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A Comprehensive PED-Database for Mapping and Comparing Positive Energy Districts Experiences at European Level

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Abstract: Positive Energy Districts (PEDs) are considered as one of the pioneer strategies to guide cities in their energy planning process towards climate neutrality in an attractive, innovative and human-centered way. The concept of PED is the result of a long co-creation process and integrates several multidimensional features, aiming to promote the sustainable development of urban areas and the transition of cities towards a climate neutral energy system. The paper provides an overview of the first outcomes of WG1 "PED Mapping, Characterization and Learning", in the research COST Action CA19126 "Positive Energy Districts European Network" (PED-EU-NET). This study describes activities that focus on creating a comprehensive PED-Database by mapping existing concepts, strategies, projects, technological and non-technological solutions related to PEDs in Europe. The main objective of the Database is to support municipalities through the decision-making process by providing strategies for building and running a successful PED that can provide alternatives to consider, and is powered by an interactive web-based map. The design of the Database framework is supported by a step-by-step methodology adopted in the framework of the CA19126 in order to develop the PED-Database as an interactive, updatable and user-friendly tool.

Keywords: Positive Energy District; climate neutrality; integrated energy planning; PED-Database; PED case study; PED-Laboratories

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1. Introduction

The European Strategic Energy Technologies Plan, SET-Plan ACTION no. 3.2 Implementation Plan [1], is the technological pillar of European energy and climate policy, and represents the main reference point for the promotion and spread of the Positive Energy District (PED) strategy among EU Member States [2]. PEDs are considered as one of the valuable strategies guiding cities in their integrated energy planning process towards climate neutrality and to fulfill the European Green Deal goals [3,4] in collaboration with citizens, a pillar that is promoted in the mission 100 Climate-Neutral Cities by 2030—by and for the Citizens [5]. Therefore, the concept of PEDs integrates both the main paradigms of smart and sustainable cities and will be incrementally introduced in the integrated energy planning of many cities and communities in the coming years [6,7] as has been suggested by the Renovation Wave [8].

This pioneering concept considers efforts among EU countries through the following initiatives and projects:

- The past Framework Programs (FP5–FP6–FP7), Horizon 2020 Program, the last Horizon Europe Program and European research and innovation missions (e.g., European Green Deal), which foster international cooperation among European countries in the field of Research and Innovation and support policy implementation while tackling global challenges such as climate change and energy transition [9].
- The Joint Programming Initiative Urban Europe (JPI UE) and the EERA Joint Programme on Smart Cities (EERA JPSC) support the planning, deployment and replication of 100 PEDs with the objective sustainable urbanization by 2025 [10].
- The "100 climate-neutral cities by 2030-by and for the citizens", identifies the mission for supporting, promoting and showcasing 100 European cities in their systemic transition towards climate neutrality by 2030 and for the transformation of these cities into experimental and innovative hubs for other cities [5,11].
- The European partnership Driving Urban Transition (DUT) aims for a sustainable future as an integral part of Horizon Europe's strategic planning process, contributing to strengthening the efforts towards viable urban development that translates multiple Sustainable Development Goals (SDGs) into local action [12].
- The Smart Cities Marketplace (SCM) platform that was created by merging the two former Commission projects "Marketplace of the European Innovation Partnership on Smart Cities and Communities" (EIP-SCC) and the "Smart Cities Information System" (SCIS), aims to bring cities, industries, SMEs, investors, researchers and other smart-city actors together [13].
- The European Regions Research and Innovation Network (ERRIN) [14] and the Eurocities [15] support the design of guidelines and the mobilization, replication and mainstreaming of best practices in several cities.
- The Covenant of Mayors and the Mayors Adapt, i.e., umbrella organisations for Sustainable Energy Action Plans (SEAPs) or Sustainable Energy and Climate Action Plans (SECAPs), [16–18] and the Green City Accord [19] are Europe-wide initiatives working in the local context in order to promote the integration of energy and environmental issues in urban planning, towards the achievement of a sustainable and carbon-free society.
- The COST Action CA19126 "Positive Energy Districts European Network (PED-EU-NET)" [20,21] and the International Energy Agency's Energy in Buildings and Communities (IEA-EBC) Annex 83 "PEDs" [22,23] are international initiatives focused on developing an in-depth definition of PEDs, collecting the adopted technologies, providing the planning tools and analyzing the decision-making processes related to PEDs.

Even though different studies and practical experiences of PEDs focus on new development districts, in order to achieve Greenhouse Gasses (GHG) emissions reduction goals by 2050 [24–26], it is necessary and urgent to undertake an ambitious transformation process of the existing districts in a sustainable and climate-neutral direction [27–30]. Today, 75% of buildings in Europe are inefficient from the energy perspective, and their annual retrofitting rate is estimated to be around 1% [8]. It is therefore necessary to intervene by promoting a series of policy measures and funding schemes that enact changes to the built environment with a systematic and integrated approach, some of which include:

- at European level, action is being taken with regard to the revision of energy efficiency policies, e.g., recasting the Renewable Energy Directive-RED II [31], and the promotion of funding for energy transition and environmental sustainability, e.g., funds allocated from the Next Generation EU Programme [32] and Fit for 55 package [33];
- at the National level, individual countries are required to draw up National Energy and Climate Plans (NECPs), specifying the ways in which they intend to foster energy efficiency in different sectors, to promote the use of renewable sources and to reduce greenhouse gas emissions [34]. Simultaneously, some countries have established

conspicuous funds to support the retrofitting and the efficiency of the existing built environment, e.g., Italy 110% incentives [35];

- at the local level, municipalities are working to overcome a planning system divided into sectoral silos and to improve their interaction with the public sector, thereby becoming able to invest in and implement strategies tailored at local context. In this sense, business and governance models that support the concrete implementation of renewal interventions are promoted, e.g., realization of One-Stop-Shop, promotion of Turnkeys and Cornerstone and diffusion of the Public-Private Partnership model [36,37]. These models must be based on the improvement of services, technologies, quality of life and comfort of the inhabitants, policies or on urban management between the public and private sectors; these requirements necessitate different capabilities to those in traditional governments [21].

Within the SET-Plan no.3.2, an open-ended and broad definition of the PED concept is introduced: 'PED is seen as a district with annual net zero energy import, and net zero CO_2 emission working towards an annual local surplus production of renewable energy' [1] (p.5). According to this definition, PEDs can integrate several multidimensional features aiming to boost urban areas' sustainable development, and to support cities transition towards a climate neutral energy system. The key features within the definition of PED, developed by the EERA JPSC and JPI Urban Europe [2], include and extend to the wide vision of the precursor PED projects from previous Framework Programs (FP5–FP6–FP7), and more recently, Horizon 2020 on Smart Cities and Communities (SCC) Lighthouse projects [38–45].

Hence, most of the studies and PEDs are available on the EU SCM platform [13] and the JPI UE "Booklet of Positive Energy Districts in Europe" [46], which are, in general, referred to the multidimensional perspective of PEDs, mainly based on the technologies and lessons learnt from these experiences at the European level. Even if these works are very relevant for mapping PED and for the creation of a structured repository of information, they do not fully address the complex set of urban challenges and the objective to support decision making, the implementation and replication of PEDs in municipalities, nor the creation of capacity and community building to drive urban transformations.

Despite the above-mentioned efforts, PED concept has yet to be standardized, and reference for PED archetypes need to be consolidated [47]. Indeed, as it can be seen in Table 1 below, four categories of PEDs have been established until now (Autonomous-PED, Dynamic-PED, Virtual-PED and Candidate-PED) [48,49], focusing on two main aspects:

- the boundaries of the PED in order to reach a net positive yearly energy balance;
- the energy exchanges (import/export) in order to compensate energy balance for surpluses and shortages between the buildings or the wider grid outside.

