load shifting and energy storage [8].
- **Local Energy Markets and Distributed Ledger Technology**: Facilitates the trading of energy within the district and its surroundings, creating incentives for local energy generation [33]. Blockchain-based peer-to-peer energy trading platforms promote decentralised energy use [8].
- **Building Energy Management Systems (BEMS)**: These systems monitor and optimise energy performance at the building level [8].
- **Data Driven approaches, Data Analytics & AI**: Advanced data processing techniques and AI-driven predictive modelling enhance energy forecasting and grid optimisation [8]. Use data analytics to improve energy efficiency and identify new business opportunities [16].
- **Interoperability**: Optimal operation of PEDs requires high interoperability among various stakeholder's systems and equipment, including systematic data exchange through application programming interfaces (APIs), with defined ontologies [8].

3.5 E-Mobility Integration

Sustainable mobility is an integral aspect of PEDs, supporting energy flexibility and reducing transport-related emissions:

- **Charging Infrastructure**: Dedicated EV charging stations are integrated into PED energy networks [8]. Integrating EV charging infrastructure into PEDs can add flexibility by using EVs for energy storage and load balancing [28], [9].
- **Smart Mobility Solutions**: Mobility-as-a-Service (MaaS) platforms encourage shared and collective mobility options [5]. Includes electric bicycles and other sustainable transportation options that reduce reliance on traditional vehicles [28].
- **Integration with Renewable Energy**: EVs are charged using locally generated renewable energy, minimising stress on the power grid [6].
- **Integration with Public Transport**: Development of public/private type vehicles, for people/goods, and associated elements and infrastructure for their deployment [31].

3.6 System and Technology Integration

Achieving energy positivity in PEDs depends on seamless coordination between various technologies and energy systems. PEDs require the integration of different systems and infrastructures, including buildings, energy systems, mobility systems, and ICT systems [10]:

- **Sector Coupling**: Integrating electricity, heating, cooling, and transport systems enhances energy efficiency and flexibility [19].
- **Demand-Side Management (DSM)**: Digital tools enable real-time optimisation of energy consumption patterns, improving self-sufficiency [12].
- **Virtual Power Plants (VPPs)**: Distributed energy resources are interconnected to function as a single entity, enhancing grid interaction and resilience [33].

4. Monitoring, Assessment, Certification, and Evaluation

The monitoring, assessment, certification, and evaluation aspects of Positive Energy Districts require a systematic and integrated approach to assess their performance throughout all phases: conceptualisation, implementation, and operation. This process integrates Key Performance Indicators (KPIs), standardised monitoring methodologies and systems, and alignment with relevant certification schemes. While these schemes were initially developed for individual buildings, many have since evolved to include district- and neighbourhood-scale frameworks. These now address criteria such as energy efficiency, renewable energy integration, carbon neutrality, and broader goals of sustainable urban development. The certification systems listed below are provided as reference examples. Their purpose is to help users identify existing frameworks that may support PED assessment, comparison, or further methodological development, depending on the local context and project objectives.

Certification System	Country/ Origin	Scope	Energy Focus
LEED for Cities and Communities	USA	City/District-scale sustainability and performance	GHG emissions, energy efficiency, renewables integration
BREEAM Communities	UK	Sustainable master planning for communities	Energy use, efficiency, and low-carbon infrastructure
DGNB Urban Districts	Germany	Sustainability of urban districts	Energy, climate-neutrality, life-cycle performance
One Planet Living	UK	Community-scale sustainable living	Zero carbon energy, low-impact lifestyles
CASBEE for Urban Development	Japan	Neighbourhood-scale environmental performance	Energy efficiency and renewable use at district scale
Living Community Challenge	USA	Net-positive, regenerative communities	Net-positive energy requirement
Green Star - Communities	Australia	Sustainability of urban developments and precincts	Energy and GHG reductions, innovation credits
PEARL Rating System for Communities	UAE	Sustainable urban planning in UAE context	Energy performance and resource efficiency
ISO 37101	International	Management framework for sustainable communities	Strategic planning for energy and resilience

Evaluation frameworks and KPIs

A robust and multi-dimensional evaluation framework is essential to measure the technical, environmental, economic, and social impacts of PED initiatives, both at the project level and the city level. Such a framework ensures alignment with international reference standards, supports performance tracking and enables comparability and replication across different urban contexts.

Evaluation Scope [34] :

The assessment should be conducted at two key levels:

- PED Level: Evaluates the specific demonstration activities and their direct impact on the district.
- City Level: Measures the broader urban implications, tracking how PED strategies contribute to city-wide sustainability and energy transition goals.

The evaluation must align with established reference frameworks to ensure consistency, comparability, and integration into wider urban planning strategies.

Project Level Evaluation [34]**:**

It focuses on assessing technical **performance, environmental benefits, economic feasibility, and social acceptance** of PED demonstration activities. It aims to **validate the effectiveness** of the implemented solutions and identify areas for improvement.

City Level Evaluation [34]:

It develops a comprehensive diagnostic method for cities to assess their progress towards sustainability and smart energy management. Provides insights into how PEDs contribute to urban energy strategies, emission reduction targets, and overall livability.

Evaluation Procedure [34]:

A structured evaluation process should include the following key steps:

- Selection and Definition of Indicators: Identifying relevant KPIs based on PED objectives and establishing a monitoring and impact assessment framework.
- Baseline Definition: Determining the initial conditions of the PED to provide a reference point for comparison.
- Monitoring: Tracking key performance indicators throughout the project lifecycle to assess progress and effectiveness of PED interventions.
- Feedback Mechanisms: Integrate findings from monitoring into ongoing planning and decision-making processes. This ensures that PEDs can adapt to dynamic conditions and continuously improve based on real-time performance.

Impact Assessment [6]:

Beyond technical evaluations, it is crucial to assess how PED initiatives align with citizens' needs, perceptions, and urban challenges. This includes issues such as air pollution, mobility, energy poverty, and access to clean energy. Evaluating PEDs in relation to these urban challenges highlights their role in creating holistic, people-centred solutions. This ensures that PEDs function not as isolated technological pilots, but as catalysts for systemic and inclusive urban transformation aligned with city-scale decarbonisation goals.

Evaluation begins with the definition of a **baseline scenario**, representing "business-as-usual" condition of the district prior to PED interventions. This baseline enables comparative assessment of energy savings, emission reductions, and social or economic benefits post-implementation.
Key Performance Indicators (KPIs) serve as essential tools for both **quantitative and qualitative** assessment of performance across various sustainability dimensions. They provide measurable insights into the effectiveness of urban interventions and help track progress towards sustainability goals.
KPIs must be clearly defined, standardised, and traceable to baseline and target values. They are selected to measure progress across different dimensions:

- Energy perfomance (e.g., final/primary energy use, on-site RES share).
- Environmental impact (e.g., GHG emissions).
- Economic viability (e.g., cost savings, payback).
- Social acceptance (e.g., engagement levels, participation).
- Mobility and accessibility (e.g., EVs and infrastructure level).
- System flexibility (e.g., demand response, load shifting) [34].

The CITYkeys framework provides a comprehensive set of Key Performance Indicators (KPIs) designed to assess sustainability and smart city initiatives at both the city-wide and project-specific levels. These indicators facilitate the evaluation of urban performance and the effectiveness of implemented projects, ensuring alignment with broader sustainability goals [35] and they are applicable and adaptable to PED evaluation.

The categorisation of KPIs typically encompasses multiple dimensions to ensure a holistic evaluation of urban sustainability. Commonly used categories include **Energy & Environment**, which assesses energy efficiency and ecological impact; **Mobility**, which evaluates transportation sustainability and accessibility; **Economy**, which measures economic resilience and growth; **System Flexibility**, which considers the adaptability and integration of urban systems; and **Social & Residents**, which focuses on citizen engagement, well-being, and social inclusivity [34]. To ensure a comprehensive assessment of urban sustainability, KPIs should cover a broad spectrum of aspects, integrating **environmental, social, and economic dimensions**. Additionally, these indicators should address the **intersections** between these domains, recognising the interconnected nature of sustainability challenges and opportunities [36].

Going more into the details of the above listed categorisation:
Energy & Environment Indicators reflect two of the core missions of PEDs, i.e. achieving a net positive energy balance, assessing energy efficiency and environmental impact [34].
Key indicators include:

- **Final energy consumption** (kWh/(m²a)), which measures the total energy demand within a given area.
- **Greenhouse gas (GHG) emissions** ($kgCO_2$-eq/(m²a)), quantifying the environmental footprint of energy consumption.
- **Reduction of emissions** ($kgCO_2$-eq/a), indicating the effectiveness of interventions aimed at decreasing carbon emissions.

Social Indicators [25], as a critical aspect of urban development, requiring active stakeholder involvement and community engagement. Key indicators include:

- **Stakeholder engagement** and **community acceptance**, which assess the level of public involvement and support for Positive Energy District (PED) initiatives.
- **Perception monitoring** and **community participation**, ensuring that interventions are inclusive and widely accepted, thereby enhancing their legitimacy.

Economic Indicators [34]**,** to evaluate the financial viability and economic impact of PED actions is crucial for long-term sustainability. Key economic indicators include:

- **Total investments (€)**, representing the financial commitment required for implementation.
- **Payback time (years)**, which indicates the period required for cost recovery through savings and returns.
- **Economic value of savings (€ per saved kWh)**, assessing the financial benefits derived from energy efficiency measures.

Mobility Indicators [34]**,** to consider sustainable mobility in urban energy transitions. Relevant KPIs in this category include:

- **Number of public EV charging stations installed**, which reflects infrastructure expansion for electric vehicles.
- **Energy delivered for EV charging**, quantifying the total energy supplied for electric mobility.

Co-Benefits and Multiple Benefits [6]**,** [37]**:**

In addition to direct energy and environmental benefits, PEDs generate **multiple indirect advantages**, which contribute to broader urban sustainability and well-being. These include:

- **Improved air quality**, resulting from reduced emissions and cleaner energy sources.
- **Reduced health costs**, as a consequence of better environmental conditions leading to lower rates of respiratory and cardiovascular diseases.
- **Increased property values**, due to enhanced urban infrastructure and liveability. While these benefits can be **challenging to quantify**, they play a crucial role in ensuring stakeholder support and long-term success of PED initiatives.

Therefore, evaluation frameworks emphasise that neighborhoods can only be evaluated by considering the combined effect of multiple factors. A holistic approach is needed to ensure the consideration of appropriate measures and mitigation of known obstacles [36]. Moreover, the multiple benefits approach, with direct involvement of the local community and key actors, ensures that the PED project is evaluated assuming the right perspective and shared values by using appropriate weighting or discount factors. This approach also facilitates the communication and promotion of the projects ensuring wider acceptance [38]. Possible methodologies include the use of the SROI to facilitate this bottom-up evaluation approach in innovative urban projects [39].

Key Performance Indicators (KPIs) are also crucial for ensuring stakeholder agreement on targets, evaluation, and monitoring. Values of indicators should be assessed using standardised methods to allow comparisons between different action plans or projects [35].
A deeper investigation into **quality-related factors** and **potential negative externalities** of Positive Energy District applications is crucial for enhancing stakeholder engagement and fostering investment willingness [5], [40].

> **Quality-Related Factors:** Ensuring the reliability, efficiency, and resilience of PED systems is essential for their long-term viability. This includes aspects such as energy system stability, interoperability of technologies, and integration with existing urban infrastructure. A robust assessment framework should address potential performance gaps and strategies for continuous optimisation.
>
> **Potential Negative Externalities:** While PEDs offer numerous advantages, it is essential to assess and mitigate unintended consequences, such as social inequalities in energy access, increased upfront costs for residents, potential land use conflicts, and technological lock-in risks. Addressing these challenges through inclusive planning, financial support mechanisms, and adaptive policies can enhance the overall sustainability and acceptance of PED initiatives.

