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Review

Transition Approaches towards Positive Energy Districts: A Systematic Review

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Abstract: The positive energy district (PED) concept is attracting growing research interest; however, the need for practical approaches to facilitate their implementation remains crucial. This study, framed in the COST Action 'Positive Energy Districts European Network', offers a comprehensive review of the roadmaps, pathways, and guidelines—namely 'PED-Transition Approaches'—currently available to support the implementation of district-scale innovative models, thereby advancing energy transitions and enhancing livability at the city level. The review involved a systematic search and web scraping of documents, including scientific and grey literature, as well as EU-funded projects' reports. The studies were identified according to multiple filters and eligibility criteria, then categorised in a structured repository using a multidimensional matrix, and finally examined following three-levels of detail (i.e., bibliometric study) overview and in-depth analysis. The findings reflect the main characteristics, gaps, and challenges in PED implementation by underlying the growing need for effective step-by-step, user-centric, and context-based transition approaches. In conclusion, the research, building on an extensive literature of multiple inspirational methodologies and their associated use cases, is a strong basis to develop sequential pathways to facilitate PED implementation among key stakeholders in a short–medium-term perspective towards a climate-neutral city vision.

Keywords: positive energy districts (PEDs); climate-neutral cities; energy transition; transition approaches; roadmapping; implementation pathway; operational tools

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1. Introduction

Cities represent complex systems characterised by a multitude of interrelated dynamics, encompassing intricate challenges and promising opportunities [1–3].

In pursuit of decarbonisation goals and strictly aligned with the European Green Deal [4], the EU Mission advocates for the Climate-Neutral and Smart City model [5]. This approach offers a tailored response to the diverse needs of urban areas, aiming to tackle global challenges such as climate change, population growth, and energy poverty.

The 'Climate-Neutral and Smart Cities' Mission plans to achieve climate neutrality for 100 pilot cities by 2030, promoting the identification of strategic urban areas for innovative experimentation towards a sustainable and resilient transformation of the entire urban system [6,7]. The district dimension, serving as an intermediate scale between single buildings and the entire city (meso-scale) [8], facilitates the adoption of solutions with immediate impact on the 'buildings-open spaces' system. This dimension allows for the investigation of local challenges and priorities within a broad and multi-level perspective,

supporting the achievement of strategic urban and regional objectives [9–13] and multiple-stakeholders co-creation.

In parallel, recently approved EU policies are advancing the scaling up of energy goals beyond individual buildings to encompass community, neighbourhood, and district levels. For instance, EU Directive 2018/844 [14] revised Article 19 to promote an integrated approach at the district scale for developing retrofit schemes simultaneously involving multiple buildings. Similarly, the newly adopted Energy Performance in Buildings Directive (EPBD) [15] triggers the renovation of building stock through 'integrated district renovation programs', incorporating solutions that address buildings, energy systems, mobility, green infrastructure, waste, water management, and other related aspects of urban planning.

Within this framework, positive energy districts (PEDs) emerge as key local assets, accelerating decarbonisation processes towards climate neutrality and amplifying urban energy transition efforts. Introduced in 2018 [16], PEDs are defined as energy-efficient and flexible urban areas that achieve zero greenhouse gas emissions and actively manage an annual surplus of renewable energy production. PEDs require the integration of diverse systems and infrastructures, relying on effective interactions among buildings, residents, local energy networks, mobility services, and ICT systems, while prioritising a high quality of life for citizens.

Expanding this vision, the newly introduced concept of positive clean energy districts (PCEDs) adds the 'clean' dimension, advocating a more holistic and integrated planning approach that considers the decarbonisation of public spaces and mobility as a service (MaaS) as essential elements. This dimension aims to foster attractive, healthy, and resource-efficient neighbourhoods, envisioning a transition towards climate-neutral urban systems [17].

While a growing interest in the PED concept is emerging, the grounding of a significant number of pilot cases remains essential [18–21]. As a result, numerous studies and researchers [19,22–31] emphasise the need for comprehensive operational approaches to facilitate the implementation of district scale innovative intervention. In this regard, structured pathways, roadmaps, and guidelines, designed as step-by-step workflows, are identified as crucial tools of urban strategies, capable of empowering cities and their local communities in adopting systemic approaches both for holistic planning and design, and for the scalability and replicability of interventions according to the PED concept.