Besides, some of the main gaps still under discussion are related to PED boundary definition, in order to quantify the energy exchanged in real applications and ecosystems. At the same time, the type of Key Performance Indicators (KPIs) need to be assessed, since they are tackled in different ways by ongoing projects and programs across Europe [50–54].

The CA19126 "PED-EU-NET" aims to drive the deployment of Positive Energy Districts (PEDs) in Europe by harmonising, sharing, and disseminating knowledge and breakthroughs on PEDs across different stakeholders, domains (technological, environmental, social, economic, financial, legal and regulatory) and sectors (energy, transport, buildings, industry). It will support cities and empower communities to achieve the city-wide positive energy transition with pioneering ideas, methods and solutions. This Action is divided into four interlinked Working Groups (WGs) structured as follows: WG1 "PED Mapping, Characterization and Learning", WG2 "PED Guides and Tools", WG3 "PED Laboratories, Monitoring and Replication" and WG4 "Dissemination, Outreach and Exploitation".

Table 1. PED categories and related definitions.

PED-Categories	Definitions	Source
Autonomous-PED	the PED has a positive power balance within its geographic boundaries and is designed to be self-managing (regardless of power from the periphery) or can even help manage/balance the external grid.	[48,49]
Dynamic-PED	the PED has a positive energy balance within its geographic limits, exchanging energy with the periphery to compensate for energy excesses and deficits.	[48,49]
Virtual-PED	the PED has a positive energy balance within its virtual limits, exchanging energy with the periphery to compensate for energy excesses and deficits.	[48,49]
Candidate-PED	the PED has no positive energy balance within its geographic boundaries, but energy balance is achieved by importing certified green energy (i.e., demarcating a zero emissions district).	[49]

Specifically, the WG1, as argued in this paper, aims to create a consolidated knowledge pool on the state-of-the-art development in PEDs and, based on the existing information, it devises methods to characterize PEDs and to recommend best practices for their implementation. Within WG1, the activities related to task 1.1 focus on creating a comprehensive PED-Database for use as an interactive, updatable and user-friendly tool by mapping existing concepts, strategies, projects, laboratories, and technological and non-technological innovations related to PEDs in Europe. To develop a common Database that includes both PED cases and PED initiatives as well as PED Labs, a collaborative study has been carried out between the WG1 and WG3.

The paper is structured as follows: Section 2, "Objective", outlines the main PED-Database's aims, clarifying that the Database is conceived as an operative tool targeted mainly towards municipalities, but also for researchers and professionals who want to explore and deepen the concept of PEDs. In Section 3, dedicated to "Methodology", the PED-Database realization process is presented. Section 4, "Results", highlights the realization of the PED-Database framework and introduces its online implementation in the form of an interoperable web platform. In Section 5, the "Discussions and Future developments" are provided, and in Section 6, the "Conclusions" are presented.

2. Objectives

As already mentioned above, the activities of Task 1.1 focus on the implementation of a well-structured and operative tool that map, analyse and compare PED-relevant experiences and concepts in the European context, considering that a PED-Database does not yet exist. The database is developed for non-commercial purposes and will be open source.

The PED-Database's design pursues the following objectives:

- Co-creation of a PED innovation eco-system that, moving from the agreed definition, will uncover information and indicators (both expected and/or assessed performances), and facilitate the implementation of PEDs around Europe.
- Systematization of the information in order to address specific needs and targets from an inclusive set of stakeholders engaged in each phase of the PED implementation process.
- Supporting the creation of capacity building, based on broader knowledge derived from innovation and lessons learnt to overcome barriers and take advantage of opportunities derived from the advanced mapping of solutions and performance, obtained in previous or ongoing experiences on PEDs.
- Envisioning the needs (demand aggregation) and expected strategies to adopt (scenarios of intervention) a more effective energy planning process and decision-making,

which are able to promote and facilitate the achievement of large-scale sustainability conscious urban areas.

- Supporting municipalities and researchers in the PED-implementation process, considering both the renewal of existing areas and the realization of new, sustainable, energy efficient and net-zero GHG emissions urban development.

The PED-Database is configured as a multidisciplinary and open tool, that starts from the aggregation and systematization of the gathered information, then returns a set of multiple features related to the PED concept, including both technological and non-technological innovations. Therefore, the designed framework is systematized in a way in which the information collected provides an overall picture of case studies and implemented projects.

The paper presents and discusses the step-by-step methodology to guide PED Database realization. Until now, PED-Database structure and the main parameters to be collected were identified and agreed on among a core group of experts on the topic. The next working step will lead to concrete Database implementation through data collection and the characterizing of best practices relevant to PED (case study, project, initiatives, strategies, technological and non-technological solutions, etc).

3. Methodology

The PED-Database was conceived of as a cross disciplinary contribution among the CA19126 Working Groups (WG2, WG3 and WG4) and foresaw the alignment with both IEA-EBC Annex83 and JPI UE-other international initiatives focused on PEDs implementation-using a collaborative approach (Table 2).

Table 2. Joint activities and interactions (within the COST Action and outside the Cost Action).

Within the CA	**Joint Activities and Interactions**
Working Group 2	Alignment on technological and non-technological tools
Working Group 3	PED Lab characteristics, input form layout
Working Group 4	Facilitating PED stakeholder interaction
Outside the CA	**Joint activities and interactions**
IEA-EBC Annex 83	In-depth alignment on PED parameters to be collected
JPI UE	Initial scoping, pilot testing
SCM	Partner for greater outreach outside of PED-EU-NET
EERA JPSC	Enabling platform for the PED-EU-NET partnership, coordination efforts

According to Figure 1, Database realization can be summarised using two main working phases. The first aimed at defining PED Database general framework and at mapping PED-relevant projects and initiatives among all CA19126 partners. While the second phase, using the developed framework, focused on the realization of the web platform that will host the PED-Database and on its implementation, starting with the mapped PED-relevant projects and initiatives.

3.1. Phase 1

As a first step, in order to define the PED-Database scope from specific target groups and its main requirements, a workshop comprising WG1 members was held in order to collect ideas, expectations and directions for Database development. Task.1.1, moving from this list, performed a comparative analysis of different relevant databases and platforms to understand the kind of structure and content a PED-Database should have, so as to meet key stakeholder needs and expectations. Table 3 provides the key parameters and questions investigated.