4.1 Monitoring Frameworks, Methodologies and Phases

A comprehensive and standardised monitoring system is essential for evaluating PED performance to ensure consistency, reliability, and comparability of results. These systems should define key performance targets (quantitative and q), process, process-oriented objectives (e.g., user engagement), high-quality data acquisition, measurement, collection, processing, assessment, and secure storage, as well as evaluation and feedback loop procedures. By establishing clear methodologies, these standards facilitate accurate performance tracking, continuous improvement, and data-driven decision-making throughout the PED lifecycle [41].

Quantitative and Qualitative Data Collection:
A robust evaluation framework for Positive PEDs requires a combination of **quantitative and qualitative data collection methods** to ensure a comprehensive assessment of energy performance, social acceptance, and environmental impact [34].

- **Quantitative methods** rely on objective measurements and technological tools such as energy meters, environmental sensors, and digital twins to track energy consumption, emissions, and system efficiency. These tools enable real-time monitoring and retrospective analysis to identify deviations from expected performance.
- **Qualitative methods** complement numerical data by incorporating stakeholder consultation, community surveys, and participatory workshops. These approaches assess perceptions, behavioural responses, and social acceptance of PED initiatives, ensuring that technical solutions align with the needs and expectations of local communities.

This mixed approach ensures that technical metrics are contextualised with social acceptance and behavioural insights.

- **Digital Tools and Technologies:**
- Advanced **digital tools** play a crucial role in monitoring and evaluating PEDs, particularly in contexts where direct measurement is challenging [34].

- **Digital twins** serve as virtual representations of energy systems, allowing for the simulation of energy flows, load profiles, and system interactions in districts where real-time monitoring infrastructure is not fully available. These models help predict energy demand, assess potential inefficiencies, and validate real-world performance against predefined sustainability targets.
- These tools also support **scenario analysis**, enabling policymakers and urban planners to explore different intervention strategies before implementation.

These technologies are especially valuable when real-time infrastructure is not yet fully developed or not available.

Long-Term Monitoring:

To fully understand the **impact and effectiveness** of PED interventions, data collection and evaluation must extend beyond the initial demonstration phase [34]. Long-term monitoring is essential for:

- **Tracking energy performance** over time, identifying seasonal variations, and assessing the durability of implemented solutions.
- **Measuring behavioural shifts** and the sustained adoption of energy-efficient practices among residents and stakeholders.
- **Evaluating co-benefits**, such as improved air quality, economic savings, and enhanced community well-being, which may take years to materialise [42].

Establishing **standardised data collection frameworks** ensures that PEDs continue to deliver their intended benefits while allowing for iterative improvements based on real-world insights, as well as being a support for replication and upscaling of PEDs [34].

4.2 Measuring and Monitoring Performance During All Phases

Effective performance measurement and monitoring is essential throughout all phases of a Positive Energy District project, ensuring that key objectives are met and that interventions remain adaptable to real-world conditions [43].

A structured approach should include the following considerations:

Assessment Across All Project Phases [43]**:**

Performance evaluation should be conducted at multiple stages of the project lifecycle to ensure consistency and alignment with sustainability goals. These stages include:

1. Planning Phase: Initial feasibility studies, site selection, and stakeholder engagement.
2. Brief and Preparation Phase: Defining project scope, objectives, and baseline conditions.
3. Early Design Phase: Exploring preliminary energy strategies and design concepts.
4. Detailed Design Phase: Refining energy models, selecting technologies, and ensuring compliance with PED principles.
5. As-Built Phase: Verifying that implemented solutions align with design specifications.
6. Operational Phase: Long-term performance tracking, maintenance, and optimisation of the PED system.

Integrating monitoring and evaluation from the start helps align goals, design, and implementation more effectively.

Integrated Energy Design Phase [19]**:**

Performance assessment should be category-specific, with clear guidelines distinguishing whether KPIs are computed during the Integrated Energy Design phase (before implementation) or in the Operational phase (after the system is in use). This distinction ensures that expectations set during design are validated through real-world data once the project is fully operational. In addition, it also helps identifying performance gaps and continuous system optimisation.

Iterative Process and Energy Balancing [12]**:**

PEDs require a dynamic and iterative feedback-based approach to optimise energy performance. Continuous examination of energy balances allows for testing different scenarios, refining system configurations, and selecting the most effective solutions for the district. This approach supports adaptive planning and ensures that PEDs can evolve in response to changing environmental conditions and energy demands. Key strategies may include the use of digital twins to simulate and optimise district energy flow, dynamic adaptation of energy strategies based on real-world data and, also, the integration of flexibility mechanisms.

Adaptations and Harmonisation with Standardised Frameworks [43], [44], [18]:

Pilot projects should be adapted in alignment with recognised Positive Energy District (PED) frameworks to ensure consistency in definitions, metrics, data management, and monitoring protocols. Harmonisation with established methodologies not only enhances comparability across projects and regions but also increases the robustness and transferability of outcomes.
While alignment with the **Zero Emission Neighbourhood (ZEN)** framework provides a solid foundation—particularly for incorporating energy performance, hourly data granularity, and multi-dimensional KPIs—further harmonisation with other standardised assessment approaches can enrich PED implementation.
For example:

- The **EN ISO 52000 series** provides a standardised approach to calculating the energy performance of buildings and districts, including primary energy factors, energy needs, and delivered/exported energy. It is particularly useful for ensuring consistency in energy balance calculations across PEDs.
- The **Smart Readiness Indicator (SRI)**, introduced under the EU Energy Performance of Buildings Directive, offers a structured evaluation of smart technologies' capacity to improve energy efficiency and flexibility—critical components of PEDs.
- The **LEED for ND, BREEAM Communities and DGNB Urban Districts** frameworks offer district-scale assessment schemes that integrate lifecycle-based sustainability indicators, stakeholder engagement, and infrastructure planning—elements that are highly relevant for the social and environmental dimensions of PEDs.

4.3 Data Strategy, Governance and Visualisation

A structured and reliable data management strategy is essential for effective monitoring, evaluation, and decision-making in PEDs. The data framework should address key aspects such as data collection, management, requirements, visualisation, and privacy, ensuring that insights are generated efficiently while maintaining compliance with legal and ethical standards.

Comprehensive Data Collection [8]:

Data should be collected at **multiple stages**, both **before, during and after** the different phases of PED initiatives (see chapter n.9).

The data scope should include energy production and consumption, environmental parameters, economic performance, and stakeholder engagement levels. By capturing pre-implementation baselines and post-implementation impacts, PEDs can demonstrate effectiveness and refine their strategies based on real-world performance.

Data Management in Monitoring and Evaluation Systems [43]**:**

Implementing a semi-automated monitoring and evaluation system enhances data consistency, reduces human error, and supports scalability. This system should integrate both quantitative (e.g., energy usage, emissions, cost savings) and qualitative (e.g., stakeholder feedback, social acceptance) data to provide a holistic understanding of PED performance.

Ensuring systematic, transparent, and standardised data handling is key to long-term project sustainability.

Defining Data Requirements and Protection Measures [34]:

Establishing clear data requirements is essential to ensure consistency and interoperability across PED projects. This includes defining:

- Datasets to be collected (e.g., energy flows, building performance, user behaviour).
- Collection methodologies (e.g., IoT sensors, digital twins, stakeholder surveys).
- Metadata specification (e.g., time resolution, units, sources).
- Protection measures, ensuring that sensitive information is handled securely and ethically.

A standardised approach facilitates comparability across projects and ensures compliance with data governance standards.

Visualisation for Enhanced Evaluation [19]:

Clear and interactive visualisation tools enhance the understanding of PED performance across different phases of implementation. Graphical representations such as dashboards, heat maps, and scenario modelling tools allow for real-time assessment and data-driven decision-making. Effective visualisation supports stakeholder communication, making technical data more accessible to policymakers, investors, and the public.

Data Availability and Privacy Considerations [34]**:**
While continuous data collection is crucial for performance monitoring, data privacy concerns and compliance with regulations such as GDPR (General Data Protection Regulation) present significant challenges.
Key considerations are:

- Anonymisation and encryption of sensitive data to protect user identities.
- Secure data-sharing frameworks, allowing authorised stakeholders to access necessary insights while ensuring confidentiality.
- Ethical considerations in data collection, ensuring that stakeholders are informed and consent to data usage.
- Addressing these challenges is essential to maintain trust, regulatory compliance, and long-term viability of PED data strategies.

5. Social Aspects & Stakeholders Engagement

Transforming urban districts into Positive Energy Districts is not solely a technical endeavour—it is also a deeply social one. Achieving lasting and inclusive energy transitions requires explicit attention to the social dimensions of change, including citizen engagement, co-creation, social justice, and cultural sensitivity. PEDs must respond not only to decarbonisation goals but also to local needs, community dynamics, and social equity considerations. This section provides an overview of key social aspects that should be integrated throughout the PED lifecycle, from planning and design to implementation and long-term governance. It also introduces the tools and frameworks available to support participatory processes, stakeholder analysis, and equitable policy design at the district scale. By embedding these social components in PED strategies, cities can ensure that energy transformations are not only sustainable but also inclusive, accepted, and resilient over time.

Key insights emphasise that PEDs are not static "products" but dynamic "processes" requiring ongoing engagement and adaptation to local contexts. The integration of social dimensions across all stages of PED development is critical for their scalability, acceptance, and long-term success [5], [3].

5.1 Social Aspects to Consider in PED Transformation

Below is an overview of the social aspects to consider at various stages of PED transformation and the tools available for social analysis and design on a district scale.

Citizen Engagement and Participation [6], [45].
Engaging citizens from the early stages is critical to align PED projects with local needs, increase transparency, and foster a sense of ownership.
A variety of participatory tools should be used to capture diverse perspectives:

- Workshops and citizen assemblies for direct interaction.
- Focus groups and informal interviews for targeted feedback.
- Digital engagement tools (mobile apps, online surveys) to broaden accessibility.

Meaningful participation helps identify priorities, concerns, and co-benefits of PEDs, ensuring their long-term acceptance and success.

Co-Creation and Urban Living Labs [8]**,** [10]**,** [11].
Co-creation methodologies and urban living labs provide an experimental and collaborative space where multiple stakeholders, including citizens, policymakers, researchers, and businesses, can jointly develop and test innovative solutions.
Living labs operate as real-world testbeds, allowing for:

- Hands-on experimentation with energy solutions.
- Capacity building and knowledge sharing among stakeholders.
- Iterative feedback loops to refine and improve PED interventions.

These collaborative spaces support adaptive governance, ensuring that PEDs evolve based on local experiences and stakeholder needs.

Social Justice and Inclusiveness [25]**,** [3].
PEDs must be designed to be socially just and inclusive, addressing potential risks such as:

- Energy poverty – ensuring fair access to affordable and sustainable energy.
- Housing affordability – preventing displacement and gentrification.
- Equitable distribution of benefits and burdens – making sure all social groups, including vulnerable populations, share in the advantages of PEDs.

Tools to assess and enhance social equity include:

- Justice evaluations to measure social impact.
- Participatory governance frameworks that include underrepresented voices.

Equity Assessments [6].
Ensuring that PEDs promote inclusive and fair energy transitions requires justice-focused evaluations that:

- Assess the distribution of benefits and burdens to prevent social exclusion.
- Address energy poverty and ensure affordable energy access for all community members.
- Mitigate risks of gentrification and displacement, ensuring vulnerable populations are not marginalised.

