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Operational Insights and Future Potential of the Database for Positive Energy Districts

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Abstract: This paper presents the Positive Energy District Database (PED DB), a pivotal web tool developed collaboratively by the COST Action 'PED-EU-NET', in alignment with international initiatives such as JPI Urban Europe and IEA EBC Annex 83. The PED DB represents a crucial step towards sharing knowledge, promoting collaboration, reinforcing decision-making, and advancing the understanding of Positive Energy Districts (PEDs) in the pursuit of sustainable urban environments. The PED DB aims to comprehensively map and disseminate information on PEDs across Europe, serving as a dynamic resource for sustainable urban development according to the objective of making the EU climate-neutral by 2050. Indeed, PEDs imply an integrated approach for designing urban areas—the districts—where a cluster of interconnected buildings and energy communities produce net zero greenhouse gas emissions, managing an annual local/regional overflow production of renewable energy. The paper describes the collaborative step-by-step process leading to the PED DB implementation, the current results and potentials of the online platform, and introduces its future developments towards a more user-friendly and stakeholders-tailored tool. The interactive web map offers a customizable visualizations and filters on multiple information related to PED case studies, PED-relevant cases, and PED Labs. Users can access detailed information through a table view, facilitating comparisons across different PED projects and their implementation phase. The paper offers insights and detailed analysis from the initial dataset that includes 23 PED cases and 7 PED-related projects from 13 European countries, highlighting the key characteristics of surveyed PEDs.

Keywords: Positive Energy Districts (PEDs); climate neutral cities; database (DB); urban sustainability; energy transition; renewable energy; resilience

Citation: Civiero, P.; Turci, G.; Alpagut, B.; Kuzmic, M.; Soutullo, S.; Sánchez, M.N.; Seco, O.; Bossi, S.; Haase, M.; Massa, G.; et al. Operational Insights and Future Potential of the Database for Positive Energy Districts. *Energies* **2024**, *17*, 899. https://doi.org/10.3390/en17040899

Academic Editor: Daniele D. Giusto

Received: 5 December 2023
Revised: 4 February 2024
Accepted: 8 February 2024
Published: 15 February 2024

1. Introduction

Cities represent areas that are especially vulnerable to the effects of climate change modifying their activity and quality of life of the inhabitants. Extreme meteorological phenomena, together with urban micro-climatic conditions, have an impact on the energy, environment, society, and economy of cities. In addition, this impact is not homogeneous due to a combination of factors: local climatic conditions, the morphology of the city, the distribution and properties of materials, and human activity itself. To alleviate these effects

and achieve more sustainable, efficient, and resilient cities, new urban models are required that meet the Sustainable Development Goals (SDG) [1]. These models should be based on efficient and affordable buildings, local renewable energy production and flexibility, efficient, and sustainable transport, green public spaces, local employment, or global urban management [2].

In this context, several international actions have been boosted, such as the New Urban Agenda [3], which promotes more efficient urbanization and sustainable urban development, or the Strategic Energy Technology—SET Plan 3.2 of the European Union [4], which inspired the discussions on the deployment of 100 Positive Energy Districts (PED) throughout Europe by 2025. Then PED is defined as an urban area that connects energy-efficient and energy-flexible buildings, producing zero net greenhouse gas emissions, and actively managing an annual local or regional surplus of renewable energy production. In addition, a PED should secure energy supply and wellbeing, considering social, economic, and environmental sustainability aspects. These districts require the integration of different systems and infrastructures, as well as the interaction between buildings, users, and local energy networks, mobility, and ICT systems, while ensuring energy supply and a high quality of life for citizens. As mentioned in the Driving Urban Transition (DUT) Partnership [5], the implementation of PEDs need to be explored in strict relation with the 15-min city concept and circular economy principles [6]. Nevertheless, the successful implementation of these innovative models will depend on a wide range of knowledge—e.g., the performance of urban structures, or the distribution and boundary conditions—and the definition of the most appropriate strategies and transition roadmaps to mitigate and adapt cities to overcome sustainability and energy poverty needs. At the same time, they include a number of challenges to be addressed in order to achieve a successful implementation.

On this topic, Krangsås et al. [7] identified seven interconnected challenges needed for the deployment of PED, carried out through the Delphi method and surveys with experts in different urban issues, and thus to be considered as the most relevant for PEDs implementation: good governance, the right incentives, support from local community, integrated planning and decision-making, balance between supply and demand, business model, and contextual differences.

Castillo et al. [8] developed a methodology that offers a highly valuable quantitative assessment of future urban scenarios, designed to aid urban planners, investors, and government in the decision-making process. This methodology defines the PED as the primary functional unit for urban design and treats its key components—i.e., buildings, streetlights, vehicles, PV, etc.—as agents capable of evolving and making decisions about their future using a fuzzy logic engine. These agents create transition pathways that outline the long-term destiny of districts as they strive to meet European commitments set for 2030 and 2050.

Similarly, the PED-ID project [9] enhances decision-makers' access to improved information regarding PED solutions and methods that bolster project development, particularly focusing on the early stages of development and establishing a knowledge-based participation process. These methods were formulated based on data and insights gathered from Living Labs and workshops carried out in Uppsala (Sweden) Vienna (Austria), Rosenaw (Czech Republic) and involving different stakeholders (e.g., property owners, utility company, municipality, etc.) with the objective to empower PED designers and developers in employing these data-driven tools and methods in the decision-making process. To further this objective, a criteria catalogue for PED has been developed, thus enabling decisions based on data, the identification of optimal scenarios for each location, and assisting stakeholders in describing different PEDs using a holistic approach.

Koutra et al. [10] reviewed exposed gaps in governance mechanisms, citizen participation processes, and grassroots approaches to fostering synergies and co-creative standards for the conception and implementation of PEDs. Additionally, the analytical process framework highlighted the need for strategic planning that aligns with social, technical, financial,

and regulatory dimensions. It also underscored the considerable challenge of ensuring data accessibility and interoperability.

Therefore, the systematization of a series of data, information, barriers and enabling factors are fundamental to support the planning of district-scale interventions in an efficient, resilient, and climate-neutral perspective, fostering the acceleration towards the ambitious objectives of the SET Plan 3.2.—i.e., 100 pilot PEDs by 2025 [4] and tackling the challenges of climate neutrality at urban level—i.e., 100 pioneer zero-emissions cities by 2030 [11].

Fitting into this perspective, this research presents the PED Database (PED DB) as the first interactive and open-access common knowledge pool on the state-of-the-art development in PEDs practices, fostering the sharing of knowledge, competences, methods, and lessons learnt towards a large-scale spread of this innovative urban model, intended as one of the possible moves towards climate-neutral cities. Indeed, the PED DB) [12] is the result of a collaborative research led by the Working Group (WG) no. 1 of the COST Action (CA) 'PED-EU-NET' [13] in strict connection with two further international initiatives working on PEDs concept—i.e., JPI UE 'Positive Energy Districts and Neighbourhoods for Sustainable Urban Development' [14] and IEA EBC 'Annex 83′—Positive Energy Districts' [15]—and accordingly with the aims of the European Energy Research Alliance Joint Programme on Smart Cities (EERA JPSC) [16] and the Driving Urban Transition (DUT) Partnership [5], whose mission is to contribute to research and innovation in smart cities by promoting research actions, at building, district, and city level, thus facilitating the transformation of the European built environment towards climate neutrality.

The research paper is structured in eight sections. Section 2 traces an overview of the state of art in PED Databases, highlighting the strong need for a comprehensive and interoperable mapping tool for PED experiences. Section 3 presents the aim of the research and the applied methodology, describing the step-by-step approach leading to the database conceptualisation and online implementation. In Section 4, the results are presented by tracing the overview of the Database structure and sections, as well as a preliminary analysis of the mapped PED cases and laboratories. Section 5 discusses the preliminary results, Section 6 envisages the future potentials for the PED DB. Section 7 draws the conclusions of the research, and finally Section 8 describes the intellectual property strategy adopted.

2. State of the Art in PED Databases

The concept of PED was introduced in 2018 [4], yet there are still not many currently available tools that allow to deepen the knowledge and characterization of this model. Recent studies and researches focusing on PEDs [17–22] highlight the emerging need to move from isolated best practices—i.e., pilot districts—to innovative, systematic, holistic and integrated approaches supporting the planning of green, healthy, efficient, liveable, and resilient districts, working in strict connection with the local planning instruments—e.g., Sustainable Energy and Climate Action Plan (SECAP), Sustainable urban mobility plans (SUMPs), City or District Plans, etc.—and relying on stakeholders' expectations and citizens' needs.

In 2020, JPI Urban Europe published the PED Booklet [23] as a catalogue of PEDs case studies, structured in two main sections: 'PED Projects'—i.e., cases that have the proper ambition to achieve a positive annual energy balance—and 'Towards PED Projects'—i.e., cases that, even without aiming at an energy surplus, adopt innovative approaches and solutions for efficient and high-quality districts. The PED Booklet represents the first paper-based attempt of systematic collection and mapping of PEDs at international level, but also of multi-level characterization of PEDs through interdisciplinary parameters and indicators.

The study carried out by Zhang et al. [24], moving from the projects mapped in the PED Booklet, builds an innovative matrix for an interoperable and updatable platform (i.e., Knime dashboard) able to compare the characteristics and peculiarities of the PEDs model according to some relevant and specific parameters (e.g., project start year, geographical distribution, project phase, size of interventions, type of financing, etc.) and to ensure a

cross overview of the analysed cases towards the definition of a series of PED archetypes or models.

Derkenbaeva et al. [25] conducted a comparative analysis of PEDs at various geographical scales, identifying elements and metrics that offer insights into how to conceptualize and put PEDs into practice. The study showcases 11 representative examples of PEDs already implemented in Europe and reveals that real-life PEDs frequently extend beyond the boundaries defined by existing definitions, highlighting significant knowledge gaps and limitations within the concept. The study adopts a Complex Adaptive System approach, incorporating the doughnut view to present a holistic system perspective and it addresses the limitations of the PED concept, identifying key issues—such as electric mobility—that warrant further attention.

Once again, moving from the best practices investigated in the PED Booklet, but with a particular focus on the Italian context, an interactive filing system was designed targeting municipalities interested in systematically integrating the PED model into their planning tools [26,27].

At the same time starting from the experience gained in the EERA JPSC initiative [16], the study conducted by Soutullo et al. [28] focused on the mapping of PED Labs—meant as pilot experiences acting as context-specific laboratories to catalyse the grounding of PEDs at local level. Through a SWOT analysis, the research identifies the main strengths, weaknesses, opportunities, and threats linked to the 16 investigated laboratories and highlights the need to test solutions in the real environment, in order to evaluate the replicability potential for these experiences in different geographical, social, and economic contexts.

As part of the European Citie4PEDs project [29], a catalogue, called 'PED Atlas' [30], was defined. Starting from the identification of 25 PEDs cases, 7 pilots were selected—3 new construction and 4 regeneration interventions—and for each of them an interviews-based storytelling was drawn, highlighting the perspectives of key involved actors, underlying the main lessons learned, barriers, and success factors, and extrapolating some recurring PEDs approaches and dynamics.

Moreover, the ongoing PED-ACT project [31] extracts the main characterization of PEDs automatically by machine learning approaches, through standardisation of the information from existing PEDs presented in the PED DB. PED-ACT further learns from the PED DB and creates digital PED references by mapping stakeholders' needs and priorities in cities of Borlänge (Sweden), Umeå (Sweden), Ankara (Turkey), Karsiyaka (Turkey), and the county of Lower Austria (Austria). This interaction of PED DB and PED-ACT project also aroused interactions for a more appropriate architecture of the PED DB in accordance with the identified stakeholders' needs in PED-ACT.

Still investigating the PED topic, further studies and publications work on the systematic collection and cataloguing of the following key aspects: (1) technologies and solutions for PED effective implementation [32–34], (2) financing tools and business models to support PED technical feasibility and economic affordability [35,36] and (3) social tools to facilitate stakeholders mapping, to foster citizens' awareness on environmental issues and to support community engagement [37,38] broadening the scope beyond the environmental dimension to encompass energy justice-related aspects emphasizing the need to integrate opportunity spaces, well-being concerns [39] and energy vulnerability mitigation [40], and (4) criteria and Key Performance Indicators (KPIs) to monitor and evaluate PEDs impacts on the built environment [41–44].

By shifting the focus of cataloguing tools on Energy Community (EC)—a transition model in many respects considered similar to PED concept [45,46], the Joint Research Center (JRC) of the European Commission, following the two Directives that define the EC model at international level [47,48], has published a preliminary report tracing an overview of 24 Communities distributed in 9 EU countries [49]. The Commission is currently developing an interactive platform, called 'Energy Communities Repository' [50], with the aim of incrementally mapping community ongoing experiences in the European context [51]. Currently the first available online version of the platform consists of a map

connected to a detailed sheet for each case study that allows to display the information collected divided in thematic sections—i.e., overall information, activities, governance, energy, economy, social impact, and useful links.

3. Aim and Methodology

According to the CA PED-EU-NET memorandum of Understanding [52] (p.12), the aim of this work was to create—among others—a comprehensive PED Database by mapping existing concepts, strategies, projects, technological, and non-technological innovations related to PEDs in Europe. The PED DB has the objective to work towards the dissemination of PEDs practices and it is structured as a comprehensive tool that, thanks to an implementable structure and updatable contents, brings together case studies, projects, solutions, KPIs, policies, and strategies to support the large-scale development of innovative pilot districts, working both on the implementation of new interventions and on the large-scale renovation of existing urban areas. Building on the previous publications presenting the initial phases of the DB development process [53,54], the present research describes the overall workflow leading from the DB conceptualisation to its online implementation. In particular, it describes the phase-by-phase development process and it presents the actual DB structures, detailing its different sections and giving an overview of the first PED cases and projects currently available online in the Database.