The "PED Pathway" within the Driving Urban Transition (DUT) Partnership [32] emphasises the urgent need to clarify the definition of a positive energy district (PED) to enhance its implementation in urban settings. While the current definition promotes general sustainability principles aimed at providing 'a good life for all', it lacks specific performance criteria [33]. To address this gap, it is suggested to adopt a series of indicators and the multimodal system analysis (MMSA) approach to methodologically connect the 'Climate-Neutral and Smart Cities' Mission of which PED can be a constitutive part [34]. Energy efficiency, flexibility, and production are highlighted as crucial factors, along with the importance of urban planning, good design (or beauty), governance, and citizen involvement in achieving the overarching goal of climate neutrality in PEDs.

Therefore, the concept of PED is increasingly evolving toward a holistic approach that encompasses direct and cross-cutting fields of activities. Simultaneously, the definition of PED is still under review to ensure alignment with the community policies and the broad lines of intervention of the Strategic Energy Technology (SET) Plan [35], the EU Cities Mission [36], the 10th Framework Programme (FP10) [37], and the DUT partnership [32].

To support this ambition, the PED Programme [38] was funded in 2018 as a mission-oriented transnational R&I funding initiative, which results from the European SET Plan Working Group to support a holistic implementation process towards 100 Positive Energy Districts and Neighbourhoods in Europe by 2025 [16]. Currently, the PED programme is one of the three main initiatives, together with the International Energy Agency's (IEA) Energy in Buildings and Communities (EBC) Program on 'Positive Energy District—Annex 83' [39] and the COST Action on 'Positive Energy Districts European Network' (CA PED-

EU-NET) [40], established between 2018 and 2020 to act towards the creation of PEDs. Among various activities, the three initiatives are collaborating on the implementation of a common online repository, the PED Database [21], aimed at facilitating the upscaling of positive energy districts (PED) across Europe and beyond.

This research is conducted within the framework of the CA PED-EU-NET. Based on the Memorandum of Understanding (MoU) [41] and utilising the data and insights collected in the PED Database, the Working Group (WG) n.1 'PED Mapping, Characterisation, and Learning', Task 1.5 seeks to develop a transition roadmap to facilitate the short-to-medium-term implementation of PED practices in the short to medium term.

Within this context, this paper aims to map and analyse the main roadmaps, pathways, and guidelines, collectively referred to as 'PED-Transition Approaches (PED-TAs)', currently available to facilitate the establishment of PEDs in real-world scenarios. Specifically, the study will prioritise the following three key objectives: (1) highlighting the necessity of PED-TA within the current research landscape, (2) providing a comprehensive state-of-the-art overview of available PED-TAs, and (3) proposing future research directions for practical and multi-layered workflows for PED-Tas, such as PED-Roadmaps.

The paper is organised into six sections: Section 2 outlines the theoretical framework of transition roadmapping. Section 3 details the methodological approach adopted for analyzing scientific and grey literature, as well as research reports from EU projects. Section 4 presents the literature review results. Section 5 critically discusses the main findings and provides recommendations and future research directions. Finally, Section 6 summarises the study's conclusions.

2. Background: Framing the Transition Roadmapping Concept

The transition toward climate-neutral cities is a challenging path influenced by economic, environmental, social, and legislative aspects. This transition requires support and acceleration through an open, dynamic, and multi-level governance approach [42]. The management of these complex processes was studied from multiple perspectives.

The theory of change (ToC) was applied across different research fields and defined in various ways. Generally, it refers to a step-by-step, structured, and systematic process for organising consecutive actions toward achieving a planned long-term common goal. According to Pringle and Thomas (2019) "ToC is a planning process which articulates how change can be achieved. It begins by defining the long-term goal or vision statement ('the change we want to happen') and works backwards to systematically laying out each step along a 'causal pathway'—a series of steps which lead towards the long-term goal" [43] (p. 1).

Noble (2019) [44] identifies two major components in the ToC: (1) the process, which provides an opportunity for the team to discuss and reach a common understanding of the decision-making path towards a solution, and (2) the output, often depicted as a diagram or flow chart, which offers a clear plan to implement the change and communicate it both internally and externally within the organisation.

Mackinnon and Amott (2006) [45] emphasised that ToC supports the articulation of all steps toward a desired change by identifying the conditions that enable or inhibit each planned step, defining the related practical activities that produce the necessary conditions, and envisioning the long-term impact and outputs they will generate.