By integrating social equity metrics into PED evaluation frameworks, projects can enhance their legitimacy and societal impact.

Cultural and Local Context Sensitivity [45].
PED interventions should be tailored to local historical, cultural, and political contexts to maximise social acceptance and effectiveness.

Successful PEDs recognise and integrate:

- Local traditions and behavioural patterns related to energy use and mobility.
- Community narratives and historical identity to strengthen public support.
- Policy frameworks and governance structures that fit the existing urban fabric.

5.2 Available Tools for stakeholder identification and engagement

Ensuring inclusive, equitable, and collaborative development of PEDs requires the implementation of structured frameworks and participatory tools that align stakeholder interests, empower citizens, and foster long-term engagement. The following strategies provide a roadmap for integrating social dimensions into PED planning and governance.

Stakeholder Mapping and Analysis [6], [4].
Identifying and mapping key stakeholders is essential to understand their roles, needs, and contributions in the PED project. Key actors usually are:

- City authorities (municipal governments, urban planners).
- Citizens and community groups (resident associations, NGOs, energy communities).
- Energy providers and mobility service operators.
- Real estate developers and the private sector.
- Academia and research institutions supporting PED development.

GIS-based spatial analysis tools can help visualise and analyse the distribution of active stakeholders, identifying existing cooperatives, NGOs, and energy communities to enhance engagement strategies.

Stakeholder Mapping and Value Proposition Canvas [4].
Stakeholder mapping is essential for identifying key actors, their roles, and interrelations within the PED ecosystem. This process enables project developers to understand:

- The influence and interests of city authorities, private sector players, citizen cooperatives, NGOs, and research institutions.
- Potential areas of collaboration and conflict to create targeted engagement strategies.

The Value Proposition Canvas complements this by aligning stakeholder goals, expectations, and contributions with the PED's objectives, ensuring that each actor sees tangible benefits from participation.

Citizen Engagement Frameworks [46], [17].
Meaningful citizen engagement requires structured frameworks to integrate public participation into decision-making.
The Smart Energy City approach provides a guiding methodology to:
- Co-design PED interventions with local communities.
- Prioritise activities based on citizen needs, ensuring energy solutions are socially accepted and contextually relevant.

These frameworks foster transparent governance and enhance community ownership of PED projects.

Urban Living Labs and Innovation Playgrounds [10], [47], [11].
Urban Living Labs (ULLs) serve as experimental environments where stakeholders can test, refine, and optimise energy solutions before large-scale implementation.
These labs function as:
- Co-creation platforms where policymakers, researchers, and citizens collaborate on real-life energy transition experiments.
- Innovation hubs that facilitate knowledge exchange, capacity-building, and iterative solution development.

By embedding real-world testing into PED development, ULLs ensure that solutions are adaptable, scalable, and aligned with community needs.

Public-Private-People Partnerships (4P Model) [6].
PED transformation requires collaboration across multiple sectors through Public-Private-People Partnerships (4P).
These partnerships ensure alignment of interests between:
- Public authorities (municipalities, policymakers) providing regulatory support.
- Private sector stakeholders (energy companies, real estate developers) ensuring financial viability.
- Citizens and local communities, who are key end-users and co-beneficiaries of PED solutions.

The 4P model fosters innovative governance, balancing economic, environmental, and social priorities.

Participatory Action Research [45].
ensures that local knowledge and lived experiences shape PED design and implementation.
Methods such as:
- Focus groups help identify community-specific energy concerns and behavioural patterns.
- Community consultations provide an open forum for residents to express needs, preferences, and challenges.
- Participatory workshops co-develop solutions, ensuring greater adoption and social acceptance.

These approaches democratise the decision-making process, fostering long-term engagement and trust among stakeholders.

Capacity Building Tools [2].
Empowering stakeholders through training and knowledge-sharing programmes is critical for PED success.
Capacity-building initiatives should focus on:
- Enhancing citizens' understanding of PED goals and benefits.
- Providing technical training for local authorities, energy professionals, and community organisations.
- Supporting behavioural change through targeted educational campaigns on energy efficiency, renewable integration, and smart mobility.

Strengthening stakeholder competencies ensures that PEDs remain sustainable and adaptable over time.

6. Financial and Business Models

6.1 Financing PEDs

The financing of Positive Energy Districts involves various financial instruments, business models, and approaches that address the multi-actor, multi-level, and multi-sector nature of these projects. Below is a summary of financial and business aspects and instruments available during the different phases of PEDs (concept, implementation, operation), with a focus on Public-Private Partnerships (PPPs), project financing, and other tools. New financial instruments can be included in the form of debt (i.e. bonds and loans) or equity (i.e. funds or grants) for PEDs. These financial instruments would help channel capital into PED initiatives, while strengthening the role of sustainable finance, defined as the integration of environmental, social, and governance (ESG) criteria into private sector investment strategies as suggest also in [48].

Public-Private Partnerships (PPPs)
PPPs play a critical role in financing and implementing in Smart Cities [35] and consequentially in PEDs by leveraging shared investments, risk distribution, and innovation-driven solutions. These partnerships enable the scalability and financial viability of PEDs by fostering collaborative funding models between public authorities, private investors, and other stakeholders.
Key Advantages of PPPs in PED Development are:

- Bridging the Financing Gap:
  - PEDs require substantial initial capital investments that municipalities may struggle to secure independently.
  - PPPs allow for a combination of public funding (grants, municipal bonds, EU funds) and private capital (venture investments, green finance, corporate funds) to cover infrastructure costs and operational expenses.
- Risk and Responsibility Distribution:
  - By structuring partnerships between public and private entities, PPPs help balance financial, operational, and technological risks.
  - Public authorities ensure regulatory compliance and long-term policy alignment, while private entities contribute technical expertise, innovation and efficiency in execution.
  - Risk-sharing mechanisms, such as performance-based contracts and long-term concessions, ensure sustainable project implementation.
- Encouraging Private Sector Innovation and Investment:
  - Private companies play a crucial role in introducing innovative technologies, business models, and smart energy solutions within PEDs.
  - Well-structured PPP models ensure competitive rates of return for private investors, making PED projects attractive investment opportunities.
  - Performance-based incentives can align profitability with sustainability goals, ensuring that energy efficiency and renewable energy targets remain a priority.

Different PPP models can be applied to PEDs to balance investment, risk, and operational responsibilities between the public and private sectors. The choice of model depends on financial strategies, risk tolerance, and the level of public sector control desired.

Shared Public-Private Investment Model
A fundamental financing approach for PEDs involves blending public and private investments to create a shared financial commitment [6].

In this model, both investments and cost savings are jointly shared between public and private partners according to a predefined agreement.
The public sector contributes funding, regulatory support, and policy incentives, while private investors provide capital, technical expertise, and operational management.
Revenue-sharing mechanisms are established to ensure that both parties benefit from energy savings and long-term returns.
This model is particularly useful for co-financing renewable energy projects, smart grid infrastructure, and building retrofits within PEDs [19].
Key contributors include [6]:

- **City authorities**: Provide public funding through grants, subsidies, or direct investment in urban infrastructure.
- **Real estate developers**: Invest in energy-efficient buildings and smart urban solutions.
- **Energy providers**: Finance renewable energy generation and smart grid deployment.
- **Private investors and venture capital**: Support innovative PED technologies and business models.

Hybrid Public and Private Models [6].
These models involve local authorities that are willing to carry part of the risk and retain some level of control, while also leveraging private sector participation for financing and technical know-how.
a. Public-Private Joint Venture Model
In a joint venture, public and private entities co-own a PED project and share risks and responsibilities.
Risk Allocation:

- The public sector can underwrite sales risk, ensuring financial stability and long-term viability.
- The private sector assumes responsibility for design, construction, and operation risks, ensuring efficient project execution.

This model allows the public sector to maintain influence over strategic decisions while benefiting from private-sector efficiency and innovation.
b. Concession Contract Model

- Under a concession contract, a public authority develops a feasibility study and then tenders the project to a private entity - often an Energy Service Company (ESCO).
- The private sector is granted a concession to design, finance, build and operate the PED infrastructure for a specified term (e.g., 15-30 years).
- The private entity recovers its investment through user fees, energy savings, or public subsidies while the public sector retains ownership of the assets.
- This model is particularly effective for large-scale PED infrastructure projects such as district heating networks, renewable energy installations, and smart energy management systems.

6.2 Mixed Financing Models

PEDs require diverse and flexible financing mechanisms to ensure long-term economic viability, scalability, and stakeholder engagement. Mixed financing models integrate multiple funding sources, allowing for risk diversification, increased investment opportunities, and enhanced public-private collaboration.

Revolving Funds and Green Bonds [35]
Revolving funds are self-sustaining financial mechanisms that enable the repayment and reinvestment of initial capital in new PED projects. They are commonly used for energy efficiency retrofits, renewable energy deployment and infrastructure upgrades. As a PED project generates cost savings, the funds are recycled into additional developments, ensuring long-term financial sustainability and continuous investment in energy transition initiatives.

Green bonds serve as low-risk investment instruments that provide long-term financing for large-scale PED developments. Issued by municipalities or private entities, they support projects focused on renewable energy, energy efficiency, and climate resilience. These bonds offer attractive investment opportunities for institutional investors, banks, and pension funds seeking sustainable financial products, aligning capital markets with climate-friendly urban development.

Crowdfunding and Participatory Budgeting [2]**.**
Crowdfunding allows citizens and small-scale investors to actively participate in financing PEDs, fostering public support and strengthening local engagement. This approach has been effectively applied in funding community solar projects, energy cooperatives, and microgrid developments. By leveraging collective contributions, crowdfunding enhances financial flexibility and provides an alternative funding stream for PED infrastructure.
Participatory budgeting enables local communities to influence public investment decisions in PED projects, ensuring that funding allocations reflect community priorities. This process enhances transparency, promotes citizen ownership, and deepens grassroots involvement in energy transitions. Additionally, participatory budgeting strengthens the social acceptance and political legitimacy of PED initiatives by aligning financial resources with the specific needs and expectations of the communities they serve.

Co-investment opportunities [46].
They provide financial arrangements that enable individual households and companies to actively invest in PED projects, fostering a sense of ownership and direct involvement in the energy transition. These mechanisms encourage local communities to contribute to PED developments, strengthening financial resilience and enhancing public trust in sustainable urban initiatives. Additionally, incentives for participation [6], including policies such as tax breaks, subsidies, or direct financial incentives, support citizens in adopting renewable energy solutions and energy-efficient technologies.

6.3 Project Financing

PEDs requires financing models that accommodate their complex infrastructure needs, long payback periods, and significant upfront costs. Project financing must integrate public and private capital, ensure long-term financial stability, and align with urban sustainability goals.
Blended Finance [6].
Blended finance is a strategic approach that combines public grants, subsidies and concessional financing with private sector investments to reduce financial risks and attract private capital. Public contributions from municipal budgets, EU funding programmes, or climate-focused grants lower the overall financial burden and make PED projects more appealing to institutional investors, energy providers, and real estate developers. This model is particularly useful for financing large-scale PED infrastructure, smart grid deployment, and renewable energy integration, ensuring a balanced investment structure that leverages both public interest and market-driven efficiency.
Long-Term Loans and Subsidies [2]**,** [35].
Long-term loans and public subsidies can play an important role in the early stages of PED development by helping to overcome high initial capital costs and ensuring financial feasibility. Low-interest loans, government-backed credit lines and direct subsidies support energy-efficient building construction and retrofits, decentralised renewable energy systems such as solar PV, district heating, and microgrids, as well as smart energy technologies and digital infrastructure for demand-side management. These financing instruments allow for gradual repayment over extended periods, ensuring that PEDs can scale without placing excessive financial strain on public or private investors.
Place-based financing [6]**,** [48].