The authors have meticulously covered different facets of the research journey on the PED DB, spanning from the initial framework design phase (Phase 1) to its subsequent development (Phase 2). The culmination of this work is observed in the practical application of data collection, used to evaluate, facilitate, and optimize urban areas to enhance the implementation of PEDs (Phase 3).

In the tricky development of a widely recognized PED Database, a methodological and systematized approach was required, also recognizable in the different phases characterizing the entire DB creation process. In fact, the PED DB is not limited to defining the requirements, the general structure and the fields of the database itself, but it has the ambition of creating an organized framework for future collection of multiple data related to PEDs. The implementation process required other additional features useful for easy database population—i.e., a guiding glossary and an online form to be shared between the so-called 'PED DB editors' and supporting actors among others. Basically, a methodological approach was adopted for the PED DB design that, built upon the above, comprises three primary development steps (Figure 1): Phase 1—DB general framework and categories (Section 3.1), Phase 2—DB fine tuning and implementation process (Section 3.2), and Phase 3—Next steps and functionalities from Web DB (Section 3.3).

Figure 1. The PED DB framework is drawn according to a step-by-step methodological approach development that consists of three main phases. Source: CA 'PED-EU-NET'.

3.1. Phase 1—DB General Framework and Categories

Phase 1 involved the definition of the general framework and inputs categories of the PED-Database. As widely explained in the previous publications describing the DB general framework [53,54], the first step consists in a comparative analysis of existing databases and platforms to understand the possible structure and content requirements for the PED-Database. Existing databases related to sustainability, energy efficiency, and adaptation district-scale practices (e.g., Urban Nature Atlas [55], Stories from the Neighbourhood [56],

C40 case studies [57] etc.), and interactive platforms mapping EU funded projects on PED/PED-similar concept (e.g., CORDIS Datalab [58], Smart City Marketplace [59], Portico urban knowledge platform [60], etc.) were reviewed together with the PED Booklet [23], the only open-access catalogue of PED/PED similar cases published in paper format.

Based on this analysis, PED DB sections were defined following the methods explained in Ref. [54], and collecting the experiences related to the PED concept selected by Turci et al. (see Appendix B in Ref. [54]).

3.2. Phase 2—PED DB Fine Tuning and Implementation Process

Phase 2 led to the concrete PED DB implementation, involving three consecutive and strictly-related steps: (1) the definition of the parameters list following an iterative alignment process and the definition of the related glossary (see Appendix A), (2) the implementation of two online easy-to-use questionnaires for data collection, called 'input forms', and (3) the realization of an open access platform for the Database widespread use. We will proceed into the details of each step in the following Sections.

3.2.1. Parameters Alignment and Glossary

According to the PED DB overall structures and related sections (as defined in Phase 1), the relevant parameters characterizing PED concept were identified through multiple rounds of contributions involving all CA PED-EU-NET Working Groups, but also enlarging the discussion and contributions to two further international initiative working on PEDs deployment—i.e., JPI UE 'Positive Energy Districts and Neighbourhoods for Sustainable Urban Development' initiative and the IEA EBC 'Annex 83—Positive Energy Districts'. In order to build on the experiences and lessons learned of the already published PED Booklet [23], the involvement of JPI EU initiatives was of fundamental relevance. In particular, several workshops were organized between the 'PED DB core team' of the CA PED-EU-NET and JPI UE to review, check, analyse, benchmark, and fine-tune the already defined parameters in both approaches. As shown in Table 1, this process consists in a one-by-one parameter comparison and related discussion in order to align and improve the necessary inputs to fully describe the PED concept in the Database. At the same time, the alignment with IEA EBC Annex 83, also thanks to its global scale of action, was crucial in identifying the main success factors, drivers, barriers, and challenges related to PED implementation and to gain a world-wide perspective on the PED concept. The first selection of the PED DB parameters was made from the information available in the different European initiatives, refined with the information available in the literature on sustainable neighbourhoods, smart cities, or urban living labs and PED oriented projects. Subsequently, this information was expanded and agreed upon by the different researchers from the involved initiatives and the representatives of Public Administrations, resulting in a list of variables required in different sections to characterize each element of a PED, a PED relevant, and a PED Lab case study. Finally, these entries were validated by groups outside the development of the PED Database according to the information from their real cases. These groups evaluated the questions in each section of the survey form for possible gaps or redundancies. This review led to a refinement of the survey in each section, providing more precise and concise questions adopted in the online form questionnaires.

Table 1. Comparative/alignment table: PED Booklet vs. PED DB (the direct correspondences among Booklet and DB are shown in grey). 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

Table 1. *Cont.*

PED Booklet [23]			PED DB [12]		
Section *	**n.**	**Parameters**	**Section ****	**n.**	**Parameters**
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 enquiries—organization
			A1	P028	Contact person for general enquiries—affiliation
			A1	P029	Contact person for general enquiries—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 objectives/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 impact
			D1	P013	Standardization 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

Table 1. *Cont.*

PED Booklet [23]			PED DB [12]		
Section *	**n.**	**Parameters**	**Section ****	**n.**	**Parameters**
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 decarbonization 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 [24]
			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

Table 1. *Cont.*

PED Booklet [23]			PED DB [12]		
Section *	**n.**	**Parameters**	**Section ****	**n.**	**Parameters**
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).

3.2.2. PED DB Implementation Process

The practical implementation of the PED DB involved a series of consecutive and interrelated steps:

1. **Online form questionnaires:** Two user-friendly online questionnaires, referred to as 'input forms', were created for efficient data collection. These forms were designed in alignment with DB structure, resulting in one for PED/PED-relevant case studies and PED labs, capturing information from sections A, B, and C (refer to Paragraph 4.1 for details). Another form targeted funded projects/initiatives, collecting data related to section D (refer to Paragraph 4.1 for details). These questionnaires were developed with crucial input from IT experts from Boutik.pt and Czech Technical University in Prague (CVUT) to: (1) integrate a glossary, encompassing definitions of parameters and related filling instructions (see Appendix A); (2) enable the saving of inputs for later completion; and (3) ensure easy accessibility through a provided link. During this phase, the role of the DB Editor was introduced. DB editors are individuals responsible for facilitating the data collection process. They contact the reference person for each PED case study or project, provide support, and guidance when necessary, review the completeness and accuracy of input data, and validate online publication. DB Editors were selected and trained from various initiatives involved in the prior PED DB conceptualization and development (e.g., CA PED-EU-NET, JPI UE, IEA EBC Annex 83, DUT, etc.).
2. **Web platform**: The design of the online platform entailed a close collaboration with a team of IT experts [12]. Their invaluable support led to the development of two key operational tools: (1) the backend web platform, and (2) the frontend web platform. The backend platform serves as the administrative hub for the DB. It enables the generation of input forms for data providers, facilitates the review of all input data, and oversees the publication of case studies and projects once finalized. On the other hand, the frontend web platform was crafted for data visualization, comparison, and filtering. Three open-access web pages were identified as essential components of the frontend: (i) a map view to illustrate the geographic distribution of case studies, enabling the identification of experiences and solutions by specific countries or regions of interest; (ii) a table view to list selected case studies and facilitate comparisons; and (iii) a projects list for visualizing and comparing various projects.

3.3. Phase 3—Next Steps and Functionalities from Web DB

As explained above, the PED DB is focused on the creation of 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 com-

munity building as key aspects of the decision-making process, implementation, and replication of PEDs. Therefore, gathering data and addressing the systematization 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. Indeed, according to the different feedbacks and comments gathered during DB presentation and workshops at multiple international events (i.e., COST Action PED-EU-NET 'Urban Stakeholders Workshop' [61], PED Conference 'Experiences and Guidance for Design and Implementation' in Amsterdam [62], EURAC Conference 'Smart and Sustainable Planning for Cities and Regions' in Bolzano [63], ENEA Conference 'Urban Transition Pathway' in Bergamo [64], COST Action PED-EU-NET and EERA JPSC Conference 'Energy in Built Environment: Climate-Driven Solutions for Next Generation EU Cities' in Lisbon) [65]—it emerged that the DB aims to collect a consistent number of information—i.e., fair data collection for a comprehensive DB—but not all the inputs are relevant for all stakeholders. Likewise, the interests and perspective of potential stakeholders, such as the promoters and the constructors in the districts or the Public Administration, have to be addressed in a specific way because different needs and expectations exist and have to be balanced through the complex PED process [66]. At the same time, DB users are supposed to have different backgrounds, competences, and skills, meaning that the information needs to be transferred by different channels and allowing for a tailored selection of the data that better fulfils their expectations and objectives.

Therefore, the PED DB aims for a user centred and tailored-made approach allowing to select relevant parameters according to four main identified stakeholders categories—i.e., public sector, private sector, research sector, and citizens and civil society—and their needs emerged during DB presentations and workshops (Table 2).

Table 2. PED DB target stakeholder and main emerged needs. Source: Authors.

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; • Recognize 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.

Table 2. *Cont.*

Target Stakeholders	Main Emerged Needs
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 and 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.

Indeed, thanks to the already 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 systems, where PED information serves as the primary material for informed decision-making at the district level through computerized 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 the 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 revolutionized 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 the urban transition;
3. **Database Query**: Allowing to enhance the data management capabilities within the PED database through adaptive and approximate query processing. This approach emphasizes the use of runtime feedback to modify query processing, aiming to achieve better response times and more efficient CPU utilization, as opposed to the traditional 'optimize-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 (Figure 2), 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.

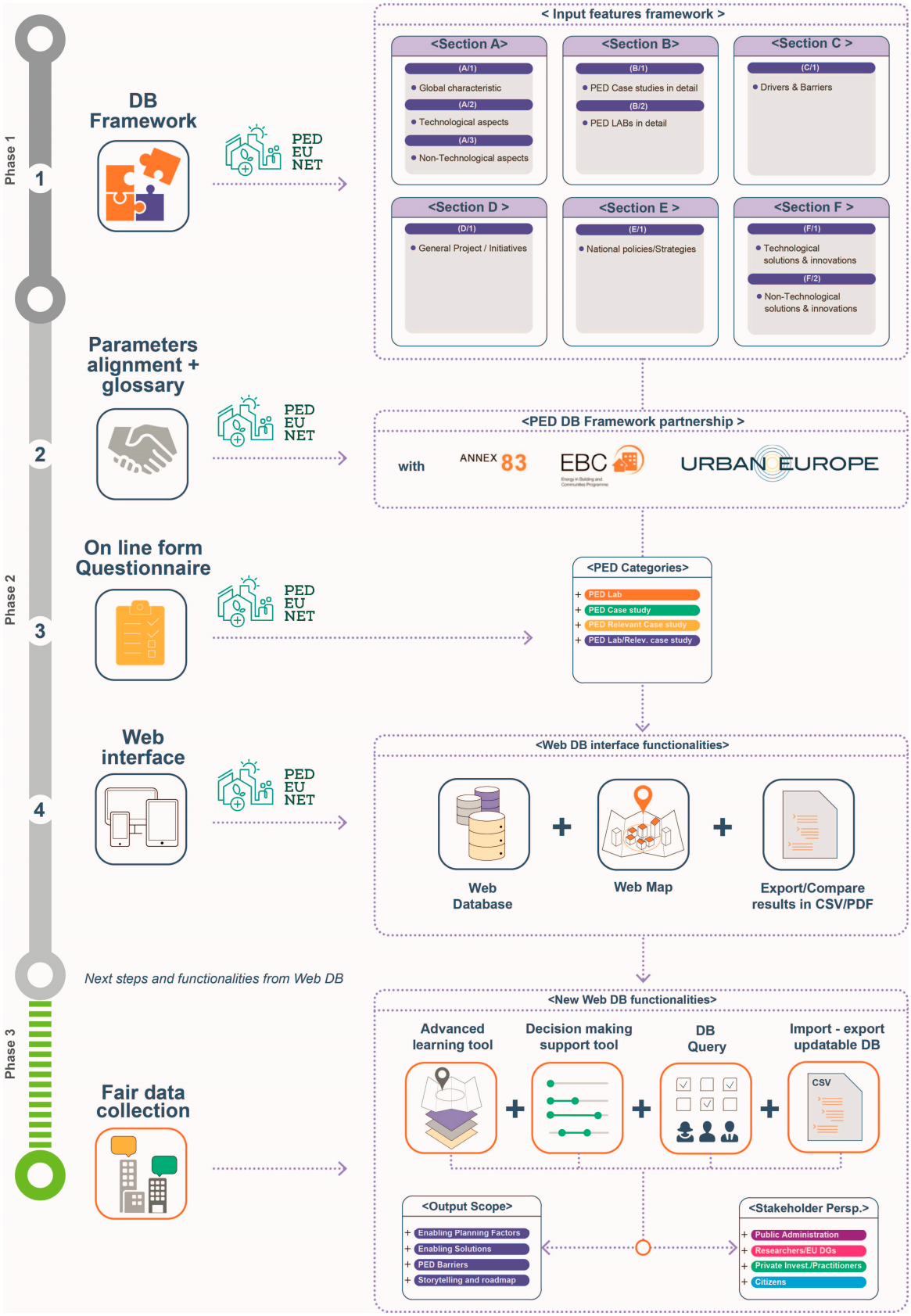

Figure 2. The phase-by-phase approach and insights of the PED Database development. Source: CA 'PED-EU-NET'.

4. Results

The following paragraphs describe the current state of the PED Database, starting from the overview of its structure and sections (Paragraph 4.1) to a first insight of the preliminary online platform (Section 4.2) showing the mapped case studies or laboratories and related projects (Paragraph 4.3).