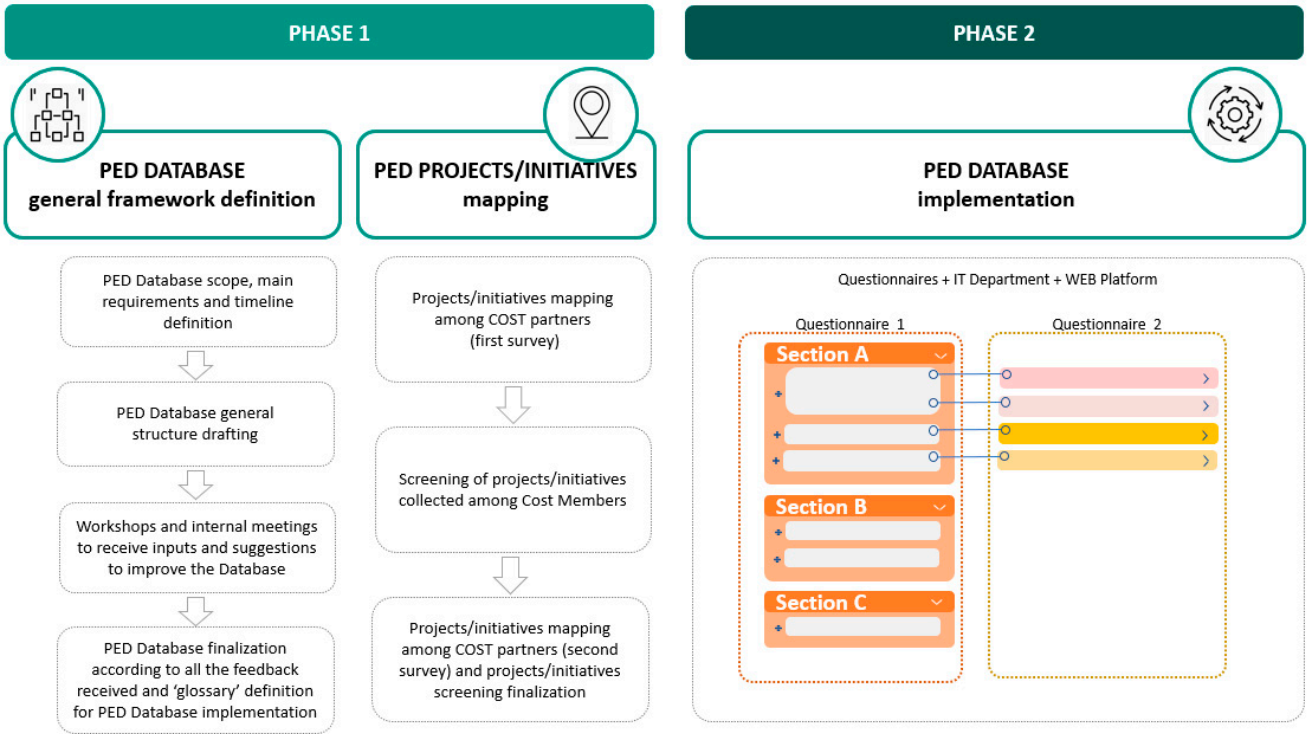

Figure 1. PED-Database working phases.

Table 3. Key investigated parameters and questions.

Key Investigated Parameters
Title of database/platform
Basic info: year of realization, financing programme, format and main users targeted
Main scope
Main contents
Sources (Publications, link to the website)
Key Investigated Questions
What are the main purposes of databases and platforms?
What format do databases and platforms have?
What information do they collect?
What search options do they offer?
To whom are the platforms and databases addressed?
What are the options for extrapolating information (paper sheets, tabs, maps, charts, diagrams)?

As can be seen from the table in Appendix A summarising the performed analysis, an interactive database on PEDs was not identified until now, the only provisions of this sort that did exist is the PED Booklet by JPI UE, which collects PED-related and similar PEDs case studies in paper format [46]. The other analysed databases do not specifically focus on PEDs; however, they collect strategies, case studies, projects, solutions and technologies related to PED-relevant issues, such as sustainability, energy efficiency and urban resilience.

This analysis, combined with different workshops among COST Action partners, meetings with different WGs and alignment with JPI UE and IEA-EBC Annex 83 initiative, was a fundamental step in order to define the general structure of the PED Database. These first steps, in fact, led to the definition of PED-Database schematic structure, which facilitated the discussion on new inputs received and on implementing other categories and data.

In parallel, COST members were asked to collect PED relevant projects and initiatives in which they are involved or in which they collaborated. For the purpose of mapping, PED-relevant projects and initiatives were described as follows: district-level experiences

with high aspiration in terms of energy efficiency, energy flexibility and energy production. The PED discussed (its demo sites/case studies) does not necessarily have to meet an annual energy positive balance, if it meets at least several other major aspects of PED Framework definition '*Positive Energy Districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability*' [2] (p. 7).

According to the definition, PED-relevant projects and initiatives were collected among COST partners and a systematic analysis and screening were performed, identifying the following two main categories:

- PED-focused: projects/initiatives directly focused on Positive Energy Districts implementation. They are in line with the PED Framework Definition.
- PED-supporting: projects/initiatives not directly focused on Positive Energy Districts. However, they collect experiences assimilable to the PED concept, such as energy communities, smart districts, local energy districts, sustainable and resilient neighbourhood. They do not cover all the aspects mentioned in PED Framework Definition.

Appendix B lists PED-focused and PED-supporting projects and initiatives collected in COST Consortium and, for each of them, it reports the following key information: acronym, title, period, scale, number of case studies and sources.

3.2. Phase 2

The second phase, as shown in Figure 1, involved two parallel processes: (1) an individual questionnaire and parameter development for data collection and (2) IT solution development of the PED-Database online platform.

Specific questionnaires for sections A, B, C and D have been compiled and individual parameters are defined in a supplementing glossary in four rounds. In the first round, the WG1 collected contributions from its members. Secondly, the list of parameters was exchanged with WG2 and WG3 and PED Lab parameters developed by WG3 were integrated as a specific sub-set to the questionnaire. Furthermore, Task 3.1 of WG3 also provided information obtained in its workshops related to drivers and barriers to feed the common sections of the questionnaire. In the third step, a task group established among COST Action and Annex 83 (Subtask D) was created to manage the alignment of the PED-EU-NET Database parameter list with another list of parameters corroborated by Annex 83 team. Fourth, a pilot testing of the questionnaire took place to gather additional inputs from WG1 members and JPI UE. This piloting brought feedback and partial inputs to both parameter definitions and questionnaire structure and user friendliness. Further alignment of the questionnaires and parameter lists with other partners such as JPI UE is also foreseen as the Database evolves.

In parallel to questionnaire and parameter list development, an IT solution for the PED-Database online platform was formulated, comprising the following three components: input forms (i.e., online representation of the questionnaires), database frontend (i.e., user interface for online data visualization) and database backend for PED-Database administration. The input form component builds on the adapted structure using the letter identifiers (A–D) introduced by WG3 online questionnaire and programmed by Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT) Information Technology Department [55]. After the CIEMAT structure and online form were assessed, the input form was newly programmed and adjusted to become an embedded sub-section of the PED-EU-NET website. The other two components (presentation frontend and administration backend) were developed in multiple iterations by an external provider according to the requirements list compiled by WG1.

4. Results

4.1. PED-Database Framework

A PED-Database is considered to be an online disruptive platform tool that allows the end-user to map, visualize, search, filter and compare results. As already explained, the Database collects information from ongoing PED relevant experiences, fosters the sharing of competences, investigates barriers, and challenges and highlights solutions that are viable, feasible, realistic and replicable in order to devise methods to characterize PEDs and to recommend concepts, solutions, strategies and best practices for PED implementation in different contexts.

As a result of the discussions that were held while designing and formatting the PED-Database, the generated "big picture" to visualize and structure the index is shown in Figure 2.