Place-based financing focuses on targeted investments in specific urban districts, aligning financial resources with broader urban planning, energy transition, and climate adaptation strategies. This approach involves strategic public-private partnerships that prioritise funding for PEDs in designated urban areas, municipal tax incentives, development funds and zoning policies that encourage local investment in sustainable infrastructure, as well as community-driven financing initiatives such as local cooperatives and neighbourhood investment schemes to ensure that economic benefits remain within the district. By embedding PED financing within territorial development frameworks, place-based financing ensures that investments are context-sensitive, equitable, and aligned with city-wide energy goals. This model not only secures essential funding, but also promotes community ownership and active participation, closely aligned with the community's core values of inclusivity and collective engagement.

6.4 Risk Mitigation and Financial Security

Effective risk management is essential for attracting investment in PEDs by ensuring financial security and building investor confidence. Given the complexity of PED projects, which involve long-term commitments, evolving regulatory frameworks, and emerging technologies, well-structured risk mitigation strategies help stabilise investments and support sustainable project development.

Regulatory sandboxes and living labs offer controlled environments where new financial models, policy mechanisms and technological innovations can be tested with reduced regulatory constraints. These frameworks allow stakeholders, including municipalities, energy providers and investors, to assess the feasibility and scalability of PED solutions before full-scale implementation. By facilitating experimentation with innovative business models and smart energy technologies, regulatory sandboxes help identify potential risks, regulatory gaps and operational challenges, enabling policymakers to refine policies and investors to make informed decisions. Living labs also promote collaboration among public and private stakeholders, fostering a co-creation process that improves the long-term viability of PEDs. [41].

Insurance mechanisms play a crucial role in mitigating risks associated with the adoption of new technologies, fluctuating energy markets, and regulatory uncertainties. As PEDs integrate decentralised renewable energy production, smart grids, and energy storage systems, financial and technical risks must be addressed to ensure project stability. Insurance solutions tailored to PEDs can cover potential losses related to technology performance failures, revenue fluctuations in energy markets, and changes in regulatory policies. Risk-sharing mechanisms between public and private actors, such as performance-based insurance and investment guarantees, further enhance financial security by distributing liabilities and stabilising long-term returns on investment. [2].

6.5 Capacity Building and Financing Support

Ensuring the successful implementation of PEDs requires capacity-building initiatives and financial support mechanisms that empower stakeholders with the necessary knowledge and resources. **Training and knowledge exchange programmes** play a crucial role in equipping city authorities, real estate developers, and citizens with a deep understanding of financial models, investment opportunities and risk management strategies. These programs enhance decision-making capabilities, ensuring that PED projects are effectively designed, financed, and implemented. Capacity-building efforts also promote collaboration among public and private actors, fostering a shared understanding of financial mechanisms that can drive PED deployment [2].

6.6 Regulatory and Policy Support

A well-defined regulatory and policy framework is essential to facilitate PED adoption and ensure financial feasibility. Policy incentives, such as subsidies and tax credits, help lower the upfront costs associated with PED projects. These financial mechanisms provide direct support to stakeholders, including municipalities, energy providers, and real estate developers, making it easier to invest in energy-efficient technologies, renewable energy infrastructure, and smart urban solutions. Incentive structures also encourage citizen participation by offering financial benefits for households and businesses adopting sustainable energy practices.

Streamlined regulations play a crucial role in reducing administrative barriers and expediting PED deployment. Aligning zoning laws, building codes, and energy regulations with PED requirements ensures a smoother permitting process and minimises bureaucratic delays (e.g. including district-level energy infrastructure such as geothermal fields or battery storage in the technical requirements for new development or regeneration projects). Simplified administrative procedures and standardised regulatory frameworks help lower transaction costs, making PED projects more attractive to investors and accelerating their integration into urban development plans. Harmonised regulations also support the scalability of PED models across different cities, facilitating knowledge transfer and replication of successful projects [2].

Finally, examples from European Union shown that support from European Commission and national programs provides critical funding and research opportunities for PED initiatives. European frameworks such as Horizon Europe, JPI Urban Europe, and other R&I funding programs offer dedicated financial resources to support PED research, development, and demonstration projects. These funding streams help cities and project developers access grants, technical assistance, and innovative financing solutions tailored to the needs of PEDs. By leveraging public funding sources, PEDs can accelerate implementation while attracting complementary private investments to scale up their impact [6].

7. Urban Planning and Spatial Integration

The successful integration of PEDs into existing cities requires a holistic and multidimensional approach that considers urban planning, land use strategies, and urban design principles. PEDs should not function as isolated energy hubs but rather as integrated components of urban ecosystems, harmonising with existing structures, governance frameworks, and social contexts. The following key aspects and considerations outline the necessary steps for embedding PEDs into urban environments.

7.1 Spatial Integration and Master Planning

Embedding PEDs within a city's master plan ensures their alignment with broader urban development objectives. Municipalities can utilise land use plans to guide the long-term structuring of cities, designating areas where PEDs can complement mixed-use developments, transportation networks, and public infrastructure. By proactively integrating PEDs into urban planning, cities can optimise energy flows, minimise conflicts with existing land uses and ensure PEDs support climate neutrality goals [46].

To enhance the integration process, land use surveys and impact assessments should be conducted before implementation. These evaluations provide valuable insights into local energy opportunities, helping to bridge the gap between energy targets and real-world implementation through participatory planning. By involving key stakeholders early on, these assessments facilitate the alignment of PEDs with community needs and local development strategies [6]. A fundamental step in PED integration is understanding the land use context and identifying suitable zones for their implementation. Cities must analyse zoning regulations at both macro and micro scales. At the macro level, this involves defining dedicated zones for residential, industrial, or public use, where PEDs can function optimally. At the micro level, detailed land-use maps, energy demand analyses, and urban morphology studies help pinpoint locations that maximise energy efficiency, mobility access, and integration with existing infrastructure [6].

The following strategies highlight key urban planning considerations necessary for the effective integration of PEDs into existing and future urban landscapes.

Guiding Development with Land Use Plans [46].

Municipal master plans and land use policies play a crucial role in guiding the long-term development of urban structures. Land use plans provide a framework for integrating PEDs into city planning by identifying suitable locations for sustainable energy districts. These plans incorporate spatial assessments, surveys, and impact evaluations, which generate valuable insights into local energy production potential, resource availability, and infrastructure needs. By embedding PEDs into zoning regulations and urban design guidelines, cities can align their energy transition goals with sustainable urban growth strategies.

Defining PED Boundaries Spatially [12].

PEDs require clear spatial boundaries that consider both physical and functional characteristics. These boundaries may encompass specific buildings, sites, or infrastructure networks, depending on energy generation capacity, land use patterns, urban morphology, and connectivity with surrounding districts. Physical constraints such as renewable energy potential (e.g., solar exposure, wind availability, NSGE), accessibility to energy grids, and infrastructure layout are key considerations in defining PED perimeters. Adaptive boundary-setting strategies ensure that PEDs remain flexible and responsive to urban development dynamics while maintaining energy-positive objectives.

Macro and Micro Scale Analysis for PED Development [6].

PED implementation requires a multi-scale analysis, ensuring that spatial integration is both strategic and location-specific. At a macro level, cities can use GIS-based spatial analysis to assess urban zoning, energy resources, and existing infrastructure. This includes mapping renewable energy potential, district heating networks, mobility corridors, and land-use functions to identify priority areas for PED establishment. At a micro level, refined assessments of urban form, building density, pedestrian accessibility, and local energy demands help define precise PED boundaries within targeted zones. This multi-tiered approach ensures that PEDs are optimally located to maximise energy efficiency and minimise environmental impact.

GIS for Spatial Data Integration in PED Planning [6].

The integration of Geographic Information Systems (GIS) and spatial data platforms plays a key role in identifying optimal PED locations and streamlining urban-energy planning efforts. GIS tools allow city planners to analyse spatial efficiency metrics, such as solar irradiation potential, building energy performance, and land use configurations. By integrating diverse data layers - ranging from infrastructure networks to climate conditions - municipalities can create data-driven planning strategies that enhance the feasibility and impact of PED projects.

PED Mapping Tool (EURAC Research – DUT KINETIC Project)

The PED Mapping tool is a GIS-based decision-support system developed by EURAC Research to assess the **suitability of existing neighbourhoods** for Positive Energy District (PED) development. It enables cities to conduct a **city-wide screening** to identify the most promising areas for PED transformation based on their current energy balances, building typologies, renewable energy potential, and existing energy infrastructure.

By integrating spatial data and multicriteria analysis, the tool allows users to:

- **Pre-evaluate neighbourhood energy balances** and energy efficiency potential.
- **Map renewable energy production capacity** and infrastructure availability.
- **Assess systemic redevelopment opportunities** at district scale.
- **Delineate optimal geographic boundaries** for future PEDs.
- **Explore alternative PED configurations and interaction scenarios.**

This spatially explicit approach supports cities in developing **evidence-based strategies** for PED planning, enabling the identification of **scalable and integrated interventions** aligned with the local context.

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https://jpi-urbaneurope.eu/project/kinetic

7.2 Integration with Existing Urban Structures

PEDs must seamlessly blend into the existing urban fabric, avoiding the risk of becoming energy "islands" disconnected from surrounding neighborhoods. Effective integration involves mixed-use development, where PEDs incorporate residential, commercial, and public spaces to enhance urban livability. The inclusion of high-quality public spaces, green areas, and blue networks (such as waterways and ecological corridors) further strengthens the connection between PEDs and their surroundings, promoting a sustainable and resilient urban environment [6].

However, challenges arise in densely built-up or historic areas, where space for on-site renewable energy generation is limited. Implementing PEDs in historic districts or high-density urban areas presents specific challenges, such as stringent building regulations, architectural preservation requirements, and limited space for renewable energy installations. Retrofitting older buildings with energy-efficient technologies while maintaining their cultural heritage can be complex, requiring customised solutions that balance modernisation with conservation.

In cases where on-site renewable generation is infeasible, cities may explore offsite energy procurement, community-based solar initiatives, or shared district energy systems to meet PED requirements. By leveraging flexible energy boundaries and integrating smart grid solutions, even compact urban areas can transition towards positive energy performance while preserving their architectural and cultural identity.

POCITYF is an EU-funded smart city project that will help historical cities to become greener, smarter and more livable while respecting their cultural heritage.
https://pocityf.eu/

Cities may establish virtual or functional PED boundaries, allowing them to be connected to offsite renewable resources such as solar or wind farms. This flexible approach ensures that PEDs can still achieve net-positive energy performance despite spatial constraints [5].

7.3 Addressing Regulatory and Organisational Gaps

Regulatory Gaps and Challenges in PED Deployment

The successful deployment of Positive Energy Districts (PEDs) requires comprehensive policy support and multi-level coordination, yet a lack of awareness or cooperation among stakeholders can significantly hinder progress [28]. Addressing regulatory inconsistencies, legal barriers, and administrative complexities is crucial for ensuring PEDs can scale effectively and integrate into existing urban frameworks.

National and EU-level legislation and commitments play a decisive role in shaping the design of PEDs and smart city solutions. However, implementation efforts are often constrained by conflicting regulations, subsidies that favour specific technologies over others, and complex regulatory frameworks that differ across governmental levels. These discrepancies create financial and legal uncertainty for project developers and municipalities, slowing down PED adoption.

Existing national legislation and legal frameworks may not always provide sufficient flexibility for innovation and experimentation, particularly in emerging sectors such as e-mobility, decentralised energy markets, and smart grid solutions [35]. Many cities encounter strict regulatory constraints that make it difficult to pilot and scale new energy solutions, reducing opportunities for technological advancement and PED optimisation.