4.1. PED DB Sections and Related Parameters

As explained above, the PED Database is conceived as an implementable and updatable structure and, so far, it consists of two main parts:

1. The central nucleus of the Database collecting PED/PED relevant case studies and PED Labs—constituted by section A aimed at framing the context where the PED is developed—i.e., A1 'Global characteristics' (Subparagraph 4.1.1), section A2 'Technological aspects' (Subparagraph 4.1.2), and section A3 'Non-Technological aspects' (Subparagraph 4.1.3)—section B aimed at deepening the concept of PED Case and/or PED Lab according to the classification provided in section A—i.e., B1 'PED case study in detail' (Subparagraph 4.1.4) and B2 'PED Lab in detail' (Subparagraph 4.1.5)—and section C aimed at analysing the driving factors and the obstacles faced during the PED planning and implementation process—i.e., C1 'Drivers and Barriers' (Subparagraph 4.1.6). The central part of the Database is available online [12] in open access mode, collecting a total of 109 parameters and 455 answer options.
2. A series of supporting sections facilitating the understanding of PED concept replication on a larger scale. This part is constituted by Section D 'General Project/Initiative' (Subparagraph 4.1.7) collecting the funded projects and initiatives experimenting PED/PED relevant concepts, section E 'National Policies/Strategies' mapping the national regulatory framework conditions facilitating the uptake of PED practices and section F 'Technological and Non-technological solutions' deepening the adopted innovative and context-tailored solution in each PED case/lab. Currently, Section D is fully developed and available online [12], while Sections E and F are in their definition phase and still not available online.
3. Table 3 summarises the contents of the following tables—i.e., Tables 4–10—according to the inputs and data collected for each DB section.

Table 3. 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**] Privates sector [**Pr**] Research sector [**Re**] Citizens and civil society [**Ct**]

The "(*)" means the identification of a mandatory parameter when the symbol "*" is used for some parameters in the following tables.

Table 4. 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]	•	•		

Table 4. *Cont.*

ID	Parameter Title	Type of Answer				Answers	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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 EUR, 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—organization (*)	•				[txt]	•	•	•	•
A1 P028	Contact person for general enquiries—affiliation (*)		•			•Research Centre/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]	•	•	•	•

(*) Mandatory parameters. "•" is used for categorising each parameter according to the type of answer required (O, Cs, Cm, A) or the target Type (Pu, Pr, Re, Ct). Instead in the column "Answer Options" is used for bullet list.

Table 5. 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]		•	•	

Table 5. *Cont.*

ID	Parameter Title	Type of Answer				Answers	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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 and 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 and Lighting); •Smart irrigation; •Digital tracking for waste disposal; •Smart surveillance; •Other, please specify	•	•	•	•

Table 5. *Cont.*

ID	Parameter Title	Type of Answer				Answers	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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	•	•		

"•" is used for categorising each parameter according to the type of answer required (O, Cs, Cm, A) or the target Type (Pu, Pr, Re, Ct). Instead in the column "Answer Options" is used for bullet list.

Table 6. 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]	•		•	
A3 P003	Strategies towards decarbonization 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	•	•	•	•

Table 6. *Cont.*

ID	Parameter Title	Type of Answer				Answers	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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]	•	•		•

"•" is used for categorising each parameter according to the type of answer required (O, Cs, Cm, A) or the target Type (Pu, Pr, Re, Ct). Instead in the column "Answer Options" is used for bullet list.

Table 7. 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]	•	•		

Table 7. *Cont.*

ID	Parameter Title	Type of Answer				Answer Options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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.	•	•	•	•

"•" is used for categorising each parameter according to the type of answer required (O, Cs, Cm, A) or the target Type (Pu, Pr, Re, Ct). Instead in the column "Answer Options" is used for bullet list.

Table 8. 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	•	•	•	•

Table 8. *Cont.*

ID	Parameter Title	Type of Answer				Answer Options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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)	•	•	•	•

"•" is used for categorising each parameter according to the type of answer required (O, Cs, Cm, A) or the target Type (Pu, Pr, Re, Ct). Instead in the column "Answer Options" is used for bullet list.

Table 9. 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 maximize 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 urbanization 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)	•			

Table 9. *Cont.*

ID	Parameter Title	Type of Answer				Answer Options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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 authorization 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 and 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 and 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; •Unfavourable 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)	•	•		

Table 9. *Cont.*

ID	Parameter Title	Type of Answer				Answer Options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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 optimization 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)	•	•		•

Table 9. *Cont.*

ID	Parameter Title	Type of Answer				Answer Options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
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 and 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)	•	•	•	•

"•" is used for categorising each parameter according to the type of answer required (O, Cs, Cm, A) or the target Type (Pu, Pr, Re, Ct). Instead in the column "Answer Options" is used for bullet list.

Table 10. 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; •Interreg; •National funding; •Public-Private Partnership; •Other, please specify. Specify the call, If available.	•	•	•	
D1 P007	Estimated project costs	•				[nr]	•	•	•	
D1 P008	Description of project objectives/concepts	•				[txt]	•		•	•
D1 P009	Description of project upscaling strategies	•				[txt]	•		•	
D1 P010	Number of PED case studies in the project	•				[nr]			•	

Table 10. *Cont.*

ID	Parameter Title	Type of Answer				Answer Options	Target			
		O	Cs	Cm	A		Pu	Pr	Re	Ct
D1 P011	Case Study	•				[txt]	•	•	•	•
D1 P012	Description of project expected impact	•				[txt]	•		•	
D1 P013	Standardisation efforts	•				[txt]			•	
D1 P014	Sources	•				[txt]	•	•	•	•
D1 P015	Contact person within PED project (*)	•				[txt]	•	•	•	•

(*) Mandatory parameters. "•" is used for categorising each parameter according to the type of answer required (O, Cs, Cm, A) or the target Type (Pu, Pr, Re, Ct). Instead in the column "Answer Options" is used for bullet list.

4.1.1. Section A1 'Global Characteristics'

Section A1 can be seen as the introductory part that allows to frame the 'PED/PED relevant case study' or 'PED lab' according to its main characteristics. This section, in fact, categorises the PED site according to three levels of classification—i.e., PED case, PED relevant case or/and PED lab—defines its phase and period of implementation, identify the localisation, the related climate zone and the extension of the projects, underlines the adopted financial schemes and overall costs and, finally, provides the contacts for the person responsible for the case study or laboratory.

Table 4 summarizes the most relevant global characteristics. It can be noted that most of the parameters are relevant for all targeted stakeholders—i.e., public sector, private sector, research sector, and citizens and civil society. This is strictly related to the main scope of section A1: framing the case study/lab by providing a first cognitive overview.

4.1.2. Section A2 'Technological Aspects'

Section A2 focuses on the technological aspect of PEDs. In the first part, it aims to collect a series of quantitative data on the annual energy demand and on the annual energy production. In the second part of Section A2, technological solutions and innovations are mapped according to three main PED energy concerns—i.e., energy generation, energy efficiency, and energy flexibility [4,32]—and mobility services.

According to Table 5, the PED technological aspects are particularly important to reach one of the key elements characterising a PED: the fulfilment of a positive energy balance on an annual basis. For this reason, the collected quantitative data are relevant both for practitioners and researchers involved in the planning of the positiveness of the district, but also for the public sector—e.g., municipalities, policy makers, etc.—trying to foster the energy transition at urban level moving from district-scale innovative models.

4.1.3. Section A3 'Non-Technological Aspects'

Since PEDs are first of all communities acting in a sustainable way, they have a significant impact on the environment, the economy, and the social well-being of a community as a whole. Therefore, non-technological aspects of PED, such as stakeholder engagement, social and cultural acceptance, financial viability, and regulatory feasibility, are essential for their successful implementation.

Table 6 summarises the most relevant non-technological aspects and their target stakeholders. Those aspects are mainly related to the public sector such as municipalities, policymakers, public technicians, etc. Furthermore, many non-technological aspects are also relevant for citizens and the civil society in general. Only when it comes to identifying

available funding, understanding economic leverages and costs or comparing technical and non-technical solutions, does the private sector show interest in non-technological aspects.

4.1.4. Section B1 'PED Case Studies in Detail'

This section needs to be filled in if the PED site—according to parameter P003 in Section A1—is classified as a 'PED/PED relevant case study'.

The parameters collected are mainly meant to deepen the reason beyond the choices that led the district transformation and to map the type of intervention according to some specific characteristics describing the context, the year of construction/renovation, the population involved, the buildings and land uses, etc.

As highlighted in Table 7, these parameters resulted to be particularly relevant for the Public Sector; in fact, municipalities and policymakers often need to understand which areas to prioritize—e.g., Urban or suburban? Mixed-use or residential? New construction or renovation?, etc.—to test a pilot project in a PED/PED relevant perspective. In addition, Citizens and Civil Society have a quite strong interest in understanding the environment of the PED development.

4.1.5. Section B2 'PED Lab in detail'

The section B2 needs to be filled in if the PED site—according to parameter P003 in section A1—is classified as a PED Lab. Based on the definition proposed by the Set Plan Action 3.2 [4], 'PED Labs' are pilot actions that provide opportunities to experiment with the planning and deployment of PEDs. Under this framework, PED labs are considered as urban laboratories where these new proposals, technologies, and services could be developed, modelled, and monitored according to place-based needs and local context baseline. These research infrastructures allow defining integrative solutions that include technological, spatial, regulatory aspects, financial, legal, social, and economic perspectives.

Therefore, with the objective of mapping the facilities, resources, and characteristics of the available laboratories, a series of questions are formulated that make it possible to classify the PED labs.

As shown in Table 8, researchers, coming both from academia and R&I centres, seem to be the main interested stakeholders in testing PED labs as infrastructures properly focused on innovation, experimentation, and monitoring aspects. At the same time, public and private sectors have also expressed a strong interest in testing PED Labs as they allow pilots grounding of different innovative solutions and approaches in a controlled and experimental environment.

4.1.6. Section C1 'Drivers and Barriers'

The implementation of PED and PED Labs will be subject to different types of factors and situations that can facilitate or block their installation and operation.

A barrier is defined as an obstacle or impediment that requires a change in mindset, priorities, management, or other to overcome the difficulty. This requires technological progress, regulatory or administrative changes, increased political commitment, greater social support, or increased economic and financial resources, although a certain degree of adaptation to the local context must always be considered [67]. On the other hand, a driver is defined as a stimulus, activity, or process that facilitates political change, technological exchange, increased social support, environmental improvement, or increased resources, resulting in positive incentives [67] in the process of implementing a PED. Drivers and barriers may arise at the local level or with different levels of influence as they are conditioned by the regional and national context of the case study.

Based on experiences in the implementation of Smart Cities projects, a list of barriers as well as driving and unlocking factors are introduced [23,68–72]. For each of the answer options, a five-point Likert scale needs to be filled in order to evaluate the impact on PED implementation from level 1—i.e., the factor/barrier is not important—to level 5—i.e., the factor/barrier is very relevant.

As shown in Table 9, the public sector, in particular municipalities, expressed a strong interest in mapping the driving and unlocking factors as well as barriers related to PEDs development, as they can support a better understanding of the state of city readiness towards this kind of innovative urban models. The other stakeholders showed interest in specific categories—e.g., the private sector seems particularly interested in legal/regulatory, technical, financial, and market barriers, while the research sector appreciates the focus on technical but also environmental, social/cultural barriers, and citizens and civil society are particularly sensitive to social/cultural, information/awareness, financial, and market barriers.

Lastly, the stakeholder involvement for each stage of the district transformation process was evaluated to be relevant for all the targeted stakeholders.

4.1.7. Section D1 'General Projects/Initiatives'

The following section collects information about the funded projects or initiatives, intended as overarching structures where one or more case studies or labs implementation processes occur at an international/national level and promote the research and development in the PED field. It allows for a brief insight of the project or initiative by framing the timeframe, the type of funding programme or financing model, and the estimated total costs. The section D1 is aimed at deepening the objectives and concepts beyond the projects/initiative development, describing its upscaling potential, expected impacts, and standardisation efforts. According to Table 10, section D1 results in being particularly relevant for public authorities interested in better understanding the mechanism behind R&I fundings and also for research centres and academia, representing central actors in the European funded projects. At the same time, private sectors, citizens, and civil society are also expressing an increasing interest in being involved in the innovative and challenging environment of PED/PED similar projects and initiatives.

4.2. Results of PED DB Implementation

4.2.1. The Online Questionnaires On-Line Platform: Backend and Frontend

The online questionnaires were made available through links generated by DB editors. The online PED cases/PED Lab survey includes all the questions and parameters previously detailed in Section 4.1. It is composed of five different pages, each dedicated to a specific section of questions (A1, A2, A3, B1 or B2, C). Figure 3 shows screenshots of two different pages of the PED online survey. A user-friendly design was chosen to better guide and facilitate the filling process by the reference person of PED case study or project. For this reason, progress bars (Figure 3, highlighted in red inlets) and a scheme of the different sections of the survey (Figure 3, highlighted in orange inlets) were inserted. Each question is accompanied by a label and its specific code to facilitate comparison among case studies or projects (Figure 3, highlighted in blue inlets).

4.2.2. The Online Platform

Two operational tools were developed for the online platform: (1) backend web platform, and (2) the frontend web platform.

Screenshots of the backend platform are depicted in Figure 4. Registered DB editors can access the backend web platform using their account and password, selecting the desired action through the navigation bar on the left of the page (Figure 4, highlighted in red). Within the "DB Editor" page, it is possible to generate new links to a case study or project surveys and send invitations to the email address of the case study/project contact person (Figure 4, top). A list of all case studies of the database is visible on the "Case Studies" page (Figure 4, bottom). When a case study survey is submitted, the list is automatically updated. The DB editor reviews the new data and publishes it, making the new input available on the frontend web platform. The same process applies to projects.