Guidelines for developing a well-structured and comprehensive ToC were established. According to Harries et al. (2014) [46], the key components for creating a successful theory include: (1) defining a long-term, realistic, and clear final goal, (2) identifying intermediate short-term outcomes as key stepping stones toward the final goal, (3) planning activities that drive changes and directly impact these intermediate outcomes, (4) identifying enablers, which are conditions and factors, both internal and external, that need to be in place to facilitate the transition, and (5) including existing evidence and assumptions.

Moreover, as emphasised in [47], the ToC should be supported by a data-driven approach. This involves conducting an in-depth situation analysis to gain a common

understanding of the local context (e.g., stakeholders, dynamics, systems, and challenges) and constructing a monitoring framework to identify key indicators for measuring the expected intermediate outcomes.

With a similar goal of driving transformation, Kotter [48] proposes the 8-step model for accelerating change: (1) create a sense of urgency, (2) build a guiding coalition, (3) form a strategic vision, (4) communicate the vision broadly, (5) enable action by removing barriers, (6) generate short-term wins, (7) sustain acceleration, and (8) institute change. Initially adopted in organisational management, the Kotter model is also successfully applied in other fields. For example, the Danish city of Sonderborg experimented with this approach to expedite the energy transition process at the urban scale, adapting it to climate-neutral urban planning [49].

Focusing specifically on transition management in the urban context, Roorda et al. (2014) [50] highlight that the process of change in cities revolves around three interrelated macro-objectives: (1) developing a 'sense of direction', which provides a strategic vision for the future, (2) creating momentum for change based on context-specific needs and ongoing initiatives that align with the envisioned strategic direction, and (3) empowering and involving stakeholders in the co-creation of the vision, ensuring their active participation in the transition process.

Based on these objectives, the guidance structures the transition path into three consecutive phases:

- **Orienting**: setting the scene for transition management by exploring local dynamics, framing transition challenges, and envisioning a sustainable city;
- **Engaging**: reconnecting short-term and long-term goals through key stakeholder involvement and anchoring;
- **Activating**: implementing actions passing through preliminary experimental transformations.

In conclusion, both the above analysed approaches (e.g., [43,44,46,50]) and literature [51–53] highlight roadmapping as a recurring way for strategic and operational decision-making as along with city energy and climate-adaptive master planning. According to Jeffrey et al. (2013) [54], roadmapping, which encompasses the process of implementing, monitoring, and updating a roadmap, can be viewed as an open and non-linear blueprint aimed at defining a consequential path by addressing three key groups of questions: (a) Scoping stage: Which direction should we take? What objectives does the roadmap aim to achieve? What are the planned time horizons? (b) Current state identification: What is the state of the art? Is there an active market to enter? Are there policies or initiatives that can facilitate the transition process? (c) Action plans: How can the vision for the short, medium, and long term be achieved? What strategies and actions need to be implemented?

The third group of questions (c) can be encapsulated within the roadmap framework, typically structured across two dimensions: the temporal axis, segmented into short, medium, and long term, and various thematic layers essential for realising the overarching planned goal or ambition [55]. The above-mentioned roadmap serves as a strategic tool, not only outlining specific milestones and timelines, but also delineating the central themes, practical actions, and key stakeholders required at each stage of the process to advance towards the desired outcomes. It provides a visual and structured approach to guide decision-making and prioritise efforts, ensuring alignment with overarching objectives throughout the whole implementation journey.

3. Materials and Methods

The review supporting the recognition of the available transition approaches towards PEDs (PED-TAs) to facilitate the establishment of PED practices was conducted following the PRISMA 2020 guidelines "https://www.prisma-statement.org/prisma-2020-statement (accessed on 20 June 2024)" and using a two-steps approach:

- Documents search and screening (Section 3.1): this step focused on exploring existing projects, initiatives, and research to gather relevant approaches and methodologies aimed at guiding stakeholders in transitioning towards PEDs.

- Documents categorisation and analysis (Section 3.2): In this step, the collected documents were categorised with a dual purpose: (a) to identify the necessity for PED-TAs and (b) to highlight actual approaches, both methodologies and case studies, that employ PED roadmapping. An analysis matrix was developed to thoroughly examine and compare the key features and contents of the different TAs.

A detailed explanation of the methodology employed and the associated materials can be found in the following subsections and visually summarised in Figure 1.