Energy communities, a potential key component of PEDs, face significant legal challenges when their legal status is not formally recognised. Without clear legal definitions, energy communities are often unfairly compared to conventional energy providers, leading to regulatory burdens and financial entry barriers due to complex licensing requirements. This lack of legal clarity discourages citizen-led energy initiatives and weakens the financial sustainability of PED-based energy-sharing models.

Many PED-based microgrids and distributed energy systems struggle to access energy markets due to grid codes and standardisation issues, effectively cutting them off from participating in energy trading or demand response programs [35]. These constraints limit the economic incentives for PED stakeholders and reduce the viability of decentralised energy systems.

Land-use and building code regulations can further complicate PED implementation by restricting the installation of renewable energy systems, energy storage units and district heating networks. Zoning laws may not always be adapted to energy-positive urban districts, creating regulatory roadblocks for integrated, large-scale PED development.

Legal gaps in district energy infrastructure regulation, as well as inadequacies in existing energy laws related to storage and energy transfer, present additional obstacles [21]. Many regulatory frameworks were designed for centralised energy systems, making it difficult for PEDs to adopt decentralised renewables and flexible energy-sharing models.

Obtaining permits for PED projects is often a lengthy and complicated administrative process, increasing project costs and delaying implementation [6]. Cities that aim to achieve climate neutrality frequently struggle with regulatory difficulties due to inflexible national legislation that does not adequately support innovative urban energy projects [8].

Moreover, existing regulations might hinder the market adoption of mature yet underutilised technologies, limiting PEDs' ability to integrate cutting-edge renewable energy solutions, energy efficiency technologies, and smart mobility systems [2].

To overcome these challenges, it is essential to develop and approve dedicated policies, regulations, and standards for PEDs that govern their construction, operation, and management [49]. Establishing clear regulatory frameworks will provide certainty to investors, municipalities, and energy stakeholders, facilitating the widespread deployment of PEDs as core components of the energy transition and sustainable urban development.

Organisational Gaps and Challenges

Several organisational challenges can create barriers to PED development, leading to inefficiencies, project delays, and fragmented decision-making.

Administrative conflicts and differences in work culture can hinder PED implementation, as stakeholders from different sectors—such as municipal authorities, energy providers, and private developers—often operate under distinct procedural norms and institutional priorities. These differences create challenges in establishing shared goals, governance mechanisms, and decision-making frameworks that align with PED objectives.

Internal collaboration within city administrations requires better organisation, as siloed structures continue to be a major obstacle [35], [49]. Many municipal departments, including urban planning, transportation, energy, and environment, operate independently, leading to inconsistent policies, resource misallocation, and disjointed strategies. Without a well-coordinated governance model, PEDs struggle to achieve their full potential in integrated urban development.

Cross-sectoral and cross-silo collaboration is essential for delivering integrated solutions [6]. PEDs require cooperation between urban departments to optimise energy use, maximise synergies, and ensure resilient infrastructure. However, traditional governance models often discourage interdepartmental collaboration, slowing down innovation and cross-sector implementation.

Administrative systems dominated by siloed structures often lack effective coordination mechanisms, resulting in delays, duplicated efforts, and poor service delivery. PED implementation requires multi-agency cooperation, yet many local governments lack dedicated PED task forces, interdisciplinary working groups, or centralised decision-making units to manage projects efficiently.

A lack of connection between development agencies and city governing bodies can further hinder strategic PED development [49]. Municipal economic development agencies, energy authorities, and urban planners often operate independently, leading to missed opportunities for public-private partnerships, integrated funding mechanisms, and co-created energy solutions. Ensuring stronger collaboration between these entities can enhance PED scalability, investment attractiveness, and long-term sustainability.

A lack of clear definition of roles and responsibilities among stakeholders can lead to confusion and inefficient project execution [35]. PEDs require a multi-stakeholder approach, involving policymakers, energy providers, developers, research institutions, and citizens. Without well-defined governance structures, overlapping responsibilities or gaps in accountability can arise, delaying decision-making and hindering implementation.

Difficulties in cooperation and coordination between partners, along with complex administrative and policy procedures, create additional bureaucratic barriers [11]. Multi-level governance—across local, regional, and national bodies—introduces regulatory complexity, approval delays, and legal ambiguities, making it difficult to align PED development with existing policies and financial mechanisms.

Integrating PEDs into urban land-use planning requires close collaboration between energy planners and municipal authorities, ensuring that PEDs are positioned in optimal locations and supported by adequate infrastructure. Without this alignment, energy infrastructure may be planned in isolation, leading to inefficient or impractical PED deployments.

The siloed nature of monitoring and evaluation processes across disciplines presents another gap in PED development [11]. Urban sustainability efforts require cross-sectoral impact assessments, but many PED monitoring frameworks are disconnected from urban mobility, air quality, or socio-economic indicators, limiting the ability to assess holistic project outcomes. A lack of integrated data collection and evaluation mechanisms reduces transparency and makes long-term performance tracking more difficult.

A lack of common understanding among stakeholders regarding PED objectives, regulatory requirements, and financial mechanisms can act as a barrier to implementation [11]. Without shared knowledge and alignment, stakeholders may interpret regulatory frameworks differently, leading to miscommunication, delays, and suboptimal project designs.

Inadequate alignment between PED visions, strategic plans, legislative frameworks, and ongoing policy commitments can further complicate deployment [35]. Many cities face policy fragmentation, where PED initiatives do not align with broader national energy policies, climate targets, or zoning regulations. Addressing this requires harmonised policy development and institutional support for regulatory adaptations that facilitate PED integration into existing governance structures.

7.4 Bridging Urban and Energy Planning

One of the major barriers to PED implementation is the lack of integration between urban planning and energy planning. Traditionally, energy aspects have been treated separately from urban development, leading to regulatory gaps that hinder PED adoption. To overcome this challenge, collaborative planning processes should be established, involving city administrations, urban planners, energy providers, and real estate developers to ensure PEDs are fully embedded in urban governance frameworks [41], [6].

For PEDs to become a core component of sustainable urban development, cities must synchronise energy and urban planning efforts. Traditional urban development models often prioritise individual building efficiency, but for large-scale energy transition success, the focus must shift towards district-level and neighborhood-scale solutions. By embedding PEDs into broader urban strategies, cities can maximise resource efficiency, energy resilience, and emissions reduction, while fostering mixed-use environments that support vibrant communities [6].

PEDs necessitate a shift from traditional siloed planning approaches to integrated urban and energy planning strategies. Cities should adopt cross-sectoral methodologies that merge spatial planning with energy system design, incorporating renewable energy generation, energy storage, and smart grids into municipal development frameworks. This integrated perspective ensures that PEDs align with city-wide decarbonisation targets and contribute effectively to the energy transition [8].

Finally urban sustainability requires a proactive approach to site planning and urban design that incorporates energy efficiency principles into spatial development. PED-oriented planning should prioritise compact, pedestrian-friendly environments with well-connected public spaces and sustainable low energy mobility options. Urban design features such as low energy safe pedestrian and cycling networks, maximised open spaces, and energy-efficient building layouts enhance both livability and environmental performance. Thoughtful urban design ensures that PEDs not only optimise energy flows but also contribute to the creation of resilient and inclusive urban districts [50]. From this perspective, it becomes particularly relevant to explore the interaction between the PED concept and emerging paradigms of sustainable urban development (see chapter 10), such as Nature-Based Solutions (NBS) and the New European Bauhaus (NEB) initiative [48], which emphasise ecological regeneration, aesthetic quality, and social inclusiveness as core values in urban transformation.

8. Governance and legal aspects

To implement Positive Energy Districts effectively, governance and legal frameworks must be restructured to foster an integrated, multidisciplinary and collaborative approach rather than being hindered by fragmented silos.
The fundamental concept of a PED requires an integrated, multidisciplinary and multi-service approach [29], [35]. As already introduced in chapter 7, traditional governance structures in cities often operate in silos, where different departments or sectors work independently without effective communication or coordination. This siloed approach hinders the holistic planning and implementation necessary for PEDs [35].

8.1 Vision and Governance Frameworks

Holistic and Integrated Approach: The PED concept requires a holistic view and consideration of systems in all planning phases. It's not just about technology but about integrating legal, regulatory, and social innovations into the local ecosystem [41]. The transition towards carbon-neutral districts requires multi-sector and multidimensional solutions [11], [25].

Collaborative Governance and Multi-Stakeholder Governance Model: PED projects necessitate governance models that foster collaborative governance, which addresses specific challenges (e.g., complex regulatory requirements, conflicts of interest, long-term sustainability). Creating a shared in-depth framework for the definition of PEDs requires a multi-stakeholder governance model [25]. Essential for implementing PEDs, collaborative governance involves creating networks and coalitions for discussions and negotiations with a wide range of stakeholders [46]. This extends beyond citizen engagement to include larger energy companies, network operators, housing associations, and project developers. For instance, collaborative governance should go beyond direct citizen engagement, involving companies, NGOs, and public institutions in open planning and decision-making processes [6].

The Quadruple Helix approach: the Quadruple Helix approach is a collaborative innovation framework that brings together four key societal actors: **government**, **academia**, **industry**, and **civil society**. In the context of PEDs, this model supports the co-creation of solutions that are not only technically feasible and economically viable but also **socially accepted and institutionally supported**.
Each actor plays a distinct but complementary role:

- **Governments** provide regulatory frameworks, long-term planning strategies, and public funding mechanisms.
- **Academia** contributes with research, data, and methodologies for system integration and impact assessment.
- **Private enterprises** bring technological innovation, implementation capacity, and investment potential.
- **Citizens and civil society** ensure that solutions are context-sensitive, equitable, and aligned with local needs and values.

An illustrative example is the **Leuven 2030 initiative** in Belgium, where the city implements the quadruple helix model to pursue climate neutrality through a shared vision and inclusive governance structures By doing so, Leuven creates a strong ecosystem for climate innovation, rooted in local engagement and cross-sectoral collaboration [8].
In some emerging frameworks, the **natural environment** is considered a fifth, equally critical stakeholder—giving rise to the **Quintuple Helix model**. This expanded approach integrates ecological systems and the biosphere into the innovation process, recognising that sustainable development must account for planetary boundaries and ecosystem health as central design constraints. For PEDs, this means going beyond carbon neutrality to actively regenerate ecological functions, integrate nature-based solutions (NBS), and align with long-term climate resilience goals.

City Leadership: is a fundamental enabler of successful PED development. As cities are both the spatial scale of implementation and the institutional actors most directly connected to residents, their role must go beyond facilitation to one of proactive stewardship and strategic alignment. Cities need to take the lead in promoting the integrated and holistic planning of PEDs, ensuring that such initiatives are embedded within their long-term urban development strategies, climate action plans, and sustainability roadmaps [2].

Public authorities function as gatekeepers, regulators, and orchestrators. Their legal competencies over land use planning, zoning regulations, building codes, infrastructure provision, and public procurement position them at the centre of the PED ecosystem [10]. Through these instruments, municipalities can:

- Define spatial and energy performance requirements for new developments.
- Facilitate urban retrofitting and densification processes compatible with PED goals.
- Mandate or incentivise renewable energy integration, building energy efficiency, and low-carbon mobility.
- Ensure that PEDs contribute to social equity, resilience, and liveability, and not only to energy metrics.

In addition, city governments are uniquely placed to mobilise and convene stakeholders, enabling participatory planning processes and aligning diverse actors—from utilities to citizen groups—around a shared PED vision. Their capacity to coordinate across departments (e.g., planning, energy, housing, mobility) is essential to break institutional silos and to operationalise multi-sectoral and multi-level governance frameworks.