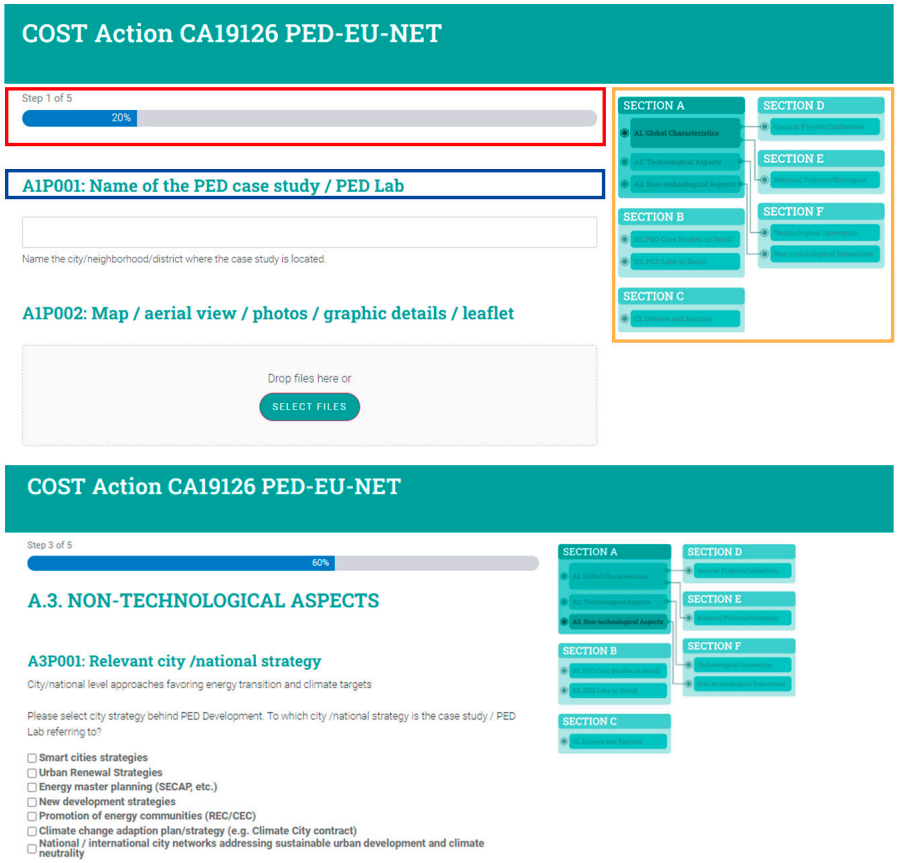

Figure 3. Online form questionnaires (Screenshot extraction). Examples of A1 questions (**Top**) and A3 questions (**Bottom**). Source: CA 'PED-EU-NET'.

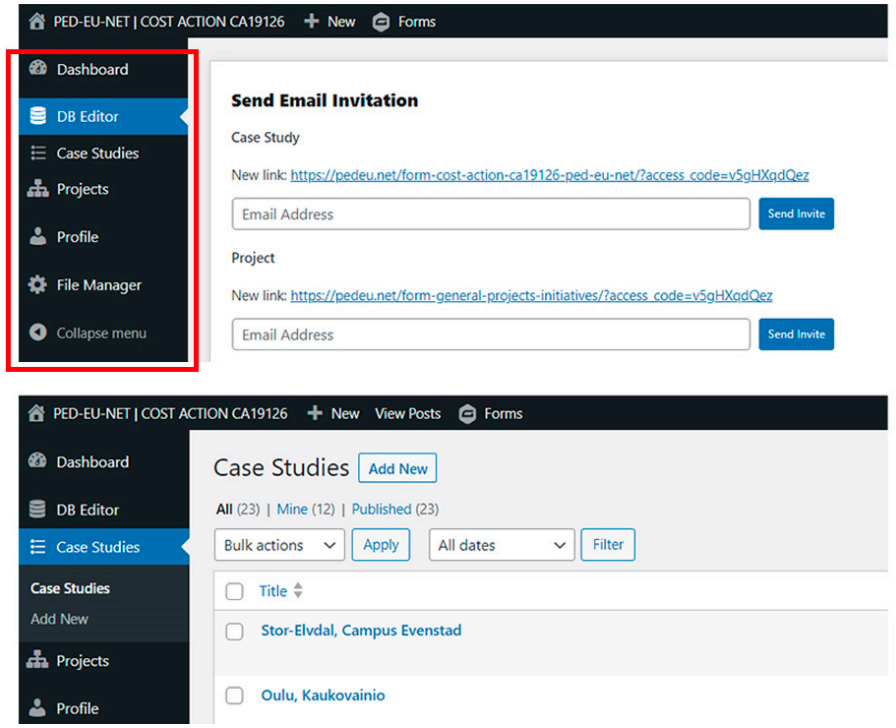

Figure 4. Web platform—backend (Screenshot extraction). "DB Editor" page (**Top**) and "Case Studies" page (**Bottom**). Source: CA 'PED-EU-NET'.

The frontend web platform was designed for data visualization, comparison, and data filtering. The web PED-DB homepage serves as the entry point to the Database accessible at [12]. The platform comprises three open-access web pages: "MAP VIEW" (Figure 5, Top), "TABLE VIEW" (Figure 5, Centre), and "PROJECTS" (Figure 5, Bottom). These pages can be accessed through the navigation bar at the top of the page (Figure 5, Top, highlighted in green).

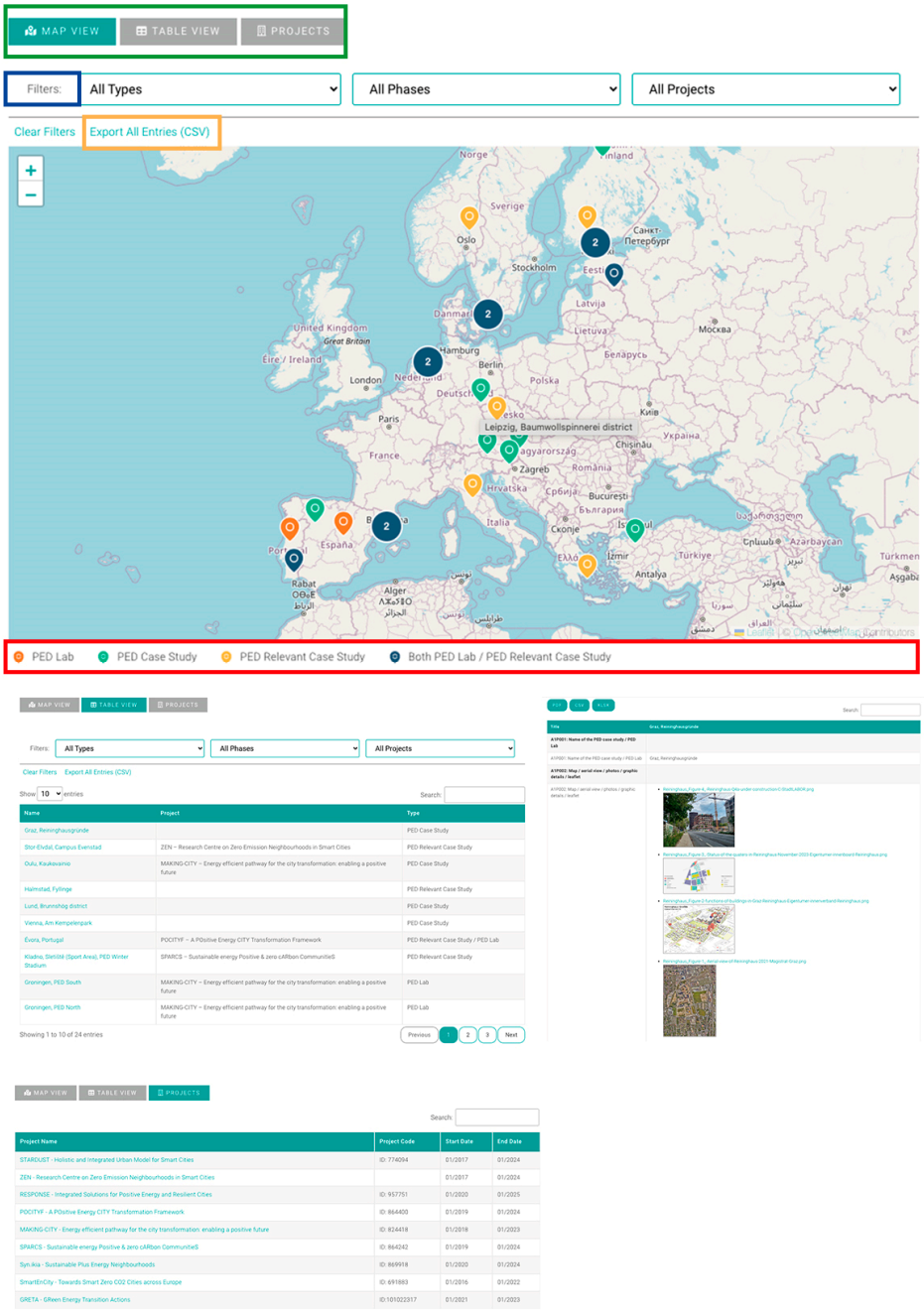

Figure 5. Web platform—frontend (Screenshot extraction). Map View (**Top**), Table View (**Centre**), Projects (**Bottom**). Source: CA 'PED-EU-NET'. Results of DB implementation.

The MAP VIEW displays the geographic distribution of the case studies using pins with four different colours, guiding users to different types of PED cases: orange for PED Lab, green for PED case study, yellow for PED Relevant case study, and blue for case studies that are both PED Lab and PED Relevant (Figure 5, Top, highlighted in red). Clicking on a placeholder on the map reveals the location and name of the chosen case study/lab.

Various filters options (Figure 5, Top, highlighted in blue) allow users to customize the visualization of PED case studies, PED Relevant case studies, or PED Labs. Filters also include the implementation phase (planning, implementation, completed, or in operation) and overarching reference projects. All data, or selected ones, can be exported in CVS files. (Figure 5, Top, highlighted in orange).

An alternative display method is the TABLE VIEW, listing cases and showing parameters such as the case study/lab name, the general project to which the case study/PED lab refers to, and the type of PED. Similar filtering options are available, and text searches are possible. When a case study is selected, the database visualizes detailed information in a table format. Parameter titles are listed in the left column, and specific input data for the selected case are shown in the right column. By clicking on 'compare', the database allows relating characteristics across the different cases/labs, presenting data for the new selected cases/labs, facilitating immediate comparisons.

The "PROJECTS" page lists all surveyed projects/initiatives, providing context for the R&I environment in which the PED case or Lab is developed.

4.3. Preliminary Analysis of 23 Mapped Case Studies

Currently, there are 23 PED cases, including both PED/PED-relevant cases and PED Labs, along with 7 PED related projects available. The interconnections among mapped case studies and projects are shown in Figure 6.

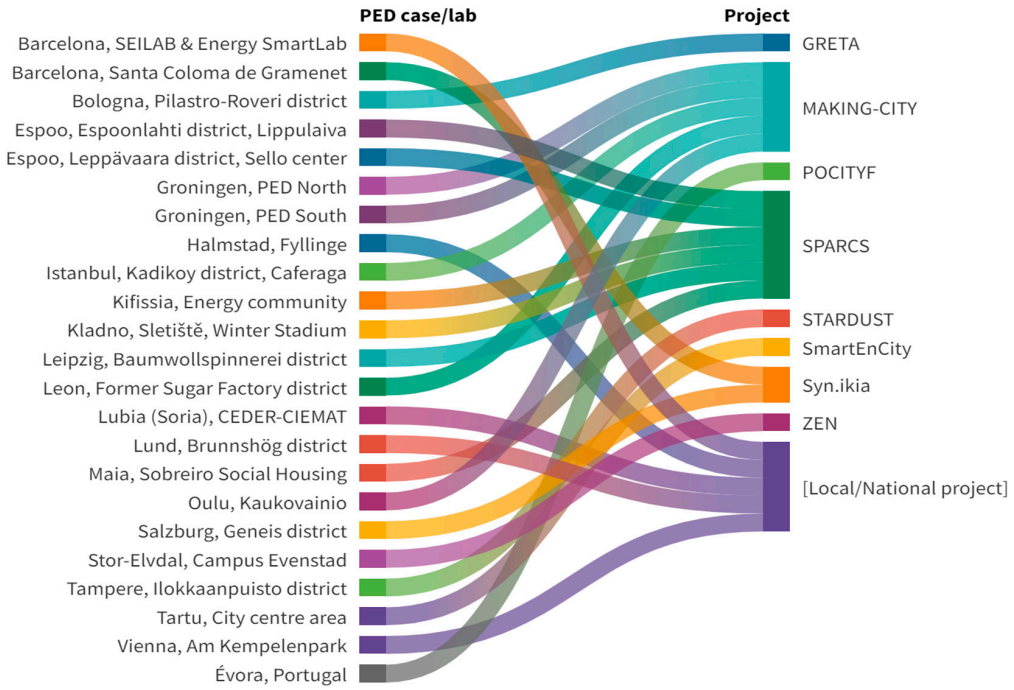

Figure 6. Referenced Case studies/Labs linkage to general Projects/Initiatives'. Designed through the support of Flourish Data Visualization tool (source: https://flourish.studio/, accessed on 25 November 2023).

Two export options are available for case studies: the .pdf format and the .csv format. Leveraging the .csv export option and using the methodologies employed in analogous research [73,74], a preliminary analysis of the mapped cases has been outlined, with future analyses and insights anticipated.