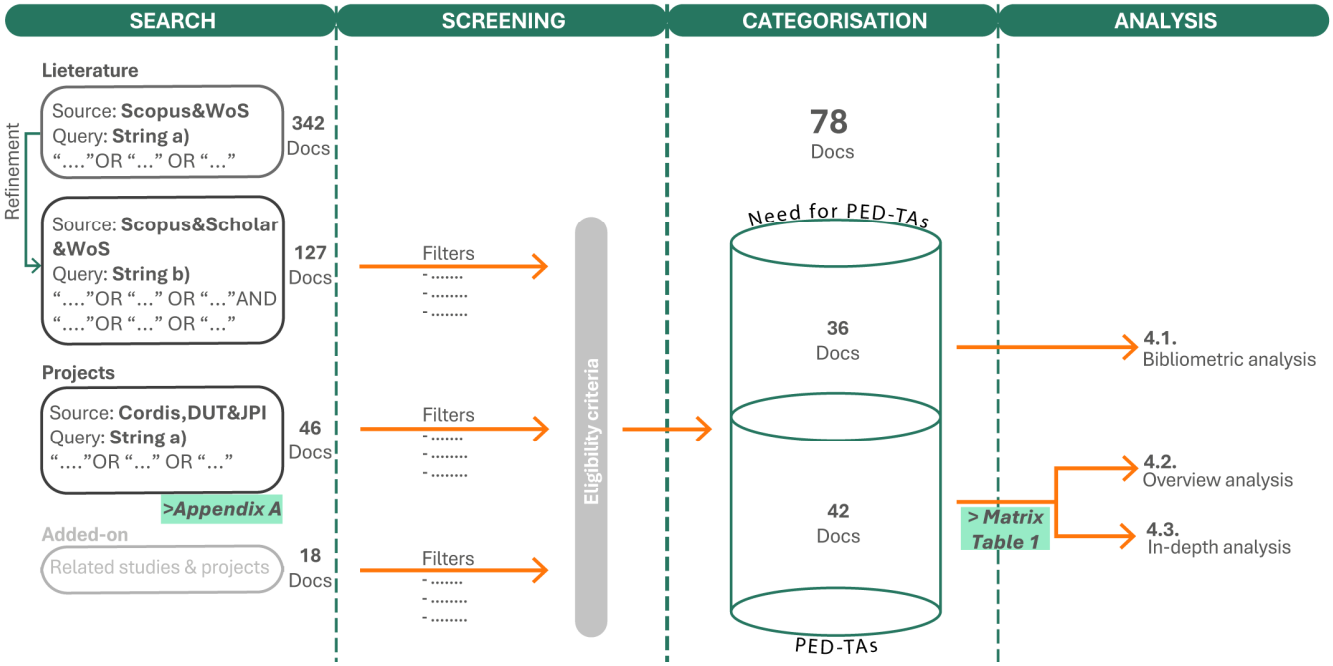


Figure 1. Flowchart: methodological approach for the review.

3.1. Documents Search and Screening

Two concurrent searches were conducted to gather pertinent literature, including journal articles, papers, deliverables, and reports, on TAs supporting the implementation of PEDs:

- Literature: The search was conducted in June 2024 using Google Scholar "https://scholar.google.com/ (accessed on 5 July 2024)", Scopus "https://www2.scopus.com (accessed on 5 July 2024)" and Web of Science "https://access.clarivate.com/wos/ (accessed on 5 July 2024)" databases. Several query strings were employed: String (a): "Positive Energy Districts" OR "Positive Energy Neighbourhoods" OR "Positive Clean Energy District", [...] including both plural and singular forms and any equivalent forms, e.g., "Positive Energy Neighbourhoods". This search returns a total of 198 documents in the Scopus database and 144 in Web of Science. In order to restrict the search field to the themes of the review, a second string (b) was used: "Positive Energy Districts" OR "Positive Energy Neighbourhoods" OR "Positive Clean Energy District" AND "roadmaps" OR "pathways" OR "guidelines". A total of 127 documents were identified: 99 from Google Scholar, 20 from Scopus, and 8 from Web of Science. All search results from Web of Science are included in the search results from Scopus which provides, compared to the previous one, additional publications of interest that were included in the analysis for the relevance to the topics and objectives of the literature review.

To conduct a systematic literature review, the methodological approach adheres to the principles outlined in [56] and follows these main steps: (1) search, (2) screening, (3) categorisation, and (4) analysis.