Moreover, municipal leadership is critical to de-risking innovation, by leveraging their credibility to attract funding, pilot regulatory innovations, and provide long-term policy stability. Cities can act as anchor clients for new technologies and financing models and play a key role in ensuring the replicability and scalability of PEDs within and beyond their jurisdiction.

Ultimately, strong and visionary city leadership is the backbone of a successful PED transition. It ensures that PEDs are not treated as isolated projects, but as strategic building blocks of climate-neutral, inclusive, and future-proof urban systems.

Permanent Improvement Loop: Implementing and maintaining PEDs requires more than one-time planning or static policy instruments—it calls for a dynamic and iterative governance model rooted in continuous learning and adaptation. This is where the concept of a Permanent Improvement Loop becomes essential.

Inspired by quality management systems (e.g. ISO 9001, ISO 14001), the Permanent Improvement Loop provides a structured framework that allows local authorities to monitor progress, identify bottlenecks, and systematically improve the planning, implementation, and operation of PEDs over time (Borsboom et al., 2019).

This approach typically follows a cyclical structure based on the **Plan–Do–Check–Act (PDCA)** logic [35]:

- **Plan**: Define strategic objectives, performance indicators, and action plans aligned with urban sustainability goals, climate neutrality, and PED targets. This includes stakeholder engagement, data gathering, and scenario planning.
- **Do**: Implement PED interventions, policies, and pilot projects—ranging from retrofitting and renewable energy integration to new governance models and behavioural programmes.
- **Check**: Continuously monitor outcomes using key performance indicators (KPIs) across environmental, social, and economic dimensions. This includes real-time energy monitoring, social feedback tools, and benchmarking with other districts.
- **Act**: Analyse lessons learned, adjust strategies, and upscale successful models. This phase involves re-engaging stakeholders, updating legal or financial frameworks, and refining the PED vision based on lived experiences and evolving conditions.

By institutionalising this feedback loop, local authorities can ensure that PEDs remain resilient, adaptive, and aligned with changing technologies, user needs, and regulatory frameworks.

Furthermore, the improvement loop supports:

- Transparency and accountability, by integrating monitoring and reporting mechanisms.
- Evidence-based policymaking, through the structured collection and evaluation of data.
- Scalability and replication, as processes become codified and transferable to new urban contexts.

In practice, this means embedding evaluation and re-evaluation capacities into municipal planning departments, linking PED performance data to digital twins or urban dashboards, and integrating feedback from citizens and stakeholders as a regular governance function—not a one-off consultation.

Ultimately, adopting a Permanent Improvement Loop allows PEDs to evolve beyond static pilot projects into living, learning systems, capable of contributing to long-term climate and sustainability transitions.

8.2 Policy and Legal Frameworks

Policy Frameworks: The successful realisation of climate-neutral districts requires well-structured policy frameworks and effective financial instruments at multiple political levels, e.g. ensuring alignment between European, national, and regional strategies in European countries [41]. The implementation of PEDs, in particular, demands coordinated policy support across governance levels to facilitate regulatory coherence, funding mechanisms, and incentive structures that drive investment and innovation in the energy sector [28]. Moreover, policies must integrate long-term sustainability goals while addressing socio-economic disparities to ensure inclusivity in the transition toward climate-neutral urban areas. Strategic urban planning, combined with cross-sectoral cooperation, is essential to enhance the resilience and adaptability of PEDs in varying urban contexts.

Legal and Institutional Challenges: The development of PEDs is not only a technological challenge but also a legal and institutional one. Regulatory frameworks play a pivotal role in shaping the technology ecosystems required for PED deployment, influencing aspects such as energy distribution, market access, and data governance. Legal advisors, policymakers, and institutional stakeholders serve as key facilitators in this process, ensuring compliance with existing laws while guiding public authorities and investors through the complex transformation towards smarter and more energy-efficient cities [6]. Furthermore, existing regulatory frameworks must evolve to accommodate new business models, innovative financing schemes and emerging energy-sharing mechanisms that support decentralised energy systems.

Overcoming Legal Barriers: Addressing legal barriers is a fundamental prerequisite for the effective implementation of PEDs, e.g. outdated urban planning laws, permitting hurdles, market monopolies. One major challenge is the regulatory complexity surrounding public-private partnerships (PPPs), which are essential for attracting private investment and fostering collaborative approaches between municipalities, businesses, and communities [41]. Legal uncertainties related to energy sharing, citizen-led energy communities, and data privacy must also be tackled to ensure regulatory clarity and encourage broader stakeholder participation. Additionally, harmonising national and international regulations concerning energy markets, grid integration, and sustainability standards is crucial for scaling up PED initiatives across different jurisdictions. Innovative regulatory approaches, such as regulatory sandboxes and experimental legal frameworks, may provide flexibility for testing new energy models and accelerating PED deployment.

8.3 Addressing Silos and Improving Governance Structures

System Thinking: Adopting a systems thinking approach is essential to addressing the complexity and interdependencies inherent in urban governance. This mindset shift enables policymakers, city planners, and stakeholders to identify and manage the dynamic relationships between different sectors, rather than treating them as isolated components. Systems thinking can be integrated into education, mid-management training, and workplace culture to build institutional capacity for holistic problem-solving [45]. Embedding this approach within policy design ensures that PED initiatives are developed with a comprehensive understanding of urban ecosystems, maximising synergies and minimising unintended consequences.

Nexus Approach: A holistic treatment of interdependent sectors requires policymakers to incorporate broader interdependencies and focus on the trade-offs and complementarities between systems [45]. By applying this perspective, decision-makers can design integrated policy frameworks that optimise resource efficiency, reduce conflicts between sectors, and enhance the resilience of PEDs. This requires the establishment of multi-sectoral planning processes and governance structures that facilitate cooperation across administrative boundaries.

Coordination Bodies: One of the primary challenges in PED implementation is overcoming institutional fragmentation. Establishing coordination bodies within government institutions can help counteract silo thinking by fostering interdepartmental dialogue and collaboration. These bodies should facilitate structured communication channels between different levels of government, private sector actors, and civil society, ensuring alignment between policies and implementation strategies [45].

Internal Collaboration: To ensure effective governance of PEDs, internal collaboration within city administrations must be systematically structured. A dedicated coordination entity - either an individual or a department - should be tasked with overseeing horizontal coordination efforts, bridging gaps between different municipal departments, and ensuring that PED policies align with broader urban development objectives. This entity must be granted a sufficient mandate, authority, and resources to facilitate cross-sectoral integration and decision-making [35].

Stakeholder Involvement: Engaging a diverse range of stakeholders - including local communities, businesses, academia, and NGOs - is critical to the success of PEDs. Widening the scope of stakeholder interaction enables the continuous co-creation of solutions, fostering adaptive cycles of PED exploration, deployment, and scaling [10]. Public participation mechanisms, such as participatory budgeting, citizen assemblies, and digital engagement platforms, can enhance transparency and ensure that PED strategies reflect local needs and aspirations. Moreover, promoting active citizen involvement in energy governance helps build public trust and support for PED initiatives.

Breaking Down Silos: Institutional silos remain a significant challenge to integrated governance. The lack of coordination between municipal departments, public agencies, and private entities can lead to inefficiencies, redundancies, and conflicting policy objectives. To address this issue, structured coordination mechanisms should be established at the municipal level to facilitate interdepartmental communication and collaborative decision-making. Additionally, creating regulatory and financial incentives for cross-sectoral cooperation can encourage stakeholders to work together towards shared sustainability goals. The promotion of interdisciplinary working groups, knowledge-sharing platforms, and joint funding schemes can further accelerate the breakdown of governance silos and support the holistic implementation of PEDs [45], [49].

8.4 Key Challenges and Considerations

Balancing Top-Down and Bottom-Up Approaches: The design and implementation of PEDs often follow hierarchical structures, aligning international sustainability goals with national policies and local urban planning frameworks. However, purely top-down approaches have proven insufficient in fostering the engagement and long-term success of PED initiatives. To achieve meaningful transformation, bottom-up strategies that incorporate locally relevant narratives and grassroots participation are essential. Effective PED deployment requires striking a balance between broad policy directives and localised implementation, ensuring that community-driven innovation and citizen engagement play a central role in shaping solutions tailored to specific urban contexts [29]. This hybrid approach enables better social acceptance, adaptive governance, and context-sensitive interventions.

Integrating Diverse Perspectives: The inherently multidimensional nature of PEDs necessitates an inclusive and interdisciplinary approach to design and implementation. Successful PED development requires the integration of various expertise areas, including energy system modelling, mathematical simulations, environmental impact assessments, and socio-economic evaluations. Furthermore, engaging a wide spectrum of stakeholders—from urban planners and policymakers to researchers, local businesses, and citizens—ensures that PEDs address real-world needs while maximising technological and social innovation [25]. A transdisciplinary perspective is crucial to aligning technical feasibility with community aspirations, economic sustainability, and environmental resilience.

Contextual Factors: The conditions under which PEDs are implemented can vary significantly depending on geographic, socio-political, economic and climatic factors. A systematic understanding of how these contextual elements influence different dimensions of PED deployment is essential for designing adaptable and resilient solutions [25]. Factors such as local energy infrastructure, regulatory environments, cultural attitudes toward sustainability and economic disparities must be carefully considered to customise PED strategies to specific urban environments. Moreover, the ability to anticipate and address potential barriers—such as market fragmentation, financial constraints or policy misalignment—enhances the replicability and scalability of PED initiatives across different European cities.

Governance Models: There is no universal governance model that can fully encapsulate the complex social and political mechanisms involved in PED implementation. Governance structures for PEDs must be flexible, adaptive, and context-sensitive, taking into account the unique regulatory landscapes and institutional settings of different urban regions [29]. Various governance configurations—ranging from centralised municipal-led initiatives to decentralised citizen-driven energy cooperatives—can influence the success of PED projects. Hybrid governance models that blend public oversight with private sector engagement and community participation can enhance institutional coordination, financial viability, and long-term sustainability. The development of inclusive decision-making processes, transparent regulatory frameworks, and supportive policy instruments is critical in fostering effective PED governance [5, 21].

9. Process Design for Implementing and Operating PEDs

The implementation of **Positive Energy Districts** is a **complex, multi-step process** requiring careful planning, stakeholder coordination, and iterative adaptation. PEDs are not static infrastructure projects but rather **dynamic processes of urban transformation**, integrating **energy systems, urban planning, governance, and community engagement**. The following sections summarise key insights from existing literature regarding **transition steps, feedback loops and actor involvement** in PED deployment.

9.1 Transition Steps, feedback loops and actors' involvement

The transition towards PEDs requires a phased, adaptive methodology, where energy performance is no longer assessed at the building level but instead through holistic, district-wide energy planning. [14] emphasize that PEDs break away from traditional building-centric energy models by applying integrated strategies for renovation, energy efficiency, and renewable energy deployment within an interconnected urban system. PED implementation varies based on local conditions, and as [3] highlights, the feasibility of achieving PED status depends on inherited local characteristics and resource availability, requiring tailored approaches for different urban contexts.
Several frameworks outline structured steps for PED deployment. The SCIS PED Solution Booklet [8] reinforces that PEDs are "not a product, but rather a process," emphasising continuous evolution and improvement. [51] highlight the significance of aligning guidelines with various phases of urban energy transitions, drawing from the six-step process outlined in the City-zen project. This structured approach emphasises the necessity of feedback loops throughout the implementation of PEDs, ensuring continuous evaluation, adaptation, and optimisation at each stage of development.
The MAKING-CITY project proposes a six-phase methodology for PED planning and execution [6]:

1. Analysis of City Characteristics – Understanding urban morphology, energy demand, and infrastructure.
2. Identification of PED Concept Boundary – Defining spatial limits and energy networks.
3. Citizen Participation & Solution Integration – Engaging communities and linking PED design to technological solutions.
4. Barrier & Enabler Analysis – Addressing regulatory, financial, and social challenges.
5. Energy Calculations – Determining energy flows, production, and consumption.
6. Solution Cards (SPECs) – Formalising design and implementation strategies.