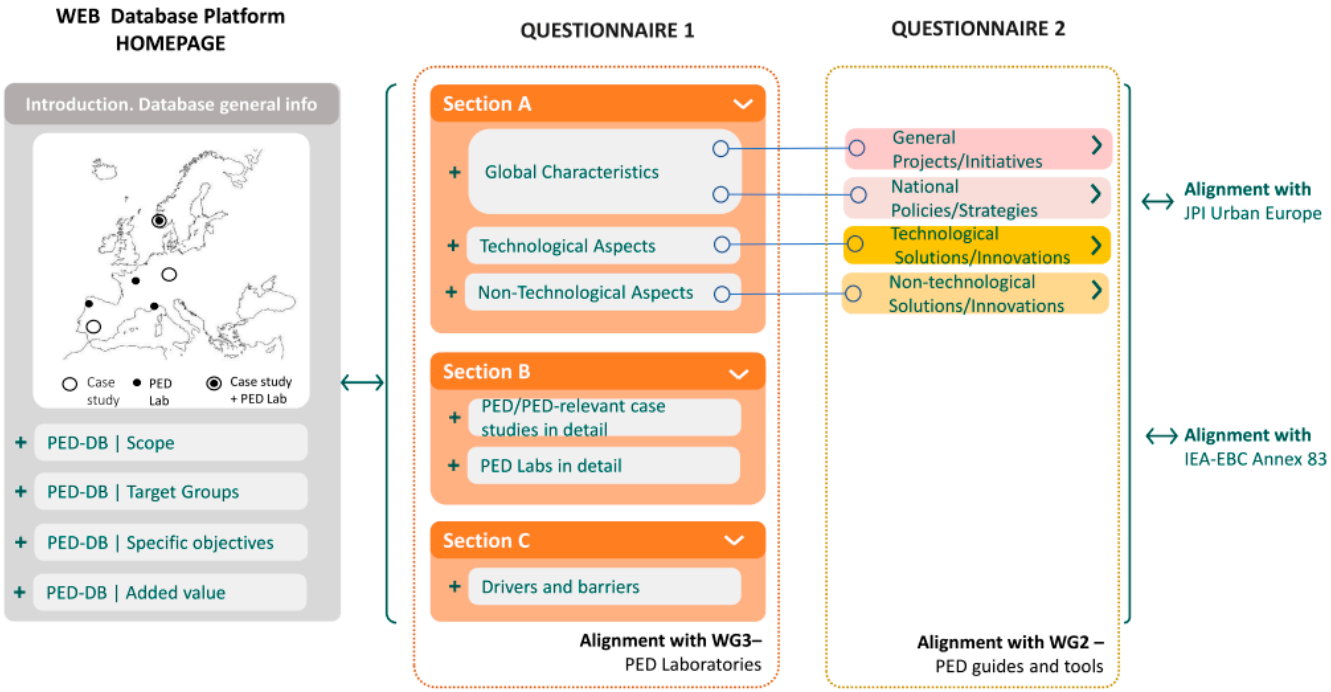

Figure 2. PED-Database framework.

Through the PED-Database homepage, a list of geo-referenced PED-relevant case studies and laboratories are visualized. -. Each case study and laboratory that is referred to across the European map is indicated with a symbol. When a symbol is clicked on, a section called 'PED-relevant Case Studies and PED Labs' appears on the screen for visualizing detailed information (Questionnaire 1-in orange). From this questionnaire, it is possible to access both to a more general level of information collecting 'General Project or initiatives' and 'National policies or strategies' (Questionnaire 2-in pink) or to a more specific and detailed level of information collecting 'Technological and Non-technological solutions and innovations' (Questionnaire 2-in yellow).

4.2. PED-Database Data Collection

The selection of the main parameters (i.e., assessed information and KPIs) is based on a holistic and exhaustive methodology which highlights the multiple dimensions related to PEDs, for which definitions and characterization are quite broad in the context of the on-going international debate [48]. This is managed by identifying the main categories that address its multidimensionality nature and the specific insights from each project and initiative according to an inclusive adherence to the PED approach definition in the EU countries.

Therefore, PEDs developers can adopt this targeted information to drive the design according to the roughness of boundary conditions, needs and criticalities that characterize their own process. Moving from the district needs, they can find the best solutions and practices to be improved in their projects, and that can help to overcome challenges.

PED-Database data collection will make use of the PED-EU-NET web-embedded online platform as an open tool for questionnaire administration [20]. Data collection will be performed according to the structure identified in PED-Database framework:

- Questionnaire 1-Sections A + B + C *'PED-relevant Case Studies and PED Labs'* (Figure 4).
- Questionnaire 2-Section D 'General Project or initiatives', Section E 'National policies or strategies', Section F 'Technological and Non-technological solutions and innovations' (Figure 3).

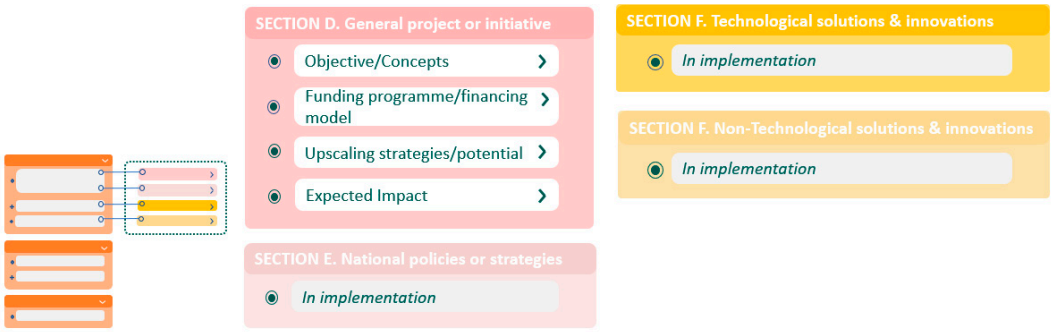

Figure 3. PED-Database-Section D 'General Project or initiatives', Section E 'National policies or strategies', Section F 'Technological and Non-technological solutions and innovations'.

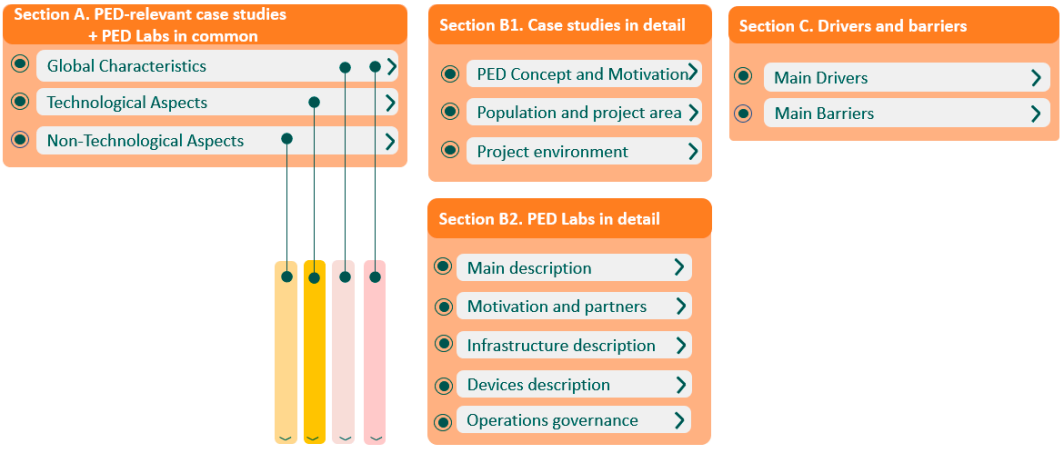

Figure 4. PED-Database-Sections A + B + C 'PED-relevant Case Studies and PED Labs'.

The tables below list the selected parameters to be collected for PED-Database implementation. In particular, Table 4 reports Questionnaire 1 parameters corresponding to Sections A + B + C, while Table 5 reports Questionnaire 2, only as far as it concerns Section D *'General Project or initiatives'*. Section E *'National policies or strategies'* and Section F *'Technological and Non-technological solutions and innovations'* will be developed in the following months.

Table 4. PED Database parameters. Questionnaire 1-Sections A + B + C.