As an initial outcome of the collection of PED cases within the PED DB, it is noteworthy that they span 13 different European countries (see Figure 7b): Of these, 10 are classified as PED Cases studies, 6 as PED relevant, while 6 are PED Labs and 2 fall under both PED relevant and PED lab categories (see Figure 7a). Finland and Spain are currently presented with 4 PED case studies, whereas Sweden, Austria, Portugal, and the Netherlands each

have 2 case studies. Norway, the Czech Republic, Turkey, Estonia, Italy, Germany, and Greece each contribute a single PED case study.

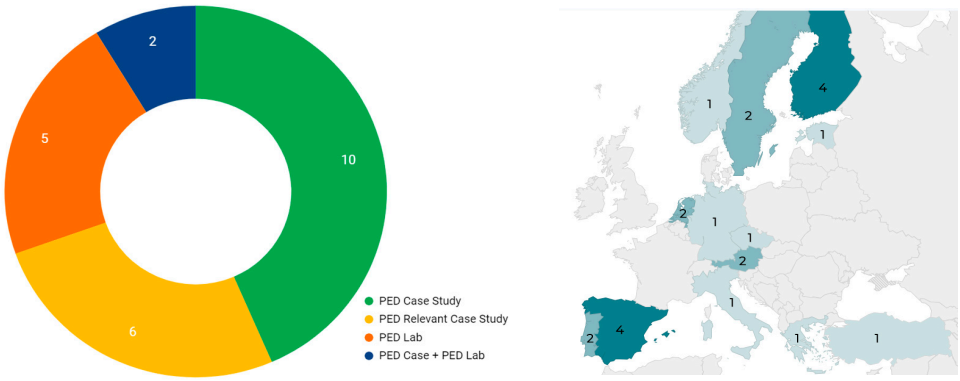

Figure 7. (**a**) Categorization of the surveyed PED case studies; (**b**) Geographic distribution and number of surveyed PED case studies from each Country.

As per the inquiry in question A1-P005 within the DB form, it is recognized that only 4 of the mapped PED cases are presently in operation, 2 are completed but not in operation, and the remaining 16 are in the planning or implementation phase (see Figure 8a). Concurrently, based on parameter A1-P018, it can be inferred that initial PED experiences tend to be of a relatively modest scale: specifically, 10 out of the 23 case studies involved fewer than 10 buildings (see Figure 8b).

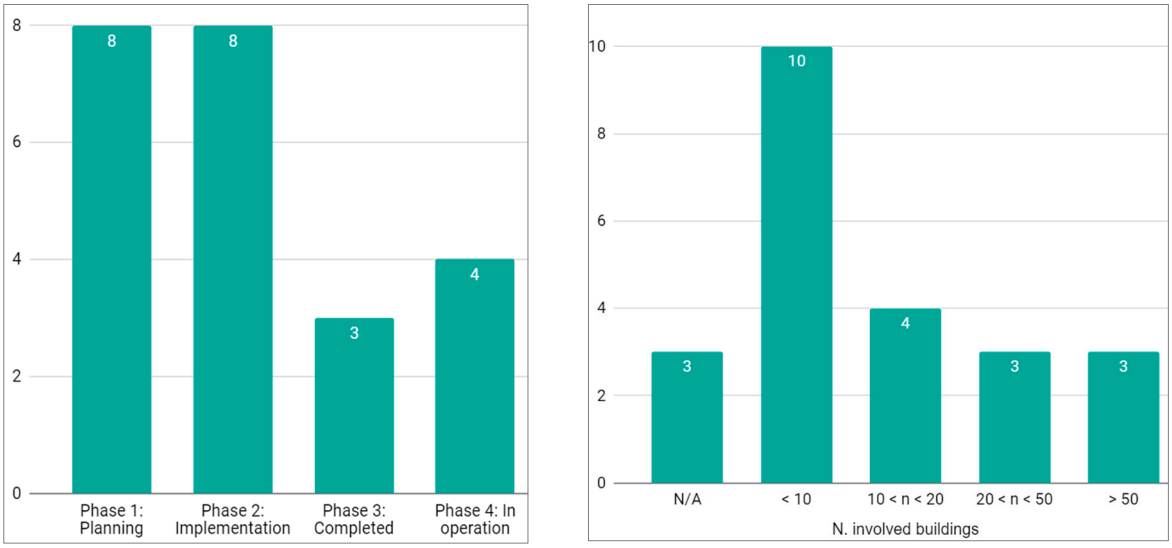

Figure 8. (**a**) Stage of the PED phase reported in the DB form; (**b**) Number of buildings involved in each PED case/lab.

Out of the 82 questions, predominantly non-mandatory, constituting the PED survey, respondents provided answers to an average of 55% of the questions (refer to Figure 9, represented by the black bar). The average completion rates for all sections (A1, A2, A3, B1, B2, C1) are delineated in Figure 9. Notably, Section A1, focusing on global characteristics of PED, achieved a good result with an average filling rate of 84%. Similarly, Section C1, centred on PED drivers and barriers, exhibited a favourable filling rate of 75%. Section A3 (Non technological aspects) and B2 (PED lab in detail) have an average filling rate exceeding

50%. However, lower completion rates were observed in Sections A2 (Technological aspects) with 37% and B1 (PED case studies in details) with 31%.

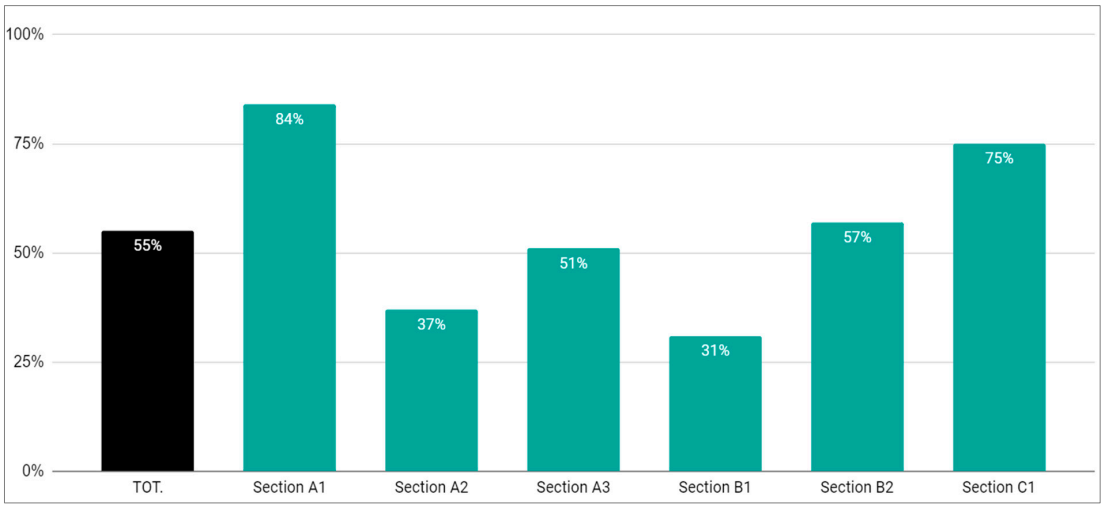

Figure 9. Average filling rate of all the questions of the survey (TOT) and of each single section.

5. Discussion

Since 2020, several initiatives—i.e., EERA JPSC, the Smart Cities Marketplace, the DUT Partnership and SET-Plan Action 3.2, the COST Action PED-EU-NET, IEA EBC Annex 83, the SCC01 TG Replication and SCALE—have been aligned to discuss how to cooperate and complement each other towards a European integrated PED definition and framework on Positive Energy Districts. This collaboration facilitates a harmonious representation of multiple nationalities and disciplines, while also ensuring a balance between different stakeholders' approach, including scientific and political viewpoints, among others. This close collaboration has streamlined and accelerated the development process of the PED Database, in order to make this tool not only the main reference for a PED cases collection, but also to set the PED DB as a strategic instrument for the European objectives under the Strategic Research and Innovation Agenda (SRIA). For this purpose, the SRIA 2022–2025, in cooperation with the SET-Plan 3.2 to create 100 PEDs by 2025, will expand towards Climate Neutral Cities (CNCs), and the EU Cities Mission to create 100 CNCs by 2030. This allows for a more coordinated and comprehensive approach to PED DB development, which can help to reach the Sustainable Development Goals (SDGs) more effectively. Therefore, the PED DB will help to spread the examples and identify the key success factors of planning, implementation, and monitoring of PEDs.

Online surveys were structured to ensure user friendliness and easy sharing among stakeholders responsible for case studies and projects. A total of 23 online surveys were successfully submitted, affirming the proper functionality of both components of the online platform, namely the backend and frontend, for data storage, revision, and publication. The collected data proved easily exportable, enabling a preliminary analysis.

While the number of collected PED cases and the filling rate of the web form may not provide a comprehensive overview of PED case studies and Labs in Europe, the ongoing PED case collection is a continuous process tested over the last months since the completion of the web form's functionality.

Presently, the PED DB includes 23 case studies locate in 13 European countries. To attain a more expansive statistical overview, a broader mapping involving a minimum of three case studies for each European country is expected in the future.

As expected, a majority of the presented case studies are in planning or implementation phases. Considering that the PED concept was introduced only in 2018 and the complexity involved in the developing a positive energy district require several years, an increase in completed and operational case studies is anticipated in the years to come.

The average filling rate of 55% for answered questions is noteworthy, given the complexity of the survey, encompassing technical, social, political, and financial aspects. High filling rates were achieved in sections focusing on general PED information and characteristics (Section A1 'Global characteristics') and questions related to drivers and barriers (Section C1 'Drivers and Barriers'). These sections primarily involve qualitative questions, requiring no specific technical expertise. Conversely, less answered questions were found in Section A2 'Technological Aspects' and Section B1 'PED Case Studies in Detail', which are more detailed and technical. Consequently, future support will be provided by DB editors to enhance the filling rate of these specific questions, suggesting the involvement of researchers and technical experts engaged in the case studies.

The data collected thus far provides a preliminary glimpse into the diverse European landscape of PED initiatives. While the current dataset may not offer a comprehensive overview, the ongoing commitment to expanding the database and capturing a more representative sample is crucial for future analyses.

The potential utility of the PED database extends beyond its role as a repository of information. It stands as a dynamic platform for sharing insights, best practices, and lessons learned from various PED case studies. As more case studies are added, the database becomes a valuable repository of knowledge, aiding decision-makers, urban planners, and researchers in developing strategies to advance PEDs.

In the context of securing grants and funding, the database serves as a foundational resource for identifying successful models, understanding key drivers and barriers, and showcasing best practices. This, in turn, can guide policymakers and grant providers in allocating resources effectively to promote sustainable urban development.

The PED database not only contributes to the ongoing dialogue on positive energy districts but also serves as a catalyst for informed decision-making, fostering collaboration, and driving advancements in sustainable urban development. Its continued growth and utilization promise to be instrumental in shaping the future of PEDs and their integration into the broader landscape of innovative, energy-efficient urban environments.

6. Future Works

6.1. Gaps and Needs for Future PED DB Development

Before embarking on the design and planning of a Positive Energy District (PED), it is necessary to formulate a series of questions that aim to highlight the key factors to consider. In the implementation of PED, what changes and benefits would we achieve in our cities? What potentials and impacts does it generate? What factors block or drive its development? What are the main challenges? The availability of a PED Database represents the opportunity to map the current situation in Europe and to identify the most common technical and non-technical characteristics, showing which technologies are the most frequent, main fields of action, positivity methods, financial models, or main actors involved in each phase. Nevertheless, the PED Database also provides information related to the main unlocking factors, driving factors and barriers encountered when approaching the design of this type of urban solutions, and that can be used as decision-support tools in city decision-making processes.

In order to set the right features and to cover all the potentialities from the PED DB, a workshop (world-café format) was held in the SSPCR Conference [63] under the IEA EBC Annex 83—namely the SubTask A and SubTask D dedicated sessions—to collect answers related to specific questions on PED DB, specifically focusing on stakeholders' involvement for the utilization and the need for an overarching PED DB. These questions were directed to all audience consisting of a diverse set of stakeholders involved in PED developments at EU Level, who provided answers to the following questions:

1. How would you use a database tool to learn about PED development process (i.e., using static information for dynamic decision-making)?
2. What would be your main interest in consulting the Database?

Regarding the first question, three clusters were developed based on the answers of the participants. The first cluster of responses were essentially about the use of the DB, upon features to be added to the DB interface—such as mapping information, filtering with a few parameters. The second cluster of options were grouped under the suggestions on parameters. In addition to the existing parameters, it was highly suggested to include the barriers, success factors, experiences from different projects, energy parameters and technologies, and motivations for PED developments. Open questions aligned with climate vulnerability and how to overcome the disadvantages and energy poverty reduction were also suggested. The third cluster was about the next steps. Most of the participants highlighted the importance of learning from each other: the case studies are compiled by the researchers or municipalities directly, but citizen/inhabitant point of views/social responses are also very important to motivate PED implementations. For this reason, a participatory approach (i.e., workshops, or Living Labs supporting new interactions) and an interactive usage of the PED DB between researchers/experts/practitioners and municipalities/users was suggested.

For the second question, the most highlighted comments were focusing on adding special references to real life implementations—e.g., data analysis and potential research on the field, metadata and benchmarking to compare PEDs—together with the need to normalize results depending on a number of factors—e.g., size, location, etc.—to really compare different initiatives and benchmarking—e.g., different technologies, energy poverty analysis, methods adopted to calculate the energy balance, etc.—to create awareness and empowerment instead of only engagement, and to have an updated reference framework to establish the energy positiveness, drivers and enablers to overcome administrative, technical, economic or functional barriers.