Similarly, the SET-Plan Action 3.2 Implementation Plan outlines six interlinked PED development modules, including European PED cities, PED labs, guidance tools, replication strategies, monitoring frameworks, and innovation actions.

The Smart City Guidance Package [35] (SCGP) provides a systematic methodology for designing, planning, and implementing integrated smart city projects that can be easily applied to PEDs, emphasising a step-by-step quality management approach (see chapter 8). SCGP presents a structured improvement loop, aligned with the European Energy Award, comprising the following stages:

- VISION: The foundation of smart city projects, where stakeholders engage in brainstorming sessions to develop a shared knowledge base and strategic direction.
- DECIDE & COMMIT: The transition from conceptualisation to strategy formulation, translating the vision into clear objectives, policies, and strategic plans.

- PLAN: Making the strategy operational by defining targets, milestones, stakeholder roles, cost-risk assessments, and resource allocation. This stage involves ten key “TO DO’s”, including financial planning, feasibility studies, and public consultation.
- DO: Execution phase, where detailed action plans are implemented, kick-offs are organised, monitoring mechanisms are established, and projects begin.
- CHECK: Continuous performance assessment using Key Performance Indicators (KPIs), regular progress evaluations, and analytical meetings to address challenges and gaps.
- ACT: Implementation of corrective actions and adaptations to ensure project goals are met, creating a dynamic response mechanism to unforeseen challenges.
- REPLICATE & SCALE UP: Establishing preconditions for knowledge transfer, enabling replication of successful projects in new locations, and sharing best practices.

The PED-LAB methodology, [11], adopted the six-stage framework proposed by the SCGP but tailored to Positive Energy District (PED) innovation and testing environments:

- VISION: Development of initial PED concepts, largely influenced by universities, research institutions, and government planners.
- DECISION: Key policy, regulatory, and financial choices that determine the feasibility of PED projects.
- PLAN: Involves detailed project design, identifying enabling infrastructure, policy alignment, and funding sources.
- DO: The implementation phase, where the private sector (industry and developers) plays a central role in project execution.
- CHECK/ACT: Ongoing performance assessment and corrective adjustments to optimise PED operations.
- UPSCALE/REPLICATE: Expanding the PED model to new locations by applying lessons learned and scaling up proven solutions.

A significant aspect of the PED-LAB methodology is its stakeholder-driven approach, recognising that different actors play dominant roles at different stages. For example, academic institutions and urban planners lead the early VISION phase, while developers and industry take the lead during the DO phase.

The report also highlights barriers and drivers affecting PED implementation, categorising them into:

- Policy, regulatory, financial, economic, social, technological, awareness, and market-related barriers, which can slow down PED adoption.
- Endogenous drivers (internal project factors, such as effective governance) and exogenous drivers (external factors like national energy policies) that influence the success and replicability of PEDs.

Additionally, PED-LAB implementation requires specific facilities and resources—both tangible (e.g., infrastructure, technology) and intangible (e.g., governance frameworks, stakeholder engagement models)—which vary in importance across different process stages.

Both SCGP and PED-LAB methodologies emphasise structured, iterative processes and stakeholder-driven approaches to urban innovation. However, their applications differ:

Aspect	**Smart City Guidance Package (SCGP)**	**PED Laboratory (PED-LAB) Model**
Scope	Broad smart city projects, including digitalisation, mobility, and energy	Focused on PED implementation, energy transitions, and sustainability
Process Phases	VISION, DECIDE & COMMIT, PLAN, DO, CHECK, ACT, REPLICATE & SCALE UP	VISION, DECISION, PLAN, DO, CHECK/ACT, UPSCALE/REPLICATE
Stakeholder Roles	Local authorities play a central role throughout	Role shifts from research institutions (early phase) to developers (execution phase)
Scalability Strategy	Emphasises systematic replication and scaling of best practices	Focuses on innovation testing before large-scale rollout

Both frameworks support a transition to sustainable urban energy solutions but differ in their focus areas and operational mechanisms. SCGP provides a city-wide governance model, while PED-LABs act as experimental environments for developing and testing PED innovations before full-scale implementation.

Also [52] identify key actors involved in the implementation of PEDs, including citizens, decision-makers, technology providers, and value generation providers. They emphasise the necessity of forming a balanced consortium that integrates beneficiaries and partners from diverse knowledge disciplines and various sectors within the energy ecosystem, ensuring a holistic and inclusive approach.
Similarly, [45] underscores the critical role of multi-stakeholder involvement in PED development, stating that the perspectives of different stakeholders must be incorporated throughout the planning and implementation process. This approach ensures that PED projects address public demands while also leveraging market potential, fostering both social acceptance and economic viability.

9.2 Process and complexity

The implementation of PEDs is an inherently complex process, requiring the coordination of multiple actors, technologies, and governance structures. [5] emphasise the complexity of implementing PEDs, stating that PEDs go beyond being technologically advanced energy systems noting that "PEDs are not only advanced energy systems from the technological point of view, but also from the integration perspective of urban design and governance." Their success depends on the seamless integration of urban design and governance frameworks, highlighting the need for a multidisciplinary and systemic approach to PED development.
PED deployment involves a high degree of process complexity, requiring extensive coordination between technical, economic, regulatory, and governance domains. The challenges span energy forecasting, urban simulation, stakeholder management, regulatory barriers, decision-making, business model development, and data integration.
To successfully implement PEDs, cities must:

1. Develop integrated planning frameworks that align urban development, energy policies, and regulatory structures.
2. Leverage digital tools and IoT-based platforms to enhance energy simulations, monitoring, and optimisation.
3. Foster multi-stakeholder collaboration by creating structured governance models and participatory decision-making processes.
4. Simplify public procurement procedures to improve accessibility for a diverse range of market players.
5. Establish flexible financial mechanisms to support business model innovation and long-term economic viability.

The following sections summarise key areas contributing to the process complexity of PEDs, highlighting insights from various sources.

Demand Forecasting and Energy Planning Complexity.
A key challenge in PEDs is the accurate prediction of energy demand, particularly for (District) Heating and Cooling (DHC) systems. These systems rely on stochastic models that require complex mathematical simulations to forecast heat and cooling loads, making planning highly data-intensive [53]. Additionally, formulating a standardised methodology for defining and evaluating PEDs is difficult due to varying local conditions and the need to account for factors like transportation energy use, which is often omitted from energy balance calculations [3].

Urban Environment Analysis and Simulation Complexity.
Detailed urban-scale analyses are essential for PED implementation, requiring assessments at neighborhood and building scales. These include evaluations of solar radiation, shading effects, thermal storage, wind conditions, and microclimate impacts. However, such simulations are computationally demanding and time-intensive [50].
Similarly, PV tool simulations at different urban scales require balancing precision and computational efficiency. The preparation of urban-scale energy models often takes longer than the actual simulation process, adding to the complexity of energy planning and optimisation [54].

PED Planning within Smart City and Climate Neutral and Smart City (CNSC) Complexity.
PED implementation is complicated by the multi-stakeholder nature of CNSC city plans [11]. The involvement of diverse actors with conflicting interests increases decision-making complexity, requiring clear frameworks to define ecosystem roles and responsibilities [35]. Other factors adding to PED planning complexity include:
- Retrofitting existing buildings and integrating them into district heating systems, which is particularly challenging for building owners [35]
- Negotiating collective agreements in multi-owner buildings, leading to legal and administrative hurdles [35].
- Public procurement procedures, often considered overly bureaucratic, time-consuming, and discouraging for small and medium enterprises (SMEs) [35], [49].
- Coordinating multiple building blocks, diverse stakeholder ambitions, and complex legal and financial structures, which demands high levels of cross-sectoral collaboration [8].

Complexity in the framework of PEDs, Energy Communities (ECs) and Peer-to-Peer Energy Trading.
The design and operation of ECs within PEDs introduce additional layers of complexity, heavily influenced by the use case, regulatory framework and number of actors involved [21]. Key challenges include:
- Managing peer preferences and grid congestion while ensuring scalability of energy trading negotiations [21].
- Developing ICT infrastructure for decentralised energy transactions, requiring sophisticated data-sharing mechanisms to maintain grid stability [21].

Urban Laboratories (PED-LABs) and Regulatory Complexity.
PED-LABs, designed to test and refine PED models, encounter multiple policy, regulatory, financial, social, and market-related barriers [11]. The implementation of PED-LABs is further complicated by lengthy authorisation procedures and the need to coordinate numerous project partners, making the process slow and administratively burdensome [11].

Decision-Making Complexity in PEDs.
The decision-making process in PEDs is shaped by technical, economic, and political interdependencies.
PED projects involve dynamic problem-solving, where different actors must align solutions with market conditions, regulatory constraints, and financial viability [29].

Modelling and Simulation Complexity.
Scaling energy models from single-building simulations to city-scale applications presents technological challenges. Integrating thermal and electrical system modelling within PEDs is particularly difficult due to differences in their dynamic characteristics [16].

Business Model Complexity.
Developing investment-ready business models for PEDs is a slow and iterative process. Key factors contributing to complexity include:
- Determining the financial viability of district heating and cooling networks, requiring long-term investment calculations and risk assessments [55].

- Defining business cases for “Energy-Positive Neighborhoods”, which involves analysing available energy resources, local market conditions, and infrastructure costs [16].

IoT and Data Management Challenges.
The integration of IoT-based platforms and data management systems in PEDs adds another layer of complexity. Ensuring interoperability between different IoT standards and technologies is a major hurdle, impacting energy network efficiency. Additionally, data federation across multiple energy platforms presents challenges in data security, privacy, and accessibility [16].

Sustainability Transitions and Systemic Challenges.
PEDs are part of a broader sustainability transition, which requires navigating deeply entrenched societal structures, unpredictable economic conditions and governance challenges across multiple sectors. System-wide transitions demand multi-level collaboration among policymakers, urban planners, energy providers and citizens, requiring a long-term perspective and adaptive policy frameworks [56].

Public Procurement and Administrative Complexity.
The public procurement process in PED projects involves multiple stakeholders at different levels, making it complex, time-consuming, and bureaucratically intensive. The complexity of contracting, compliance with regulatory requirements, and ensuring competitive participation can discourage smaller market players from engaging in PED initiatives [49].

10. The Role of Positive Energy Districts in Urban Sustainability Initiatives

The integration of Positive Energy Districts within urban sustainability frameworks reflects the growing need for climate action, smart city development, and energy-efficient urban planning. PEDs align with key European initiatives such as Climate Neutral Cities, Smart Cities, Nature-Based Solutions (NBS), Nearly Zero-Energy Buildings (NZEB), ESG Taxonomy, New European Bauhaus and Energy Communities. The alignment with key European initiatives is relevant because PEDs do not operate as isolated technical projects. They sit at the intersection of several policy, planning, funding, and implementation frameworks that already guide urban transformation in Europe. Their development is further reinforced through international best practices and case studies, which provide insights into implementation strategies, challenges, and successful models.