These documents underwent screening and eligibility based on the following exclusion criteria: (1) unavailability of full text in English, (2) lack of open access, and (3) duplicity. Additionally, thorough examination of abstracts and preliminary scans of full texts enabled the exclusion of literature not directly relevant to the review topic, i.e., PED-TA.

- Projects: As in previous research, e.g., [57], in order to carry out a comprehensive study, simultaneously, a search was performed on the Cordis EU Research and Innovation platform "https://cordis.europa.eu/ (accessed on 5 July 2024)" using the query: "Positive Energy Districts" OR "Positive Clean Energy Districts" OR "Positive Energy Neighbourhood". Additionally, research was conducted on PED projects funded under JPI Urban Europe pilot calls and the DUT partnership. A total of 46 projects and related publications were reviewed, leading to the identification and detailed analysis of 16 methodologies supporting PED-TA (see Appendix A).

Furthermore, some interrelated studies and projects were incorporated. These integrations aim to enrich the scope of the review by providing relevant insights and findings from existing research that align with the themes of Energy Communities and Digital Energy Modelling. This approach was adopted to support a comprehensive analysis of relevant literature and projects and aimed at contributing to a wider understanding and advancement of TAs for PEDs.

Finally, gathering all the findings emerged from the search and screening process, 78 publications were selected during the inclusion phase, and then categorised and fully reviewed (see Appendix B).

3.2. Documents Categorisation and Review

In alignment with the objectives identified for the literature review, the documents were divided in two main categories: (1) need for PED-TAs—this category includes studies and research that articulate the rationale behind the need for transition approaches towards PEDs. It explores the reasons for implementing such roadmaps, identifies the stakeholders involved, and clarifies the benefits and challenges associated with their adoption; (2) PED-TAs—this category encompasses existing methodologies and applicative examples aimed at facilitating the implementation of PEDs or similar experiences. These methodologies provide structured frameworks and guidelines for planning, implementing, and monitoring PED initiatives in various contexts, showcasing their real-world applications and outcomes.

By categorising the literature into these two main groups, a structured and systematic literature database is established as a key resource to inform further research and practical applications in the field of PEDs (see Appendix B).

At the same time, a collaborative online workshop was conducted using the Mirò "https://www.miro.com (accessed on 29 May 2024)" interactive dashboard, involving CA PED-EU-NET participants from several disciplines such as architects, engineers, urban planners, social scientists, economists, and IT experts employed in various sectors, e.g., research, academia, public administration, private companies, etc. Through active discussion, also carried out in the following weekly meetings with CA Task 1.5 members, the final objectives and expectations of the analysis were calibrated, as well the most relevant aspects to consider in the currently available paths and transition guidelines for PEDs.

Several distinctive aspects were addressed during the workshop, including the definition of a step-by-step approach, calculation of key performance indicators (KPIs), scenario simulation, context-based methodologies, and stakeholder engagement strategies. Interviews based on key investigative questions were also performed, such as defining the scopes, i.e., action areas, of the roadmap, identifying the target audience, and determining key content areas.

Based on these insights, an analysis matrix (summarised in Table 1) was designed to facilitate the structured review of materials collected. This step enabled the identification of the review objectives and expectations, as well as the selection of appropriate methods for conducting it. The content matrix serves as a tool to systematically analyse,

collect, compare, and evaluate the identified approaches and comprehensively address their specific characteristics. Specifically, the review addresses the following main research questions (RQs):

- RQ1—Why is a PED-TA needed: Which are the trends to be considered for a comprehensive approach? Which is the final scope?
- RQ2—What are the main PED-TAs recurring features: Which are the principal contents, steps, and elements to weight? Which are the main gaps?
- RQ3—Who are the key stakeholders for a PED-TA: Who should be the target user? How can the local partnership towards PEDs be constituted?
- RQ4—When can the PED-TA be applied: which are the key phases to prioritise?

Table 1. Content framework for the analysis matrix of the PED-TAs.