On that issue, additional workshops were organized by the PED-ACT project [31] during the SSPCR Conference with its pilots to understand the need for a PED DB. The PED-ACT project aims to innovate the early-stage design of a PED by improving the process for stakeholder cooperation and reinforced decision-making. PED replication is not simple, so it is important to plan and model the possibility of PED replication in the early design stages, by learning the characteristics of existing PEDs (which can be derived from the PED DB) for tailor-made solutions in local contexts, and by adopting a digitized and standardized PED database for the exchange of information through machine learning. A survey has been conducted with the stakeholders, to understand the needs and priorities, and to create a common understanding with regards to the general structure and the components of the final product, through the following questions:

1. How do you prioritise the basic functions of a digital tool/PED DB?
2. How do you prioritise the basic properties/features of a digital tool/PED DB?
3. What are the components/dimensions that need to be included in a PED DB? (in four categories—General, Quantitative—Energy and Emissions, Human/Social and Lessons-Learnt and recommendations).

With regards to the basic functions of a digital tool/PED DB, "Access to thoroughly collected and well-organized quantitative and qualitative data sets", "Knowledge/experience sharing component/platform", and "Data exchange opportunity" are respectively the most preferred dimensions of a digital tool/PED DB, while "User-friendly interface", "Facilitated storage, representation, import/export, modification, and deletion of data", and "Data integrity management" respectively reflect the top-level features that the digital tool/PED DB needs to have in terms of its basic features/properties.

6.2. Next Steps for Data Collection: Digitalization and Future Application Potential

The choice to implement the PED DB as an online interoperable platform is linked to a two-fold order of reasons: on the one hand, the will to map in a flexible and updatable way the grounding of the first pilot PED experiences and, on the other hand, the need for future upgrades of the platform towards a more digital and user-friendly tool, collecting multiple functionalities according to the evolving features and challenges characterising PED large-

scale deployment. In fact, thanks to its digital format, the users (e.g., municipalities, practitioners, researchers, etc.) can easily take advantage of the Database as a tool to browse different practices, search for similar examples and access practical information and insights. Likewise, researchers and professionals can use the Database to search for technical solutions and other information, compare and analyse data, learn and identify common patterns and narratives, and share knowledge. So, the commitment to scenario analysis and energy and climate optimization at the building and city scale aligns perfectly with the goal of facilitating data-driven decision-making in urban energy supply planning.

In this perspective, data auditing plays a crucial role in aligning the data collection process with the objectives of the PED Database, enabling stakeholders to make more informed decisions and reap greater benefits by focusing on relevant information and stakeholder perspective. Therefore, collecting feedback and updating existing information on stakeholders is also valuable to support story-telling and upcoming meetings in Living Labs, workshops, or world-café initiatives. To achieve this goal, assessing potential stakeholders' engagement can be achieved through website and social media digital analytics. These analytics can track stakeholder interactions and behavioural data in PED Database, such as clicks, mouse movement, pages visited, and time spent on pages, providing insights into the stakeholder journey. This information can help to assess how stakeholders discover the PED Database website, their navigation paths, and the points where they convert or exit. Additionally, website heat maps can be employed to identify areas of the PED website with the most and least interaction. Tracking this data is essential for identifying what is and is not working and improving the overall PED database user experience.

Another aspect to consider is the re-evaluation of current data capture forms based on what the users have been willing to provide in the preliminary PED cases. Adjusting these forms based on stakeholder preferences and usefulness while maintaining transparency about data collection, informing users about what data is collected and why, is important. To enhance the benefits of contributing data to the PED Database, it is crucial to establish a clear and personalized advantage for stakeholders. This fosters trust and encourages the sharing of the information, alongside a transparent process.

6.3. Storytelling and Roadmap: A Stakeholders Tailored Approach

In addition to the above-mentioned objectives and future insights of the PED DB, what emerged from the workshops and calibration meetings has been the importance of involving a wide range of stakeholders in the planning and development of a PED that includes residents, businesses, government agencies, and non-profit organizations.

Stakeholder engagement helps to ensure that the needs and interests of all stakeholders are taken into account, but also that several obstacles can be overcome to develop and operate a PED, as it is important to collaborate with government agencies to identify and address any regulatory barriers. This could involve changes to zoning laws, building codes, and energy efficiency standards. Therefore, PEDs can have a significant impact on the lives of residents and businesses in a community. It is important to consider the social and cultural implications of PEDs and to work with stakeholders to ensure that they are accepted by the community. This could involve education and outreach programs, community benefits, and financial assistance programs for low-income residents. Furthermore, PEDs can be expensive to develop and operate. It is important to develop a financial model for the PED that is viable and sustainable in the long term. This could involve government subsidies, tax breaks, and public–private partnerships.

To harness the power of the PED Database as an impactful learning tool it needs to offer the stakeholder experience from the PED cases/labs in an appropriate form, i.e., going beyond the presentation of information, benchmarking, and data. For the upcoming phase of the PED Database development, it has been discussed that a story-telling approach can enable faster and more effective learning by the target groups [65]. The stories can bring new dynamic element to the PED Database, describing the PED design and implementation process through experience of particular stakeholder(s). Such an approach complements

the already available static element of collected available data and information on PED cases/labs [20,23,75].

A preliminary story-telling framework (currently in its design phase) to be implemented as an add-on to the PED Database fulfils the following aims: (1) define the general framework and formal design of the PED case story for collection and reposition, (2) define the communication strategy and architecture of the story, containing clear instruction on how to further disseminate, present, and interpret the story beyond the scope of the PED Database itself.

7. Conclusions

PEDs are still a relatively new concept [4], but they are gaining traction around the world. As PEDs become more popular, they are likely to play an increasingly important role in the global transition to a clean and sustainable energy future. Overall, PEDs offer a number of advantages over building-level and city-level approaches to sustainable development. Indeed, PEDs take a holistic approach that considers the needs of the entire community [38]. Starting from these considerations, the design of the PED Database arises from two preliminary questions shared within the research group:

- Will the PED DB tool be designed following a systemic approach, able to support cities in taking advantage of this rapid and challenging technological and non-technological change and to reach the global commitments of the 2030 Agenda in cities?
- Can the learning and awareness goals be achieved through ontological reasoning using big data and machine learning, without losing contact with the real world and local context?

With regards to the first question, we believe that the collected PED data and exponential growth in processing power due to distributed computing can be adopted as reference information for cities to clarify if they are aligned and heading in the right direction toward sustainable goals; on the other hand, as the World Economic Forum Global Future Council on Cities of Tomorrow identified in its 2022 reports on climate resilience, digital technologies, city finance, and urban inclusion [76,77], a systemic approach is essential if cities aim to achieve their goals for people and the planet. Indeed, the second answer was also 'yes', because data can help to leverage awareness of Citizens, Public, and Practitioners about future scenarios, and they can address vexing and seemingly intractable problems of urban governance. In addition, big data, or data in general, has currently fuelled rapid advances in the field of artificial intelligence, and will increase in the future. Therefore, this is why we decided to start collecting data in a systematic way before we can accomplish everything we can do with it. Indeed, the way and the framework we adopted to collect data in .csv format is designed according to an incorporated ontology able to maximize semantic interoperability, thus differently from other existing PED collection/DB on similar experiences. Among the expected future development, the ambition is to create a python package—e.g., to automatically populate the dashboards (e.g., interoperable dashboard from Zhang et al. [24] or to calculate KPIs and mapping experience (e.g., Advanced learning/storytelling tool)—and creating friendly report for different stakeholders. The stakeholder-related key to the project will be, through the Decision Support System (DSS), the element that can outline shared strategies and actions to maximize the project's impact on the PED implementation area. As an example, the algorithms will be able to weigh the various parameters in relation to each stakeholder group and identify the best strategy with related synergistic actions.

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

The three methodological steps that led to the definition of the structure of the PED DB also enabled a process of harmonization and rationalization of data fields and the

outlined glossary may form the basis for the subsequent interoperability of PED data to other systems. Starting from the project experiences, as well as the work done in the PED Booklet and EU Energy Community, we went on to break down each experience, each project into the prime factors and identified the enabling facts, as well as the challenges and barriers.

Through the compilation of the DB, each stakeholder in the PED world is able to get a broader reading of the experiences already done because of the parameters identified and their level of detail, and will be able to replicate future ones.

8. Patents

The intellectual property strategy has been consistent from the outset of the CA PE-EU-NET (see the Deliverable 1.1 [53]) which stressed the open access to all information and data of the PED database and suggested the Creative Commons Attribution 4.0 (CC-BY-NC 4.0). Users are only obligated to give appropriate credit (attribution) and indicate if they have made any changes, including translations. This license applies to all data that are published, i.e., once they have been cleaned for publication by the respective PED Database Editor. The full list of authors of the PED Database framework and contributors remains open for updates as the PED Database grows constantly. The list is updated regularly and is accessible directly at the PED Database website, and it should therefore be referenced together with the last date of access [12].

Author Contributions: Conceptualization, P.C., G.T., B.A. and M.K.; methodology, P.C., G.T., B.A. and M.K.; software, P.C., G.T., B.A., M.K., S.S., M.N.S. and O.S.; validation, P.C., G.T., B.A., M.K., S.S., M.N.S., S.B., M.H., G.M. and C.G.; formal analysis, P.C., G.T., B.A., M.K., S.S., M.N.S., S.B., M.H. and C.G.; investigation, P.C., G.T., B.A., M.K., S.S., M.N.S., S.B. and M.H.; resources, P.C., G.T., B.A. and M.K.; data curation, P.C., G.T., B.A., M.K., S.S., M.N.S., O.S., S.B., M.H. and C.G.; writing—original draft preparation, P.C., G.T., B.A., M.K., S.S., M.N.S., S.B., M.H. and G.M.; writing—review and editing, P.C., G.T., B.A., M.K., S.S., M.N.S. and S.B; visualisation, P.C., G.T., B.A. and S.B.; supervision, P.C. and G.T.; project administration, P.C., G.T., B.A., M.K., S.S. and O.S.; funding acquisition, P.C., G.T., B.A., M.K., S.S., M.N.S., O.S., S.B., M.H., G.M. and C.G. All authors have read and agreed to the published version of the manuscript.

Funding: The research leading to these results has received funding COST (European Cooperation in Science and Technology) under the Action 19126 Positive Energy Districts European Network (PED-EU-NET). Paolo Civiero acknowledges the funding received from project ECS 0000024 Rome Technopole - CUP F83B22000040006, NRP Mission 4 Component 2 Investment 1.5, Funded by the European Union - NextGenerationEU. Michal Kuzmic acknowledges the funding received from the European Union's Horizon 2020 research and innovation programme under the SPARCS grant agreement No. 864242. Beril Alpagut acknowledges the funding received from the European Union's Horizon 2020 research and innovation programme under the MAKING-CITY project agreement No. 824418. Matthias Haase acknowledges the funding received from the project "DECARB" of ZHAW, CIEMAT acknowledge the funding received from European Union's Horizon Europe research and innovation program for project CO2NSTRUCT [grant agreement No. 101056862].The APC was funded by the European Energy Research Alliance Joint Programme on Smart Cities (EERA JPSC).

Data Availability Statement: The data presented in this study are openly available at: https://pedeu.net/map/ (accessed on 5 February 2024).

Acknowledgments: This article is based upon work from COST Action 19126 Positive Energy Districts European Network PED-EU-NET (https://pedeu.net/ accessed on 14 November 2023), supported by COST (European Cooperation in Science and Technology, www.cost.eu accessed on 14 November 2023). The authors acknowledge COST Action 19126 WGs and other international initiatives—in particular the IEA Annex 83, JPI Urban Europe, Smart Cities Marketplace and EERA Joint Programme on Smart Cities—for the fruitful and continuous collaboration in PED-Database development.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

CA	COST Action
COST	European Cooperation in Science and Technology
DB	Database
DUT	Driving Urban Transition
EERA JPSC	European Energy Research Alliance Joint Programme on Smart Cities
EIP-SCC	European Innovation Partnership on Smart Cities and Communities
ERRIN	European Regions Research and Innovation Network
EU	European
GHG	Greenhouse Gasses
IEA-EBC	International Energy Agency's Energy in Buildings and Communities
IT	Information Technology
JPI UE	Joint Programming Initiative Urban Europe
KPIs	Key Performance Indicators
NECPs	National Energy and Climate Plans
PED	Positive Energy District
SCIS	Smart Cities Information System
SCM	Smart Cities Marketplace
SDGs	Sustainable Development Goals
SEAPs	Sustainable Energy Action Plans
SECAPs	Sustainable Energy and Climate Action Plans
SET	Strategic Energy Technology
SMEs	Small and Medium Enterprises
SRIA	Strategic Research and Innovation
SUMP	Sustainable urban mobility plan
WGs	Working Groups

Appendix A. PED Database Glossary

Table A1. Section A1—Global Characteristics.

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A1 P001	Name of the PED case study/PED Lab (*)	N/A	Name the city, neighbourhood/district where the case study is located.
A1 P002	Map/aerial view/photos/graphic details/leaflet (*)	N/A	Please upload at least one file (min 150 DPI).
A1 P003	Categorisation of the PED site (*)	See individual answer options' definitions below: •PED case study: district-level project with high level of aspiration in terms of energy efficiency, energy flexibility and energy production. The project has to address of the aspects listed in the JPI UE PED Framework Definition, including the ambition to achieve annual energy positive balance; •PED relevant case study: district-level project with high level of aspiration in terms of energy efficiency, energy flexibility, and energy production. The project does not necessarily have to meet annual energy positive balance, but it has to address aspects listed in the JPI UE PED Framework Definition; •PED Lab: PED Labs are pilot actions that provide opportunities to experiment with planning and deployment of PEDs, as well as provide seeding ground for new ideas, solutions, and services to develop. PED Labs follow an integrative approach including technology, spatial, regulatory, financial, legal, social, and economic perspectives.	What is the categorisation of your PED?