10.1 Alignment of PEDs with Climate Neutral Cities and Smart Cities

Urban areas play a dual role in addressing climate change while driving economic growth. For example recognising this, the European Union (EU) has emphasised reducing energy demand, cutting CO_2 emissions, and enhancing urban sustainability and competitiveness [28]. EU policies, including the Energy Union Strategy, the Urban Agenda for the EU, and the SET Plan, all support this [28]. A major initiative under the SET Plan, the Smart Cities and Communities program, directly integrates PED development into urban decarbonisation efforts. The objective is to establish 100 PEDs in planning, development, or operation across Europe by 2025, reinforcing their role as localised solutions for emissions reduction and energy transition [10].
Beyond energy considerations, smart cities focus on improving quality of life, efficiency and sustainability using information and communication technology across various sectors [57]. Within this framework, the Smart Energy City (SEC) concept sees PEDs as a fundamental component. Some scholars argue that managing urban energy footprints is a core function of smart cities, with integrated urban energy planning and energy-efficient infrastructure as key enablers [57]. PEDs specifically fit into broader digitalisation and smart city governance **models** (e.g., IoT-enabled energy monitoring, AI-based urban planning).
PEDs serve as localised mechanisms for achieving broader EU energy transition objectives, aligning with the EU's energy and climate ambitions and Smart City targets [8]. The development of "plus energy neighborhoods" fits within the goals of the European Partnership Driving Urban Transition and contributes to meeting COP21 commitments [36] [6].
Additionally, the Horizon Europe program prioritises Climate Neutral and Smart Cities, reinforcing the importance of a bottom-up, stakeholder-driven approach to urban sustainability strategies [35]. Initiatives like Climate Neutral City Contracts further integrate PEDs within sustainable urban planning frameworks, emphasising their role as scalable, systemic solutions rather than isolated projects [11].

10.2 PEDs and Nature-Based Solutions

While direct references to synergies between PEDs and NBS are limited in the literature, the concept of "integrated sustainability" suggests a strong relationship between the two. PEDs are not solely focused on energy production but aim to create affordable, inclusive, and resilient urban environments [8]. Incorporating

NBS—such as urban greenery, water management systems, and biodiversity enhancements—can improve air quality, mitigate heat islands, and support ecological balance in PEDs [58]. Exploring the broader principles of sustainable urbanisation reveals that ecological integration and PED development are mutually reinforcing strategies.

10.3 PEDs and Nearly Zero-Energy Buildings (NZEBs)

The connection between PEDs and Nearly Zero-Energy Buildings (NZEBs) is explicitly documented [32]. While both aim for high energy efficiency, NZEBs focus on individual buildings, whereas PEDs operate at the district level, incorporating energy sharing, storage, and grid interactions. SET Plan Action 3.2 promotes the integration of NZEBs and positive-energy buildings within zero-energy blocks and districts, highlighting the role of energy-efficient buildings as the foundation of PEDs [47].

Projects like SPARCS further emphasise this connection, integrating NZEBs and retrofitted buildings into PED frameworks [3]. The very definition of a PED as an “energy-efficient urban area” aligns with the NZEB principle of minimising energy demand, ensuring that local renewable generation can meet consumption needs and achieve a net-positive energy balance [28].

10.4 PEDs, ESG and New European Bauhaus

The integration of Environmental, Social, and Governance (ESG) principles into the planning, implementation and evaluation of PEDs represents a transformative opportunity to align sustainable urban energy development with broader societal values and institutional accountability. While PEDs are primarily framed around energy performance and climate neutrality, embedding ESG dimensions expands their scope and impact, enabling a holistic transition towards socially grounded, environmentally restorative, and ethically governed, resilient, equitable future-proof cities.

The alignment between PED objectives and ESG principles is not only desirable—it is essential for building trust, unlocking finance, and delivering long-term value for people and planet. The New European Bauhaus initiative adds depth and narrative to this alignment, making PEDs not just sustainable, but also beautiful, inclusive, and deeply human in their impact [48].

To translate ESG principles into actionable PED criteria, several steps can be taken:

- Incorporate ESG-aligned indicators into PED monitoring frameworks (e.g. GHG reductions, stakeholder diversity, governance transparency).
- Apply ESG filters to investment planning, enhancing access to green finance.
- Use tools like the New European Bauhaus Compass to assess alignment with ESG-relevant values (sustainability, aesthetics, inclusion).
- Align with the EU Taxonomy for Sustainable Activities, ensuring regulatory compliance and credibility in reporting.

10.5 PEDs and Energy Communities: Common Goals and Strategies

Energy Communities and PEDs have disconnected trajectories in the literature:

- **Renewable Energy Communities (RECs)** are rooted in European energy legislation (RED II, Article 22), emphasising citizen ownership, social and environmental benefits, and local renewable energy production. The literature on RECs focuses primarily on:
    - Governance models and citizen participation.
    - Legal and regulatory frameworks.
    - Economic and social co-benefits (e.g., energy poverty reduction).
    - Community self-consumption and prosumerism.
- PEDs, on the other hand, stem from urban energy planning and innovation projects (e.g., MAKING-CITY, SPARCS and this IEA EBC Annex 83), emphasising:
    - Net-positive energy balances at the district scale.
    - Integration of buildings, mobility, ICT, and infrastructure.
    - Energy system impacts and climate neutrality goals.
    - Top-down planning with public-private collaboration.

In synthesis there is no clear integration of REC principles (citizen-led, legally defined) with PED principles (net energy surplus, systemic integration).
This lack of integration leads to several limitations:

- The role of communities in contributing to district-level energy positivity remains underexplored.
- Conversely, the systemic and spatial logic of PEDs is rarely applied to community-based models like RECs.
- There's a risk of conceptual redundancy, or worse, policy misalignment between community energy, positive energy districts and urban energy planning.

Integration of PEDs and Energy Communities.
Still few sources highlight the synergies between PEDs and Energy Communities, underscoring their shared objectives of decentralised renewable energy generation and community-driven energy governance. The ATELIER project in Amsterdam, for instance, actively integrates PEDs within existing energy communities, demonstrating their potential for collaboration [25].
A strong network of community energy groups across Europe provides an existing social and organisational foundation to foster local participation and engagement in PED projects [6]. These structures help build social capital, enhance local ownership, and improve implementation success rates by integrating a top-down approach (PEDs) to a bottom-up approach typical of the Energy Communities.
Shared Ownership and Peer-to-Peer Energy Models.
PEDs support collective ownership models, where district occupants co-own renewable energy infrastructure—even if it is located outside PED boundaries [3]. This shared investment approach aligns with energy community principles, where local actors jointly manage and benefit from renewable energy assets [5].
Moreover, PEDs facilitate peer-to-peer energy trading, enabling local energy markets within PEDs to optimise resource utilisation and engagement. This decentralised governance model strengthens energy resilience and sustainability at the community level [21].
The Social Dimension of PEDs.
The explicit recognition of Energy Communities as a core social component of PEDs highlights the importance of collective action in achieving energy-positive goals [11]. Their involvement in renewable energy production and peer-to-peer markets directly supports PED operations and enhances local energy autonomy [21].

11. Conclusions and recommendations

The implementation of Positive Energy Districts marks a major shift in the way cities approach the energy transition - from individual building efficiency to integrated, district-scale strategies that achieve a net positive energy balance. PEDs aim to produce more renewable energy than they consume annually, while promoting climate neutrality, social equity and economic resilience.

The journey towards energy-positive urban districts is complex but achievable. With the right vision, planning tools, and collaborative governance, PEDs can become central pillars of climate-neutral, resilient, and socially just cities.
City planners are at the forefront of this transformation—empowered to turn technical potential into spatial, environmental, and societal value.

Adopting a Holistic and Systems-Based Approach.
City planners must embrace a **cross-sectoral mindset** that bridges energy, mobility, land use, housing, and governance. PEDs are not merely technical interventions, they are socio-technical-spatial constructs that require coordination across urban planning, climate strategies, and infrastructure development. Integrating PEDs into wider urban sustainability goals and initiatives amplifies their transformative potential.

Championing Participatory and Inclusive Planning.
Successful PEDs depend on the **active involvement of local stakeholders**—from citizens and civil society to developers and energy providers. Participatory planning ensures context-sensitive design, builds public trust, and aligns PED solutions with local aspirations. Planners must apply co-creation methods and inclusive governance frameworks from the earliest planning stages to implementation and monitoring.

Standardising Methodologies and Evaluation Tools.
A major barrier to PED scalability is the **lack of harmonised definitions, indicators, and assessment tools**. Planners should advocate for:

- Common Key Performance Indicators (KPIs) spanning energy, environment, economics, and equity.
- GIS-based spatial analysis, Urban Building Energy Models (UBEMs) and scenario tools.
- Clear spatial boundary multicriteria and feedback-oriented monitoring systems to support continuous improvement.

Leveraging Technology with Flexibility and Adaptability.
PEDs depend on a portfolio of technologies—including renewable generation, storage, e-mobility, smart grids, and efficiency retrofits. Yet, flexibility is just as vital: PEDs must adapt to fluctuating energy needs, user behaviours, and policy conditions. Planners should prioritise modular, interoperable, integrated and scalable technologies that allow for phased implementation and long-term resilience of cities.

Unlocking Finance and Managing Risk.
PEDs require long-term investment frameworks and risk-sharing mechanisms. Innovative instruments such as:

- Public-Private Partnerships (PPPs).
- Blended financing models.
- Community investment platforms.

can mobilise capital and attract investors. City planners and managers play a strategic role in advocating for enabling regulations, reducing permitting barriers, and ensuring that local institutional capacity can manage complex, multi-stakeholder investments.

Embedding PEDs into Spatial Planning and Urban Design.
PEDs should be fully integrated into master plans, zoning codes, and development strategies—not treated as isolated energy hubs. This requires:

- Designating suitable areas based on solar potential, density, infrastructure and equity criteria.
- Embedding PED logic into building codes and mobility networks.
- Prioritising the regeneration of underserved and vulnerable neighbourhoods to avoid reinforcing inequalities.

Reforming Governance for Integrated Delivery.
City governance systems often function in silos, limiting cross-cutting planning. Planners must lead efforts to:

- Establish horizontal coordination across departments and agencies.
- Create joint mandates and shared decision-making structures.
- Build institutional mechanisms for interdisciplinary collaboration that align energy planning with spatial and social development.

Aligning PEDs with Broader Urban Sustainability Agendas.
Planners should reinforce and derive synergies from urban agendas, such as:

- Nearly Zero-Energy Buildings.
- Energy communities.
- Nature-Based Solutions (NBS).
- New European Bauhaus.
- ESG.
- Climate adaptation and social cohesion programmes.

This alignment strengthens policy coherence, funding access, and public legitimacy—while increasing the overall impact of PED strategies.

Final Recommendations for Urban and City Planners
To support the effective rollout and integration of PEDs, the following actions are recommended:

1. **Promote a harmonised and adaptable definition of PEDs** tailored to diverse urban contexts while maintaining key principles of energy positivity.
2. **Standardise assessment methodologies** for district-level energy performance, including spatial boundary criteria and mobility-related energy metrics.
3. **Support R&D and pilot projects** that test innovative technologies and governance models aligned with real urban conditions.
4. **Establish monitoring and evaluation frameworks** using KPIs to guide decision-making, ensure transparency, and identify improvements.
5. **Ensure inclusive stakeholder engagement** across all PED phases through participatory processes and social impact assessments.
6. **Enable innovative financing mechanisms** combining public and private investments to ensure long-term viability and scale-up.
7. **Integrate PEDs into urban planning tools and regulatory frameworks** to guarantee spatial coherence and infrastructural alignment.
8. **Break down institutional silos** via legal reforms, joint mandates, and collaborative governance platforms.
9. **Adopt iterative and adaptive planning approaches** that respond to feedback, evolving needs, and real-time performance data.
10. **Leverage synergies with other urban sustainability initiatives** to maximise system-level impact and enhance policy support.

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ANNEX 83

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