Section	Question Title	Obligatory Question		Type of Question		Defined in the Glossary	
		Yes	No	Open	Closed	Yes	No
A_1	Case study title	x		x			x
A_2	Photo(s)		x				x
A_3	What is the definition of the PED site?	x			x	x	
A_4	Project Phase of case study/PED Lab	x			x	x	
A_5	General project/initiative (link to section D)	x			x		x
A_6	Geographic coordinates	x		x		x	
A_7	Country	x			x		x
A_8	Climate zone (Köppen–Geiger classification)	x			x	x	
A_9	Total land area occupied by your case study/PED Lab (m^2)		x	x		x	
A_10	District boundary		x		x	x	
A_11	Project targets of the PED case study/PED Lab	x			x	x	
A_12	Ownership of the case study/PED Lab	x			x		x
A_13	Number of buildings in PED		x	x			x
A_14	Contact person (name and e-mail)	x		x			
A_15	Sources (publication, link to website, deliverable)		x	x			x
A_16	Fields of Application		x		x	x	
A_17	Renewable Generation on-site (GWh/annum)		x	x		x	
A_18	Non-renewable resources (GWh/annum)		x	x		x	
A_19	Annual energy demand in buildings (GWh/annum)		x	x		x	
A_20	Annual energy demand for e-mobility (GWh/annum)		x	x		x	
A_21	Annual energy use (GWh/annum)		x	x		x	
A_22	Annual energy delivered (GWh/annum)		x	x		x	
A_23	Energy Generation technologies		x		x	x	
A_24	Energy Flexibility technologies		x		x	x	
A_25	Energy Efficiency technologies		x		x	x	
A_26	Municipal policy/strategy		x	x			x
A_27	National and regional policy/strategy		x	x			x
A_28	Economic strategies		x		x		x
A_29	Social models		x		x		x
A_30	Planning models		x		x		x
A_31	Climate change mitigation and adaptation measures		x	x			x
A_32	Legal/Regulatory aspects		x	x			x
B1_1	PED concept definition		x	x		x	
B1_2	Motivation behind PED development		x	x			x

Table 4. *Cont.*

Section	Question Title	Obligatory Question		Type of Question		Defined in the Glossary	
		Yes	No	Open	Closed	Yes	No
B1_3	District population (ab.) before intervention		x	x			x
B1_4	District population (ab.) after intervention		x	x			x
B1_5	Conditioned Area (closed building area)		x	x		x	
B1_6	Population density (inh./m^2) before intervention		x	x		x	
B1_7	Population density (inh./m^2) after intervention		x	x		x	
B1_8	Building and Land Use		x		x	x	
B1_9	Project context		x		x	x	
B1_10	Type of intervention		x		x		
B2_1	Installation life time		x	x		x	
B2_2	Scale		x		x	x	
B2_3	Boundary conditions for the operation of your laboratory		x		x	x	
B2_4	Replication framework		x	x		x	
B2_5	Lifecycle process		x	x		x	
B2_6	Policy framework of PED Lab		x		x	x	
B2_7	Motivation for developing the PED Lab		x		x	x	
B2_8	Incentive for the definition, implementation/operation of the PED Lab		x	x		x	
B2_9	Lean and collaborative Partners		x		x	x	
B2_10	Synergies between the activities		x	x		x	
B2_11	Available facilities to test urban configurations		x	x		x	
B2_12	Incubation capacities		x	x		x	
B2_13	Availability to the facilities for external people		x	x			x
B2_14	Monitoring measures		x	x		x	
B2_15	Key Performance indicators measured		x	x		x	
B2_16	Execution of operations		x	x		x	
B2_17	Capacities needed		x	x		x	
B2_18	Relations with stakeholders		x	x		x	
B2_19	Standardization or certification process		x		x	x	
B2_20	Tools available		x	x		x	
B2_21	External accessibility		x	x		x	
C_1	Endogenous Unlocking Factors		x		x		x
C_2	Exogenous Driving Factors		x		x		x
C_3	Administrative Barriers		x		x		x
C_4	Policy		x		x		x
C_5	Legal and Regulatory		x		x		x
C_6	Technical		x		x		x
C_7	Environmental		x		x		x
C_8	Social and Cultural		x		x		x
C_9	Information and Awareness		x		x		x
C_10	Economical and Financial		x		x		x
C_11	Market		x		x		x
C_12	Stakeholders Involved		x		x		x

Table 5. PED Database parameters. Questionnaire 2-Sections D.

Section	Question Title	Obligatory Question		Type of Question		Defined in the Glossary	
		Yes	No	Open	Closed	Yes	No
D_1	Project/initiative Code assigned		x	x		x	
D_2	Name of your project/initiative		x	x			x
D_3	Project/initiative period		x	x		x	
D_4	Funding programme/financing model		x		x		x
D_5	Description of projects/initiative objectives and concepts		x	x		x	
D_6	Upscaling strategies and potential		x	x		x	
D_7	Related case studies (link to Section A)		x	x		x	
D_8	Expected impact		x	x		x	
D_9	Sources (publication, link to website, deliverable)		x	x			x

The questionnaires for PED-Database data collection are supplemented by a detailed Glossary providing definitions related to each parameter and the related KPIs. The Glossary's main purpose is to provide definitions and references to enable better consistency of the data and information collected for the PED Database. The Glossary will be provided to the respondents during the information-collection process in the form of explanatory text, in order to avoid confusion during the self-filling of the online questionnaire.

4.3. PED-Database Online Platform

All of the efforts that have been conducted under PED-Database creation will lead to the release of an online platform accessible from the PED-EU-NET website. The full release is planned for 2022. This platform will act as a unified database for identifying PEDs and PED Labs in the EU. Once the database is implemented, another research paper will be developed to present the quantitative and qualitative data derived from the PED case studies and PED Labs included in the database.

In this section, the format of the PED-Database online platform will be presented. The platform, as already mentioned, has been developed in three components: (1) online input form, (2) database frontend (i.e., user interface for online data visualization) and (3) database backend for PED-Database administration.

4.3.1. Online Input Form

Structured in line with the questionnaires described in Section 4.1. The form will be accessible to database respondents based on a link provided by the Database editor. An additional advantage to the standard online forms, e.g., an EU Survey [56], is the embeddedness and seamless connection with the frontend and backend for data visualization. It is complemented by the following additional features: navigation key plan, summary overview of input values before submission.

4.3.2. Database Frontend for Data Visualization

In the release-candidate version, the PED case studies, and PED Labs are accessible using map view, based on OpenStreet Map and table view (see Figure 5).

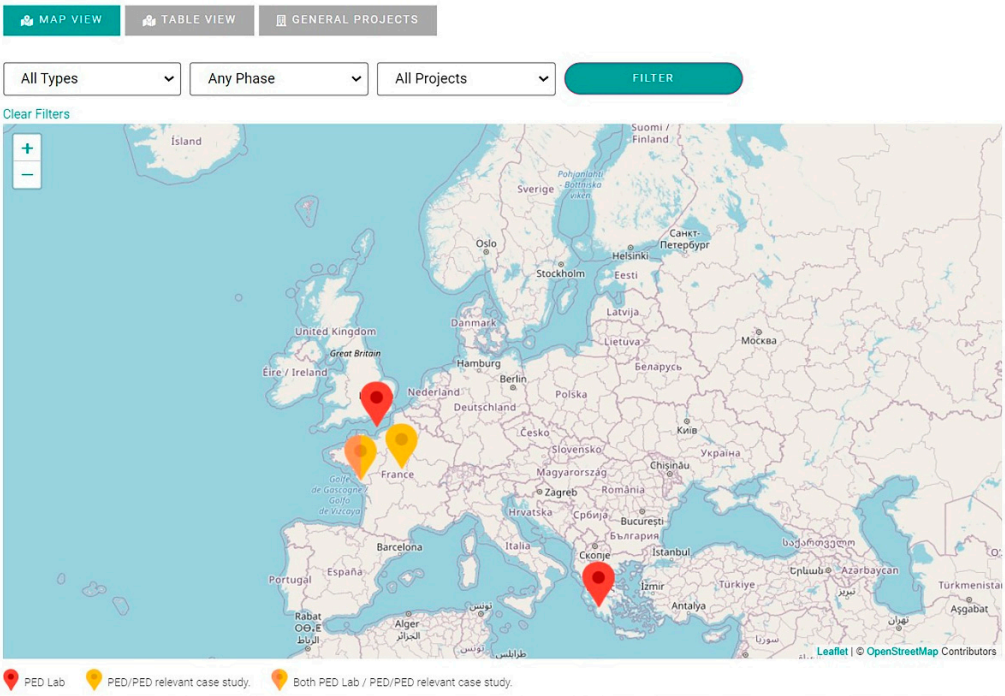

Figure 5. PED Database front end mockups: map view.