Table A1. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A1 P004	Targets of the PED case study/PED Lab (*)	See the definitions of individual answer options below: •Air quality and urban comfort: the objective of improving air quality is aimed at reducing the concentration of the five main pollutants: O_3, NO_2, SO_2, PM2.5, and PM10; •Circularity: circular systems employ reuse, sharing, repair, refurbishment, remanufacturing, and recycling to create a closed-loop system, minimizing the use of resource inputs and the creation of waste, pollution, and carbon emissions. In the case of PED, the revalorization of waste (such as residues from the different sectors) for the energy production is prioritized, but many other pathways could be taken, considering the cycle of water, food, etc.; •Climate neutrality: climate neutrality means that on a period basis the carbon dioxide emissions within the limits of the district are compensated with the exported energy or by carbon capture; •Electrification: electrification is the process in which the supply of any energy needs of a district and/or city, such as the heating needs or the mobility sector, are supplied by electricity-driven technologies; •Energy Community: energy community refers to a wide range of collective energy actions that involve citizens' participation in the energy system. Energy communities can be understood as a way to 'organize' collective energy actions around open, democratic participation, and governance and the provision of benefits for the members or the local community; •Net-zero emission: a net-zero emissions building produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources. •Net zero energy cost: the amount of money the utility pays the building owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year; •Annual energy surplus: the total annual energy balance is positive, therefore the area will deliver, on average, an energy surplus to be shared with other urban or peri-urban zones; •Self-sufficiency (energy autonomous): self-sufficiency means that within a year, the district will never import energy from outside the boundaries (e.g., consume electricity or gas from the grids); •Maximise self-sufficiency: maximise self-sufficiency means that within a year, the district is allowed to import energy from outside the boundaries, however the energy content of the imported energy products to the district should be less than (or equal to) the energy content of the energy products exported from the district. Thus, the "net imports" is zero or negative.	Check all that apply.

Table A1. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A1 P005	Phase of the PED case study/PED Lab (*)	See individual answer options' definitions below: ●Planning stage: Case Study or Lab is being designed; ●Implementation stage: Case Study or LAB is being deployed; ●Completed: Case Study or LAB is already finalized; ●In operation. Case Study or LAB is being used.	Choose one of the following answers.
A1 P006	Start Date	N/A	Please specify starting date from planning (month/year)
A1 P007	End Date	N/A	Please specify the end date to commissioning (month/year). If not available, provide estimate.
A1 P008	Reference Project	N/A	Indicate if the case study/PED lab is part of any publicly funded project (e.g., Horizon 2020 project, Interreg project, etc.). Please choose from existing projects in the drop-down menu. If your project is not available there, please fill in the Input form on General Projects/Initiatives first (Section D).
A1 P009	Data availability	N/A	Please indicate which datasets would you be willing to share with the research and practitioner community in the future?
A1 P010	Sources	Any publication, link to website, deliverable referring to the PED/PED Lab	Please provide any additional resources with details about your case study/PED Lab.
A1 P011	Geographic coordinates (*)	Geographic coordinate system, latitude and longitude	You can learn the coordinates by clicking on a map on Google Maps or another map portal. Please, consider the district's central point.
A1 P012	Country (*)	N/A	N/A
A1 P013	City (*)	N/A	N/A

Table A1. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A1 P014	Climate Zone—Köppen Geiger classification (*)	The most widely used climate classification system. It divides climates into five main climate groups based on seasonal precipitation and temperature patterns. •Af: Tropical-Rainforest •Am: Tropical-Monsoon •Aw: Tropical-Savanna •BSh: Arid-Steppe-Hot •BSk: Arid-Steppe-Cold •BWh: Arid-Desert-Hot •BWk: Arid-Desert-Cold •Cfa: Temperate-Without_dry_season-Hot_Summer •Cfb: Temperate-Without_dry_season-Warm_Summer •Cfc: Temperate-Without_dry_season-Cold_Summer •Csa: Temperate-Dry_Summer-Hot_Summer •Csb: Temperate-Dry_Summer-Warm_Summer •Cwa: Temperate-Dry_Winter-Hot_Summer •Cwb: Temperate-Dry_Winter-Warm_Summer •Dfa: Cold-Without_dry_season-Very_Cold_Winter •Dfb: Cold-Without_dry_season-Warm_Summer •Dfc: Cold-Without_dry_season-Cold_Summer •Dsa: Cold-Dry_Summer-Hot_Summer •Dsb: Cold-Dry_Summer-Warm_Summer •Dsc: Cold-Dry_Summer-Cold_Summer •Dsd: Cold-Dry_Summer-Very_Cold_Winter •Dwa: Cold-Dry_Winter-Hot_Summer •Dwb: Cold-Dry_Winter-Warm_Summer •Dwc: Cold-Dry_Winter-Cold_Summer •Dwd: Cold-Dry_Winter-Very_Cold_Winter •EF: Polar-Frost •ET: Polar-Tundra	Choose one of the following answers.
A1 P015	District boundary	See the definitions of individual answer options below: •Functional: buildings are not close to each other, but they are interconnected, thanks to a gas, electric, or heating network. •Geographic: the boundaries are delimited by spatial–physical limits, including delineated buildings, sites, and infrastructures. •Off-Grid: district is self-sufficient or autonomous, which means it is not connected to any utility grids (e.g., electricity, water, gas, and sewer networks). This is advantageous in isolated locations where normal utilities cannot reach and is attractive to those who want to reduce environmental impact and cost of living. •Virtual: energy demand is covered by a generation unit (e.g., a wind turbine), which is typically shared with other consumption points and located outside the geographical boundaries of the district, then it could be considered a virtual boundary •Other—specify: N/A	Choose one of the following answers.

Table A1. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A1 P016	Ownership of the case study/PED Lab (*)	See individual answer options' definitions below: •Private: Ownership of a private individual or organization. •Public: Ownership of an industry, asset, or enterprise by the state or a public body representing a community as opposed to a private party. •Mixed: Ownership of the assets within the PED by both public and private entities.	Choose one of the following answers.
A1 P017	Ownership of the land/physical infrastructure (*)	N/A	Choose one of the following answers.
A1 P018	Number of buildings in PED	N/A	Only numbers may be entered in this field
A1 P019	Conditioned space	Closed building area, where there is intentional control of the space thermal conditions within defined limits by using natural, electrical, or mechanical means	Only numbers may be entered in this field
A1 P020	Total ground area	The ground space includes green areas and streets within the defined physical boundaries.	Only numbers may be entered in this field
A1 P021	Floor area ratio: conditioned space/total ground area	N/A	This parameter is automatically calculated
A1 P022	Financial schemes (*)	N/A	Please select the adopted funding scheme and if available, add the value in EUR.
A1 P023	Economic Targets	N/A	Check all that apply.
A1 P024	More comment	N/A	Include any additional comments about general characteristics that you wish to share.
A1 P025	Estimated PED case study/PED LAB costs	N/A	Mil. EUR
A1 P026	Contact person for general enquiries—name (*)	Name of the person who filled in the form	N/A
A1 P027	Contact person for general enquiries—organization (*)	Organization of the person who filled in the form (e.g., Municipality of…, University of…)	N/A
A1 P028	Contact person for general enquiries—affiliation (*)	Affiliation of the person who filled in the form	Choose one of the following answers.
A1 P029	Contact person for general enquiries—e-mail (*)	Contact e-mail of the person who filled in the form	N/A
A1 P030	Contact person for other special topics—name	Name of the project manager of the site	N/A
A1 P031	Contact person for other special topics—e-mail	Contact e-mail of the project manager of the site	Fill in only when you have consent of the person/if the e-mail address is publicly available.

(*) Mandatory parameters.

Table A2. Section A2—Technological solutions.

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A2 P001	Fields of application	See the definitions of individual answer options below: •Energy efficiency: energy efficiency simply means using less energy to perform the same task—that is, eliminating energy waste. •Energy flexibility: in the electricity system, flexibility helps to maintain or restore the stability of a system, because only by reacting flexibly to constantly changing conditions—fluctuating electricity consumption, fluctuating electricity generation—is the system is balanced. •Energy production: In terms of Renewable Energy production •E-mobility: e-mobility refers to clean and efficient transport, using electric vehicles, powered either by batteries or by hydrogen fuel cells. •Urban management: N/A •Urban comfort and air quality: N/A •Digital technologies: digitalization can be thought of as the increasing interaction and convergence between the digital and physical worlds. Digital technologies are set to make energy systems around the world more connected, intelligent, efficient, reliable, and sustainable. Stunning advances in data, analytics, and connectivity are enabling a range of new digital applications such as smart appliances, shared mobility, and 3D printing. Digitalized energy systems in the future may be able to identify who needs energy and deliver it at the right time, in the right place, and at the lowest cost. •Water use: water use refers to water used by end users (e.g., households, services, agriculture, industry) within a territory for a specific purpose such as domestic use, irrigation, or industrial processing. •Waste management: the new agenda for waste management thus focuses upon the development of more appropriate, sustainable definitions so that what is now commonly perceived as being waste will in fact be increasingly seen as resource-rich, 'non-waste'. The role of waste management is explained as control of all waste-related activities, with the aim of preventing, minimizing or utilizing waste. •Air quality: in order to protect human health and the environment as a whole, it is particularly important to combat emissions of pollutants at source and to identify and implement the most effective emission reduction measures at a local, national, and community level. Therefore, emissions of harmful air pollutants should be avoided, prevented, or reduced and appropriate objectives set for ambient air quality by taking into account relevant World Health Organisation standards, guidelines, and programmes. •Construction materials: N/A •Other, please specify: N/A	Check all that apply.

Table A2. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A2 P002	Tools/strategies/ methods applied	N/A	Which tools/strategies/methods do you apply?
A2 P003	Application of ISO52000	ISO 52000–1:2017 establishes a systematic, comprehensive, and modular structure for assessing the energy performance of new and existing buildings (EPB) in a holistic way.	Do you apply ISO 52000?
A2 P004	Appliances included in the calculation of the energy balance	N/A	Are appliances included in the calculation of the energy balance?
A2 P005	Mobility included in the calculation of the energy balance	N/A	Is mobility included in the calculation of the energy balance?
A2 P006	Description of how mobility is included (or not included) in the calculation	N/A	How is mobility included (or not included) in the calculation?
A2 P007	Annual energy demand in buildings/Thermal demand	National standards, national statistical data (with estimated energy demand per square meter dependent on the climate zone of the area, etc.), measured data (if available), or bills can be used to calculate the thermal demand. Furthermore, when structural data of the building and data from the existing system are available, an energy modelling tool can be useful to estimate the demand.	Only numbers may be entered in these fields.
A2 P008	Annual energy demand in buildings/Electric Demand	National standards, national statistical data (with estimated energy demand per square meter dependent on the climate zone of the area, etc.), measured data (if available), or bills can be used to calculate the thermal demand. Furthermore, when structural data of the building and data from the existing system are available, an energy modelling tool can be useful to estimate the demand.	Only numbers may be entered in these fields.
A2 P009	Annual energy demand for e-mobility	N/A	Only numbers may be entered in these fields.
A2 P010	Annual energy demand for infrastructure	N/A	Public infrastructure (all except building and mobility). Only numbers may be entered in this field.
A2 P011	Annual renewable electricity production on-site during target year	After identifying which solutions will be considered for a certain district, energy systems can be listed and the connections between each other (schematics) and the renewable energy source that is supplied to it can be identified. Renewable sources for electricity production include wind, solar (solar photovoltaic and hybrid PVT), tide, wave and other ocean energy, hydropower, and biomass.	Only numbers may be entered in these fields. Please, specify production in GWh/annum.
A2 P012	Annual renewable thermal production on-site during target year	Renewable sources for thermal production include solar (solar thermal hybrid PVT), geothermal energy, biomass, landfill gas, sewage treatment plant gas, and biogas.	Only numbers may be entered in these fields. Please, specify production in GWh/annum.

Table A2. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A2 P013	Renewable resources on-site—Additional notes	N/A	According to the previous question, if some clarification is needed, please include them in this space.
A2 P014	Annual energy use	Annual sum of thermal energy use and electric energy use. Thermal Energy Use (TEU) refers to energy input into the heating, cooling, or hot water system to satisfy the energy needs for heating, cooling, or hot water, respectively. Electric Energy Use (EEU) refers to electricity directly consumed by buildings and e-vehicle charging (from grid or local RES as PV, wind, etc.) to be delivered to cover the energy needs (for DHW, heating, and cooling when an electricity-driven system is used; and ventilation, appliances, and lighting).	Only numbers may be entered in these fields. Please, specify production in GWh/annum.
A2 P015	Annual energy delivered	Energy supplied to the district (thermal and electricity) that is produced outside the district boundaries. Usually comes from heating/cooling networks, gas, or electric grids and feeds the energy systems available on-site in the district. Some of these energy flows can be quantified based on the meters, and in case of gas consumption, which is usually measured in m3, a conversion factor will be needed. The conversion factors shall be coherent with the choice of referring to gross calorific value or net calorific value.	Only numbers may be entered in these fields. Please, specify production in GWh/annum.
A2 P016	Annual non-renewable electricity production on-site during target year	N/A	Please specify, if non-renewable on-site production exists. In case, specify production in GWh/annum.
A2 P017	Annual non-renewable thermal production on-site during target year	N/A	Please specify, if non-renewable on-site production exists. In case, specify production in GWh/annum.
A2 P018	Annual renewable electricity imports from outside the boundary during target year	Similar to energy delivered definition, but just RES for electricity.	Only numbers may be entered in these fields. Please, specify production in GWh/annum.
A2 P019	Annual renewable thermal imports from outside the boundary during target year	Similar to energy delivered definition, but just RES for thermal.	Only numbers may be entered in these fields. Please, specify production in GWh/annum.
A2 P020	Share of RES on-site/RES outside the boundary	N/A	Automatic calculation
A2 P021	GHG-balance calculated for the PED	N/A	Is a GHG-balance calculated for the PED? If yes, provide the calculated value in tCO_2/annum
A2 P022	KPIs related to the PED case study/PED Lab	N/A	Do you have any KPIs related to the PED case study/PED Lab? If yes, please specify the associated KPIs next to each relevant category.