Basic Info						PED-TAs Analysis				
Title, Source, Keywords	**Type of Document**	**Focus PED**	**EU Projects Funded**	**Scale**	**Scopes (Action Areas)**	**Key Features**	**Target Users**	**Phases**	**Brief**	**Graphic**
[txt]	[single choice]	[single choice]	[single choice]	[single choice]	[single choice]	[multiple choice]	[multiple choice]	[multiple choice]	[txt]	[img]
/	- Journal article; - Conference paper; - Project deliverable; -Book chapter; - Website	- Yes; - No.	- Yes; - No; if Yes, specify	- City; - District; - Buildings block.	- Orienting -Engaging -Activating	- Step-by-step approach; - Focus on renovation; - KPIs calculation; - Scenario simulation; - Digitalisation; - Context-based; - Stakeholders participation; - Customer oriented.	- Public Sector; - Private Sector; - Research Sector; - Citizens and civil society.	- Planning; - Design; - Construction; - Operation.	/	/

4. Results

This section presents a series of insights deriving from the review of PED-TAs:

- bibliometric analysis aimed at providing a visual overview of the mapped literature on the need for PED-TAs (Section 4.1);
- comprehensive review of the available TAs aimed at guiding PED practices/projects in the current R&I landscape (Section 4.2);
- in-depth analysis of some PED-TAs aimed at providing a focus on the most relevant identified use cases (Section 4.3).

4.1. Bibliometric Analysis: Need for PED-TAs

This section focuses on the bibliometric analysis of the scientific literature with the aim to depict the research background, trends, and directions at the basis of this research study.

Figure 2 illustrates the main bibliometric features of the scientific literature resulting from the Scopus database using the search string (a), i.e., temporal and geographical distribution of the documents, funding frameworks, and topic sectors. On the other hand, Figure 3 describes the temporal distribution of the published works corresponding to search (b) in Scopus.

As shown in Figure 2, part (a), the number of research on PEDs increased during the last decade, in particular in the period between 2017 and 2024, demonstrating the growing interest of the scientific community towards PEDs, with an inverse trend starting from the peak recorded between 2021 and 2022. The temporal distribution profile (b), as per Figure 3, illustrates an inverse trend during the last two years with a positive slope. This trend graphically represents the growing need to investigate systematic planning processes, holistic design frameworks, and tailored-made roadmaps for PEDs.