The user is able to switch between the view modes, to access/browse individual database tables, to customize the data shown based on multiple parameters and to apply advanced filter of selected parameters next to the map. In the comparison section, case studies can be selected, compared and a customized combination of case studies can be exported (see Figure 6). The map view will be based on OpenStreet Map.

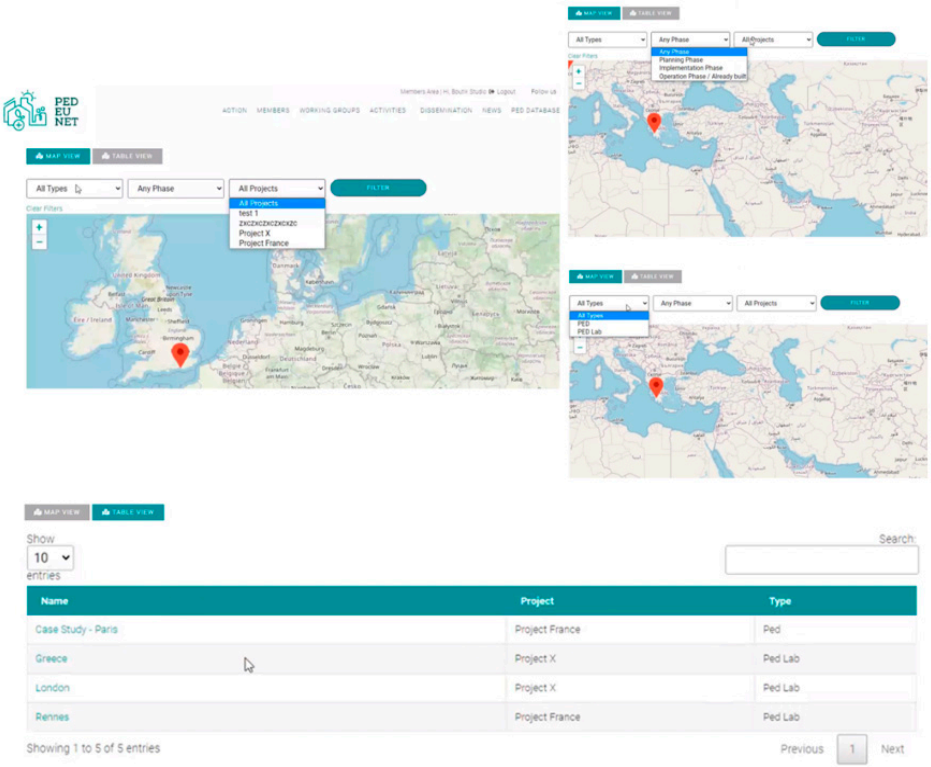

Figure 6. PED Database front end mockups: filters and table view.

4.3.3. Database Backend for Administration

The system foresees the role of a Database editor (PED-EU-NET authorized user) and input from editors (any database contributor without need for registration). The editor's task is to invite input form editors and review the submitted input forms before publication in the Database frontend. Since all the information and data provided by the contributors (input form editors) are intended to be publicly available to anyone, this process serves as a minimum for quality assurance.

5. Discussion and Future Developments

This research supports Municipalities in passing from an integrated energy planning stage to the implementation of strategies towards the climate neutrality target, by using an attractive, innovative and human-centered approach. This approach facilitates the decision-making process by providing information on the available district resources, the solutions and innovations adopted, urban directives, implementation processes, expected and measured metrics, or associated drivers and barriers. The transition process needs to consider contextual and regional factors in order to achieve favorable PED implementations with low resource investments and utilization of local resources.

The designed PED-Database introduces definitions and insights that will guide cities' stakeholders in the creation of capacity at different levels as well as by defining core capabilities. The developed framework provides an understanding of the state of play and PED concept directions, views, values and functionality to create a learning environment for capacity building and, at the same time, to establish a vision for tomorrow.

PED concepts must be highly structured, based on local resources, with the high involvement of urban stakeholders and should be strongly linked to global governance models for which no factor can be left out.

Indeed, in this PED scenario, several stakeholders are required to cooperate in a strategical PED vision, where technological and non–technological solutions are tightly connected. It is necessary to consider citizens' needs and challenges, through the process of authorization and the realization of both public and private buildings intervention, with the involvement of the relative municipal officers. Local citizens' associations play a role in enhancing opportunities and synergies in the social field that can arise in a PED context. Alongside the non-technological elements, there is also a link to the choices of efficiency, energy flexibility, RES-production, storage, reducing CO_2 emissions and any other element as recorded in the associated technological aspects and innovations section of the PED Database. These PED scenarios can be contextualized within the creation of an energy citizenship community, as well.

The PED-Database provides a balanced overview of the technological and non–technological solutions that require the cooperative involvement of several stakeholders, and those that collect the key resources, making sure that such resources are effectively integrated. The capacity building process encourages participation by all those involved. Through the capacity building process, each stakeholder can learn to develop an element of the PED in close connection with all partners. This is why a PED needs a strategical shared vision among all the actors of the process.

A well-structured form of data collection is the starting point to reach this goal. This task requires external assistance from PED developers who are in charge and responsible for the gathered information (e.g., researchers, energy vendors, DSO, TSO, aggregate, technology providers, etc.), auditors (e.g., technical architect in charge, energy audit company, consulting expert) or any other actors within a public–private partnership who are actively involved in the projects.

Aligned with this target, COST Action 'PED-EU-NET' has developed pioneer initiatives in conducting research on PEDs and aligning the identified parameters with their expertise and their ongoing research on the generation of PED Databases. Since there are overlaps and gaps in their research, an alignment process is essential to balance the work load for experts (developers of the Databases) and city authorities (who are trying

to answer questions of the parameters and indicators). On the other hand, knowledge and experience sharing are necessary in order to maximize the benefit to target groups in terms of advancing the scientific, technological and social awareness as well as to realise the added value generated by networking at a pan-European level and beyond.

With this intent, the first urban stakeholders workshop held by the PED-EU-NET in Rome in early October 2021 proved to be an example of an efficient platform for exchange and a stimulus for cooperation among different types of stakeholders.

The PED-Database is intended for release in 2022. The collaboration among the PED-EU-NET WGs the Database is expected to grow further, in two respects. First, the data collection will be initiated with PED-relevant case studies and widened over time. Second, new sections will be added to the database in the coming years, based on the framework (especially the sections E and F) of national level and technological and non-technological solutions and tools.

This Action will run until the end of 2024, and the leadership has been assessing the options of maintaining the database after that. The COST Action website needs to be kept open and the data should remain available for two years after the end of COST Action. After the end of COST Action, it might be possible to transfer the Database to another host, e.g., European Energy Research Alliance or other European initiatives that the COST works closely with.

6. Conclusions

The methodology developed for the generation of a PED Database, and its structural format have been developed under CA 19126 by WG1 leaders and T1.1 leaders. Moreover, the WG3 team contributed to the parameters regarding the PED LABs. The main advantage of the PED-Database is its use as an operative tool, targeted mainly for use in municipalities, but also for researchers and professionals who want to explore configure PED concepts. The framework of the PED-Database comprises the implementation process, starting with the identification of the definition scope, the main requirements, a development of the parameters that characterize PEDs and generates the glossary for defining each parameter. The PED projects/initiatives are listed by the COST partners, resources as to identify the resources that are available that would feed the Database. At the implementation stage, questionnaires are generated regarding global characteristics, technological and non-technological aspects, PEDs/PED-LABs detailing, Main Barriers, Enablers and Stakeholders and General Projects.