Table A2. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A2 P023	Technological Solutions/Innovations—Energy Generation	N/A	Check all that apply.
A2 P024	Technological Solutions/Innovations—Energy Flexibility	See individual answer options' definitions below: •Information and Communication: Information and Communication Technologies (ICTs) is a broader term for Information Technology (IT), which refers to all communication technologies, including the internet, wireless networks, cell phones, computers, software, middleware, video-conferencing, social networking, and other media applications and services enabling users to access, retrieve, store, transmit, and manipulate information in a digital form. •Technologies (ICT): N/A •Energy management system: N/A •Demand-side management: DSM is the concept of influencing consumers' energy demand in respect to the consumed amount of energy in general and the time dependent consumption behaviour, with the purpose of changing the load-shape according to the concurrent availability of electricity in the grid. the typical DSM concept was extended towards the idea of Dual Demand Side Management (2DSM), a concept controlling electrical and thermal energy flows on the local and on the city district level in a holistic way. •Smart electricity grid: N/A •Thermal Storage: N/A •Electric Storage: N/A •District Heating and Cooling; N/A •Smart metering and demand-responsive control systems: N/A •P2P—buildings: N/A •Other, please specify	Check all that apply.
A2 P025	Technological Solutions/Innovations—Energy Efficiency	See individual answer options' definitions below: •Deep Retrofitting: •Energy efficiency measures in historic buildings: •High-performance new buildings: high performance buildings can thus deliver on the climate challenge by reducing the energy requirements of buildings to a point at which residual needs can be met by no or low-carbon energy sources; •Smart Public infrastructure (e.g., smart lighting): •Urban data platforms: •Mobile applications for citizens: a self-contained program or piece of software designed to fulfil a particular purpose. It is an application, especially as downloaded by a user to a mobile device; •Building services (HVAC and Lighting): •Smart irrigation: •Digital tracking for waste disposal: •Smart surveillance: •Other, please specify	Check all that apply.

Table A2. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A2 P026	Technological Solutions/Innovations—Mobility	N/A	Check all that apply.
A2 P027	Mobility strategies—Additional notes	N/A	Please share any additional notes about the applied strategy in mobility
A2 P028	Energy efficiency certificates	N/A	If present, please specify and/or enter notes.
A2 P029	Any other building/district certificates	N/A	If present, please specify and/or enter notes.

Table A3. Section A3—Non-Technological solutions.

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
A3 P001	Relevant city/national strategy	City and national level approaches favouring energy transition and climate targets	Please explain the city strategy behind PED Development. To which city/national strategy is the case study/PED Lab referring to? Check all that apply.
A3 P002	Quantitative targets included in the city/national strategy	N/A	Does the city/national strategy include quantitative targets? If yes, please specify.
A3 P003	Strategies towards decarbonization of the gas grid	N/A	Check all that apply.
A3 P004	Identification of needs and priorities	N/A	Please explain the needs and priorities behind PED Development.
A3 P005	Sustainable behaviour	N/A	Please explain what kind of sustainable behaviours are present behind PED Development.
A3 P006	Economic strategies	N/A	Check all that apply.
A3 P007	Social models	N/A	Check all that apply.
A3 P008	Integrated urban strategies	N/A	Check all that apply.
A3 P009	Environmental strategies	N/A	Check all that apply.
A3 P010	Legal/Regulatory aspects	N/A	Please name the relevant legal/regulatory aspects dealt with in your PED/PED Lab.

Table A4. Section B1—PED case study and PED relevant case study in detail.

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
B1 P001	PED/PED relevant concept definition	N/A	Specify why the district should be considered a PED/PED-relevant case study.
B1 P002	Motivation behind PED/PED relevant project development	N/A	Specify what is the purpose for implementing the PED Project and what were the reasons that led the initiator to start with PED development.
B1 P003	Environment of the case study area	See individual answer options' definitions below: •Rural: / •Rurban: land in the countryside on the edge of a town or city, on which new housing, businesses, etc. are being built; •Suburban area: mixed-use or residential area, existing as part of a city/urban area, or as a separate residential community within commuting distance of one; •Urban area: area characterised by human settlement with a high population density and infrastructure of built environment.	Choose one of the following answers.
B1 P004	Type of district	N/A	Check all that apply. If the district combines new construction and renovated buildings, please check both options.
B1 P005	Case Study Context	See individual answer options' definitions below: •Re-use Transformation Area: / •New Development: / •Retrofitting Area: / •Preservation Area: Protected areas or conservation areas are locations that receive protection because of their recognized natural, ecological, or cultural values.	Choose one of the following answers.
B1 P006	Year of construction	N/A	If the PED has already been implemented, provide information about the date of construction.
B1 P007	District population before intervention—Residential	N/A	Only numbers may be entered in this field.
B1 P008	District population after intervention—Residential	N/A	Only numbers may be entered in this field.
B1 P009	District population before intervention—Non-residential	N/A	Only numbers may be entered in this field.
B1 P010	District population after intervention—Non-residential	N/A	Only numbers may be entered in this field.
B1 P011	Population density before intervention	Calculated as Population Before Intervention/(Conditioned Area + Total Land Area)	This field is calculated automatically.
B1 P012	Population density after intervention	Calculated as Population Before Intervention/(Conditioned Area + Total Land Area)	This field is calculated automatically.
B1 P013	Building and Land Use before intervention	N/A	Check all that apply and, if possible, specify the sqm.
B1 P014	Building and Land Use after intervention	N/A	Check all that apply and, if possible, specify the sqm.

Table A5. Section B2—PED Lab in detail.

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
B2 P001	Scale of action	The scale of action defined for the PED Lab determines the type of experiments that can be done. Four options are available: building, campus, district, and virtual. The differences between them are based on the dimensions, boundary conditions, and the energy fluxes that can be evaluated by these facilities.	Choose one of the following answers.
B2 P002	Motivation for developing the PED Lab	See individual answer options' definitions below: •Strategic: strategic motivation driven by governments or large commercial actors. Host by multiple projects; •Private: private motivation driven by private companies or industries. Hosted by private initiatives; •Civic: civic motivation driven by local urban actors such as universities, cities or urban developers. Hosted by stand-alone projects or city-districts; •Grassroots: grassroots motivation driven by urban actors in civic society or not for profit actors. Host by micro-projects or single projects. •Other, please specify	Check all that apply.
B2 P003	Lead partner that manages the PED Lab	N/A	Choose one of the following answers.
B2 P004	Collaborative partners that participate in the PED Lab	N/A	Check all that apply.
B2 P005	Incubation capacities of the PED Lab	N/A	Check all that apply.
B2 P006	Available facilities to test urban configurations in PED Lab	See individual answer options' definitions below: •Buildings: buildings with different profiles: residential, offices, schools, industrial, etc.; •Demand-side management: combination of permanent and non-permanent techniques through Demand-side management; •Prosumers/P2P: customers that can produce and supply electricity and thermal energy; •Renewable generation: such as PV, wind, solar thermal collectors (low, medium, and high temperature), biomass, geothermal, etc.; •Non-renewable generation: Non-renewable generation means energy production based on fossil sources such as coal, oil, gas, etc.; •Energy storage: thermal and/electrical storage systems; •Energy networks: heating, cooling, and grid networks; •Efficiency measures: integration of efficient measures in the fields of buildings, generation, and distribution systems or storage systems. •Waste management: management of the waste treatments; •Water treatment: management of the water treatments; •Lighting: efficient lighting technologies; •E-mobility: sustainable transport and e-mobility; •Green areas: integration of innovative actions by using nature-based solutions;	Check all that apply.

Table A5. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
B2 P006	Available facilities to test urban configurations in PED Lab	•User interaction/participation: integration of different models that consider the user involvement in the laboratory such us the influence of the user behaviour; •Information and Communication Technologies (ICT): implementation of technical innovation for technologies of communication in the fields of energy, buildings, lighting or mobility; •Ambient measures: ambient measures such as thermal monitoring, urban heat island, air quality, noise, lighting measures, etc.; •Social interactions: interactions between users, stakeholder involvement, etc.; •Sustainability processes: sustainable process that consider smart capabilities such as prioritisation algorithms, sensitivity analysis, or decisions making process; •Blockchain: blockchain technology based on: environmental sustainability, data protection, digital identity, cybersecurity, and interoperability; •Business models: viable business models implemented in the laboratory •Financial models: financial models such as demand side management, market prices; •Circular economy models: measures covering the whole life cycle: from production and consumption to waste management and the market for secondary raw materials; •Other, please specify	Check all that apply.
B2 P007	Synergies between facilities in the PED Lab	Identification of synergies between the different fields of activities in the laboratory. The full implementation of a complete PED requires analysing, in a combined way, different activities in the laboratory such as energy, market, economic aspects, or social aspects. The combination of these activities requires the optimization of resources, capacities, evaluation, and analysis tools	N/A
B2 P008	Available tools	See individual answer options' definitions below: •Energy modelling: description of the available tools used to model the energy performance of the studied solutions. •Social models: description of the available tools used to model social processes. •Business and financial models: description of the available tools to test business and financial models. •Sustainable models: description of the available tools used to model sustainable solutions. •Decision making models: description of the available tools to test decision making models. •Fundraising and accessing resources: description of the tools available to raise funds and access resources for the implementation and improvement of the laboratory. •Matching actors: Description of the available tools for matching actors. •Other, please specify	Describe available tools to use the facilities for external people.

Table A5. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
B2 P009	Monitoring capabilities	See individual answer options' definitions below: •Execution plan: execution plan for the monitoring process; •Available data: information about the available data: measured, simulated or statistics; •Type of measured data: information about the type of measured data: variables measured, periodicity, storage of data, etc.; •Equipment: information about the equipment used in the laboratory; •Restricted access to facilities: / •Other, please specify	Check all that apply.
B2 P010	Any accredited laboratory services?	N/A	Choose one of the following answers.
B2 P011	Replication and scalability framework in the PED Lab	Identification of the basic pre-conditions to replicate the necessary procedure in the laboratory deployment.	N/A
B2 P012	Stakeholders accessing the facilities	N/A	Choose one of the following answers.
B2 P013	Stakeholders' accessibility framework to facilities	Modality of the external accessibility to the laboratory	Choose one of the following answers.

Table A6. Section C1—Drivers and Barriers.

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
C1 P001	Unlocking Factors	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P002	Driving Factors	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P003	Administrative barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P004	Policy barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P005	Legal and Regulatory barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P006	Technical barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P007	Environmental barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P008	Social and Cultural barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5

Table A6. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
C1 P009	Information and Awareness barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P010	Financial barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P011	Market barriers	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5
C1 P012	Stakeholders involved	1—Unimportant; 2—Slightly important; 3—Moderately important; 4—Important; 5—Very important	Please rate from 1 to 5

Table A7. Section D1—General Projects/Initiatives.

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
D1 P001	Name of the project (*)	A project is the overarching structure where one or more case studies implementation processes occur at an international/national level. (e.g., Smart Cities and Communities SCC projects may involve two or more case studies).	N/A
D1 P002	Project assigned code	N/A	Reference to official Project Code assigned
D1 P003	Start date	N/A	Please specify project starting date (month/year)
D1 P004	End date	N/A	Please specify project ending date (month/year)
D1 P005	Ongoing project	N/A	Is the project currently ongoing? Choose one of the following answers.
D1 P006	Funding programme/financing model	Funding programmes and financial models are intended as tools that support the research, experimentation, and implementation processes in the field of energy transition and urban sustainability	Please, if possible, specify the programme call.
D1 P007	Estimated project costs	N/A	Please specify the estimated project cost
D1 P008	Description of project objectives/concepts	What are the technical, social, economic, political, and environmental objectives of the project? How is the concept defined to achieve PEDs in this project?	N/A
D1 P009	Description of project upscaling strategies	Which methodology is the project/initiative adopting in order to upscale, replicate, and adapt solutions and strategies to different social, geographical, and economic contexts? (i.e., Lighthouse cities and Replicator cities in H2020 projects)	N/A

Table A7. *Cont.*

ID	Parameter Title	Parameter Definition/Answer Options Definition	Instruction
D1 P010	Number of PED case studies in the project	How many PED/PED-relevant case studies (demonstrations, pilots) are in the project?	N/A
D1 P011	Case Study	List all case studies within the project.	Choose from the list.
D1 P012	Description of project expected impact	What effect took place because of the project/higher level strategic goals. The impact is generated by the project's results.	List quantitative/qualitative impacts and add all that apply
D1 P013	Standardization efforts	Standards can relate to either people or things and serve a wide range of functions. Associated functions are awarding, filtering, ranking, and differentiating. The process of standardisation required the definition of indicators, targets, and thresholds to meet the standard and procedures for measuring, testing, and examining the subject. In addition, standards are commonly revised in order to keep them up to date.	List indicators, targets and thresholds eventually adopted in the project
D1 P014	Sources	Any publication, link to website, deliverable referring to project	N/A
D1 P015	Contact person within PED project (*)	N/A	N/A

(*) Mandatory parameters.

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