The results will be highlighted for the realization of the PED-Database framework and its online implementation in the form of a web interoperable platform. The platform is still under construction and will be finalized soon after the data collection phase. The Database Editors will review the gather data and transform them into an understandable, common language that will be displayed in the platform. The sustainability of the Database is critical in terms of contributions and research, and, for this reason, we have planned to maintain the Database after the Action lifetime, as it will be adopted by another host that works closely with Action group.

This intensive research on defining a framework for characterizing PEDs by definition, concept boundary, strategies and technological and non-technological innovations utilized facilitates a cross disciplinary working environment within the CA19126 WG1 team. The alignment efforts with the pioneer initiatives (IEA-EBC Annex 83 and JPI UE) will result in an overarching approach within the PED environment, since there are still overlaps or conflicts on the concept of PEDs. A unified database for mapping, filtering, sorting, comparing and benchmarking PED planning or implementations will help decision makers or experts in realizing the main concept.

Once the PED case studies and PED LABs are implemented in the Database, the CA19126 WG1 team plans to develop another publication on the collected data and results.

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investigation, G.T., B.A., S.P., P.C., M.K. and V.A.-S.; resources, G.T., B.A. and S.P.; data curation, B.A., G.T., M.K., P.C., O.S. and S.S.; writing—original draft preparation, G.T., B.A., P.C., M.K., S.P. and G.M.; writing—review and editing, G.M., O.S., S.S. and V.A.-S.; visualization, G.T. and B.A.; project administration, M.K., P.C., B.A., G.T. and V.A.-S.; funding acquisition, V.A.-S. All authors have read and agreed to the published version of the manuscript.

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Nomenclature

CIEMAT	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
CO_2	Carbon dioxide
COST	European Cooperation in Science and Technology
DUT	Driving Urban Transition
EERA JPSC	European Energy Research Alliance RA 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
PED-EU-NET	Positive Energy Districts European Network
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
WGs	Working Groups

Appendix A

Table A1. Comparative analysis of different existing relevant databases and platforms.

Title	Basic Info	Scope	Main Contents
PEDs BOOKLET	**Year** 2020 **Programme** JPI UE **Format** Paper (tables) **Targeted users** Municipalities **Source** [46]	The Booklet collects 59 pilot case studies at the district scale aimed at activating sustainable urbanization processes in a logic of maximum energy efficiency. It is structured in two sections: (1) PEDs projects, (2) Towards PEDs. Each section is divided into the following: Projects in Operation, Projects in Implementation Stage and Projects in Planning Stage.	**Structure:** - General information (City, project name, project status, project start-end, contact, project website, size of project area, building structure, land use, financing); - Overview description of the project; - Strategies (goals/ambition, indicators/expected impact, overall city strategies, factors included in implementation strategies, innovative stakeholder involvement strategies, typology of energy supply); - Success factors; - Challenge/barriers.
OPPLA: **Repository of NBS**	**Year** 2016–2020 **Programme** European Commission FP7 **Format** Digital platform **Targeted users** Public, private and voluntary sectors; large and small organisations, as well as individuals **Source** [57]	OPPLA provides: - Knowledge Marketplace, where the latest thinking on natural capital, ecosystem services and nature-based solutions is presented; - Ask Oppla, a crowd-sourced enquiry service; - Oppla Community, a system for networking with other members from around the world. - Case study repository, an integrable platform containing example of NBS application	**Research options:** - Scale - Type **Structure:** - Objective; - Actions; - Lessons learned; - Financing; - Challenges: - Benefits; - Stakeholder - Participatory Planning; - Success and Limiting Factors; - Monitoring and evaluation; - Contacts; - Further information.
URBAN NATURE ATLAS	**Year** 2017–2021 **Programme** European Commission H2020 **Format** Digital platform **Targeted users** N/A **Source** [58]	URBAN NATURE ATLAS provides 1000 examples of Nature-Based Solutions from across 100 European cities.	**Research options:** - Quick Search by icons; - Advanced Search **Structure:** - Brief description (location, city population, project duration, project cost, financing source(s)) - Overview (urban setting, key challenges, main beneficiaries, project objectives, implementation activities); - Governance (type of organizations, management set-up, community involvement) - Monitoring (expected impacts, presence of monitoring system, presence of indicators, presence of evaluation reports); - References
C40 CASE STUDIES	**Year** / **Programme** C40 Cities Climate Leadership Group **Format** Digital platform **Targeted users** N/A **Source** [59]	C40 CASE STUDIES describes pilot projects developed in cities that are taking bold climate action, leading the way towards a healthier and more sustainable future.	**Research options:** - location; - topics; - benefits. **Structure:** - Title (brief description, image) - Benefits (social, environmental, economic) - Details (key impact, project start date); - Next steps
CASE STUDIES: **stories from the Neighbourhood**	**Year** / **Programme** ECODISTRICTS certification standard **Format** Digital platform + Paper (tables, images) **Targeted users** N/A **Source** [60]	The Platform browses case studies on Ecodistricts from around the world, capturing how neighborhood-scale innovation can drive the development of neighborhoods for all.	**Structure:** - Title; - Date; - Snapshot (Project type, site size, demographics, economy, anticipated outcomes, key stakeholders); - Neighborhood overview; - Project governance; - Early wins (place, health and wellbeing, connectivity, living infrastructure, resource regeneration) - Lesson learned + challenges; - Next steps
NEIGHBOURHOOD planning + design Learning from best practices	**Year** 2017 **Programme** UBC Stadium Neighbourhood **Format** Paper (tables) **Targeted users** Community and designers who take part in the participatory design process **Source** [61]	NEIGHBOUR-HOOD planning + design shows examples of best-practice to help unearthing new ideas and assessing potential policy and design possibilities for the Stadium Road Neighbourhood, Vancouver (USA).	**Structure:** - Title; - Site area dimension; - n. dwelling units; - Construction period; - Project overview; - Lessons learned - Adopted solutions/strategies (resources + natural systems, place + experience, convenent connection, social cohesion + community) - Photos; - Maps; - Comparative capacity (density, building type)

Table A1. *Cont.*

Title	Basic Info	Scope	Main Contents
SMART SCALE: cities to watch	**Year** 2020 **Programme** World Economic Forum-Community Paper **Format** Paper (tables) **Targeted users** N/A **Source** [62]	SMART SCALE shows examples of successful smart city solutions to leverage critical success factors and to move forward smart, sustainable and innovative initiatives and projects.	**Structure:** - governance and policy; - society; - infrastructure and services; - environment; - business and economy. **Case studies sheets' structure:** - what - why - how - scale (implementation in another context)
Smart Cities Marketplace Platform -SCMP	**Year** 2020 **Programme** European Commission H2020 **Format** Digital platform + Paper (tables, images) **Targeted users** project developers, municipalities, research institutions, industry, experts and citizens **Source** [13]	SCMP is a knowledge platform to exchange data, experience and know-how and to collaborate on the creation of smart cities, providing a high quality of life for its citizens in a clean, energy efficient and climate friendly urban environment.	**Research options:** - Filter by Project type - Filter by Energy - Filter by Mobility and transport - Filter by ICT - Filter by Country/City - Filter by Funding Programme **Structure:** - Facts and figures (geographical area, area dimension, population, total investment, funding from EU, Final energy savings, primary energy savings, CO_2 emission reduction); - Energy efficiency in buildings; - Key impact; - Type of technologies; - Lesson learned.

Appendix B

Table A2. PED-focused initiatives and projects collected among COST Action partners (1–16).

PED-Focused Initiatives						
				Scale		
N°	Acronym	Title	Period	International	National	Source
01	COST PED-EU-NET	COST Action on Positive Energy Districts European Network	2020 2024	x	N/A	https://pedeu.net/ Accessed on 16 November 2021
02	IEA EBC Annex 83	International Energy Agency, Programme on Annex 83 Positive Energy Districts	2020 2024	x	N/A	https://annex83.iea-ebc.org/ Accessed on 16 November 2021
03	JPI-UE	Positive Energy Districts and Neighbourhoods for Sustainable Urban Development	2018 -	x	N/A	https://jpi-urbaneurope.eu/calls/ped-call/ Accessed on 16 November 2021
04	EERA JPSC	European Energy Research Alliance Joint Programme Smart Cities	2016 2021	x	N/A	https://www.eera-sc.eu Accessed on 16 November 2021

Table A2. *Cont.*

PED-Focused Projects							
				Scale			
N°	Acronym	Title	Period	International	National	N° Case Studies	Source
05	Syn.ikia	Sustainable Plus Energy Neighbourhoods	2020 2024	x		4	https://synikia.eu/ Accessed on 16 November 2021
06	SPARCS	Sustainable energy Positive & zero cARbon CommunitieS	2019 2024	x		7	https://www.sparcs.info/ Accessed on 16 November 2021
07	+CityxChange	Positive City ExChange	2018 2023	x		7	https://cityxchange.eu/ Accessed on 16 November 2021
08	MAKINGCITY	Energy efficient pathway for the city transformation: enabling a positive future	2018 2023	x		8	http://makingcity.eu/the-project/ Accessed on 16 November 2021
09	POCITYF	A POsitive Energy CITY Transformation Framework	2019 2024	x		8	https://pocityf.eu/ Accessed on 16 November 2021
10	Atelier	AmsTErdam BiLbao cItizen drivEn smaRt cities	2019 2024	x		8	https://smartcity-atelier.eu/ Accessed on 16 November 2021
11	RESPONSE	integRatEd Solutions for POsitive eNergy and reSilient CitiEs	2020 2025	x		8	https://h2020response.eu/ Accessed on 16 November 2021
14	EXCESS	FleXible user-CEntric Energy poSitive houseS	2019 2023	x		4	https://positive-energy-buildings.eu/ Accessed on 16 November 2021
12	QEP	Smart Capital Region programme-Quartier à Energie Positive	2016 -		x	5	https://www.papillon-koeniz.ch/ Accessed on 16 November 2021
13	ZEN	Research Centre on Zero Emission Neighbourhoods in Smart Cities	2017 2024		x	9	https://fmezen.no/category/pilot-projects/ Accessed on 16 November 2021
15	/	Parma Smart City	2017 -		x	1	https://smartcityweb.net/smartcities/parma Accessed on 16 November 2021
16	/	Santa Chiara District	2017 -		x	1	https://www.comune.trento.it Accessed on 16 November 2021

Table A3. PED-supporting initiatives and projects collected among COST Action partners (17–40).

PED-Supporting Initiatives							
				Scale			
N°	Acronym	Title	Period	International	National	N° Case Studies	Source
17	ETIP SNET	European Technology & Innovation Platforms (ETIPs)	2020 2030	x		N/A	https://www.etip-snet.eu/ Accessed on 16 November 2021
18	SCIS-SCM	Smart Cities Information System-Marketplace	-	x		N/A	https://smart-cities-marketplace.ec.europa.eu/ Accessed on 16 November 2021
19	Local Energy District	Tecnologie per la penetrazione efficiente del vettore elettrico negli usi finali	2019 2021		x	N/A	https://www.enea.it/it/Ricerca_sviluppo/lenergia/ Accessed on 16 November 2021
PED-Supporting Projects							
				Scale			
N°	Acronym	Title	Period	International	National	N° Case Studies	Source
20	SmartEnCity	SmartEnCity project: Towards Smart Zero CO2 Cities across Europe	2016 2021	x		5	https://smartencity.eu/ Accessed on 16 November 2021
21	GRETA	GReen Energy Transition Actions	2021 2024	x		5	N/A
22	SUSHI	SUStainable HIstoric city districts	2018 2021	x		6	https://sustainablehistoriccitydistricts.wordpress.com/ Accessed on 16 November 2021
23	Sharing Cities	Building smart cities together Common solutions for shared challenges	2016 2021	x		6	http://www.sharingcities.eu/ Accessed on 16 November 2021
24	CENTS	Co-operative Energy Trading System	2019 2022	x		3	http://www.centsproject.ie/ Accessed on 16 November 2021

Table A3. *Cont.*

PED-Supporting Projects						
25	Triangulum	Demonstrate, Disseminate, Replicate	2015 2020	x	6	https://www.buildup.eu/en/explore/links/triangulum-project Accessed on 16 November 2021
26	REPLICATE	REnaissance of PLaces with Innovative Citizenship Additionally, TEchnologies	2016 2021	x	6	www.replicate-project.eu Accessed on 16 November 2021
27	Sinfonia	Smart INitiative of cities Fully cOmmitted to iNvest In Advanced large-scaled energy solutions	2014 2019	x	7	http://www.sinfonia-smartcities.eu/en/project Accessed on 16 November 2021
28	STREAMER	Geo and Building Information Modelling for Energy-efficient Buildings Integrated in Mixed-use Healthcare Districts	2013 2017	x	4	http://www.streamer-project.eu/ Accessed on 16 November 2021
29	PROFICIENT	Collective self-organised processes in the construction and retrofit of energy efficient residential districts	2012 2016	x	4	https://www.proficient-project.eu/ Accessed on 16 November 2021
30	GECO	Green Energy COmmunity	2019 2021	x	1	https://www.gecocommunity.it/ Accessed on 16 November 2021
31	SusCity	Urban data driven models for creative and resourceful energy transition	2015 2017	x	1	https://www.inesctec.pt/en/projects/suscity#news Accessed on 16 November 2021
32	FIRST	Mapping flexibility of urban energy systems	2017 2020	x	1	http://in3.dem.ist.utl.pt/first/#first Accessed on 16 November 2021
33	/	EnStadt:Pfaff	2017 2022	x	1	https://pfaff-reallabor.de/ Accessed on 16 November 2021
34	VISORE	Psychological Factors of Effective Visual Public Service Announcements	2017 2019	x	1	http://visore.mruni.eu/ Accessed on 16 November 2021

Table A3. *Cont.*

PED-Supporting Projects						
35	2000-Watt-Sites	/	2006 -	x	4	https://www.2000watt.swiss/en/2000-watt-areale-finden.html Accessed on 16 November 2021
36	Kosovo Energy Efficiency Project	Kosovo Energy Efficiency Project-Training of Energy Auditors in Kosovo	2017 2021	x	5	https://www.giz.de/en/worldwide/81190.html Accessed on 16 November 2021
37	PAW	PAW Programma Aardgasvrije Wijken (Gas Free Districts Programme)	2019 2024	x	46	https://aardgasvrijewijken.nl/default.aspx Accessed on 16 November 2021
38	PUJ	Prato Urban Jungle	2020 2022	x	1	https://www.uia-initiative.eu/en/uia-cities/prato Accessed on 16 November 2021
39	MilanoSesto	MilanoSesto: an evolving city	2020 2025	x	1	https://www.milanosesto.it/en/ Accessed on 16 November 2021
40	LIC	Lugaggia Innovation Community	2019 2024	x	1	https://lic.energy/ Accessed on 16 November 2021

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