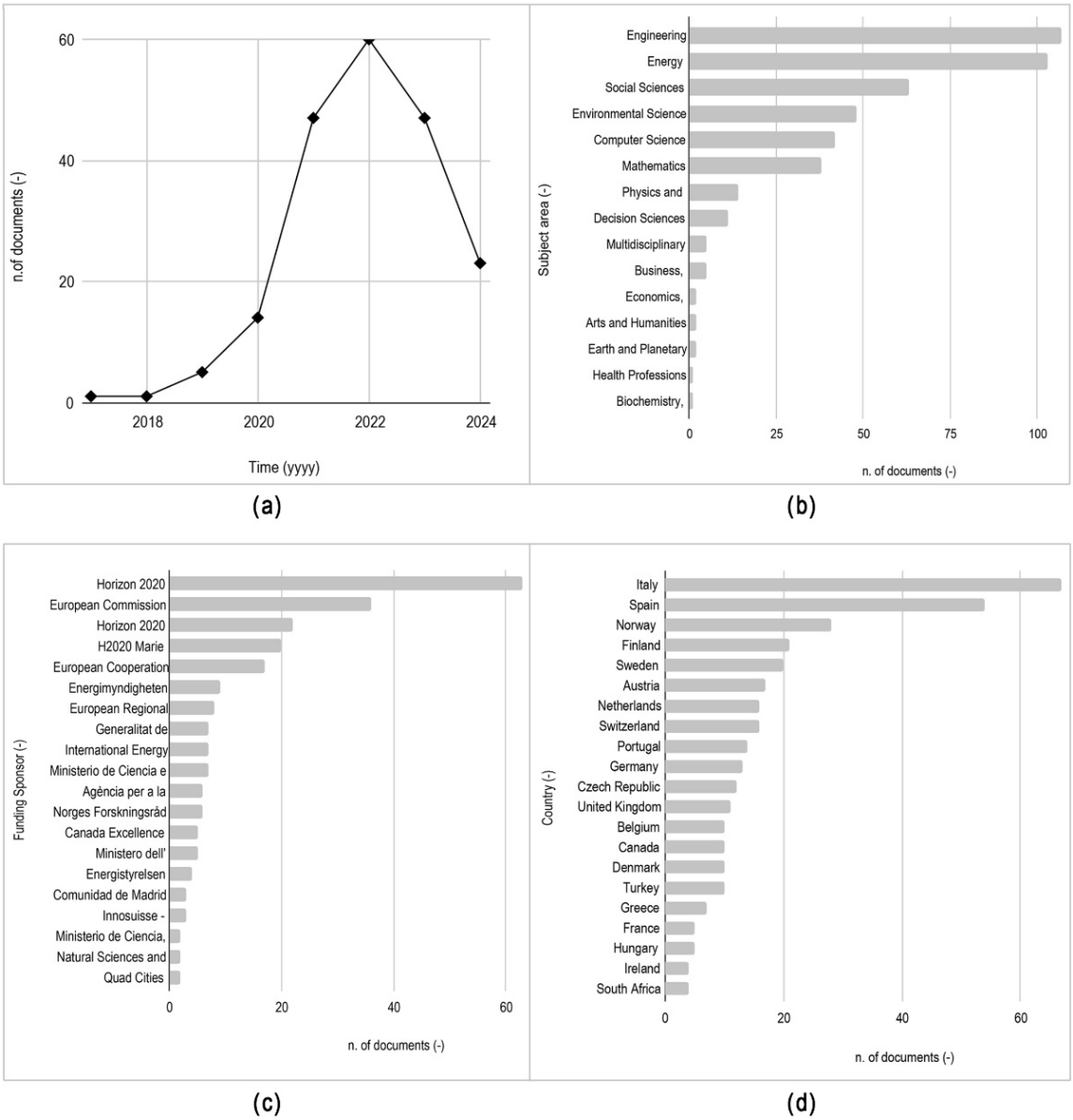


Figure 2. Bibliometric characterisation of the scientific documents from the Scopus database using string (a): (**a**) temporal distribution, (**b**) geographical distribution, (**c**) funding sponsors, and (**d**) overview of research sectors of the literature.

As per Figure 2—part (c) and (d), most of research on the topic is developed from Mediterranean countries and within the Horizon H2020 Programme. Furthermore, Figure 2, part (b), represents the multidisciplinary nature behind research on energy-innovative and sustainable districts, which reflects the need to integrate knowledge and expertise from different research sectors into a holistic roadmap towards PEDs.

As in previous research, a Bibliometric Analysis on the authors' keywords was conducted using VOSviewer software 1.6.20 [58] with the aim of highlighting research trends on PEDs, research background and the correlations between thematic areas and sectors (sustainability, technological innovation, planning, etc.). Figure 4 depicts the main overview of authors' keywords co-occurrence of scientific literature, while Figure 5 shows an enlargement on the temporal distribution of the co-occurrence of relevant authors' keywords within the scientific literature.

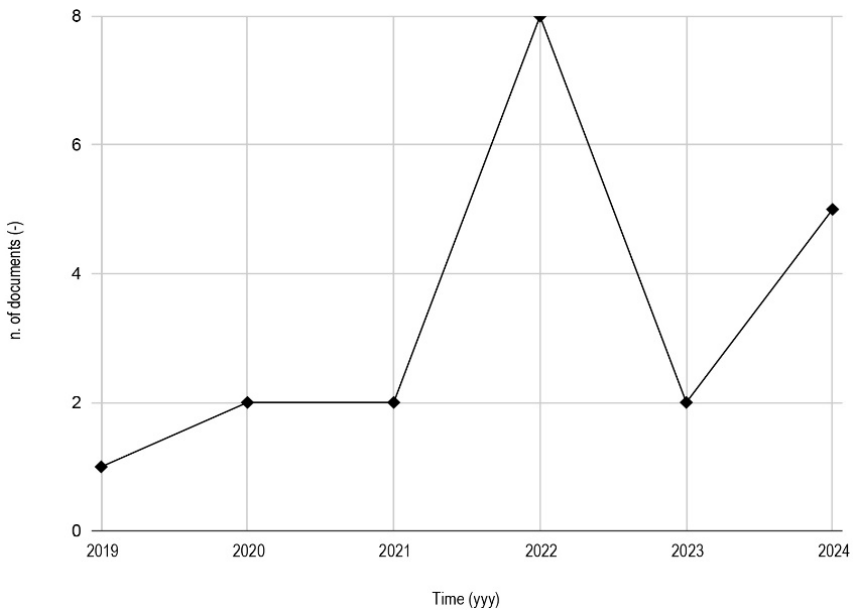


Figure 3. Temporal distribution of the literature documents from the Scopus database using string (b).

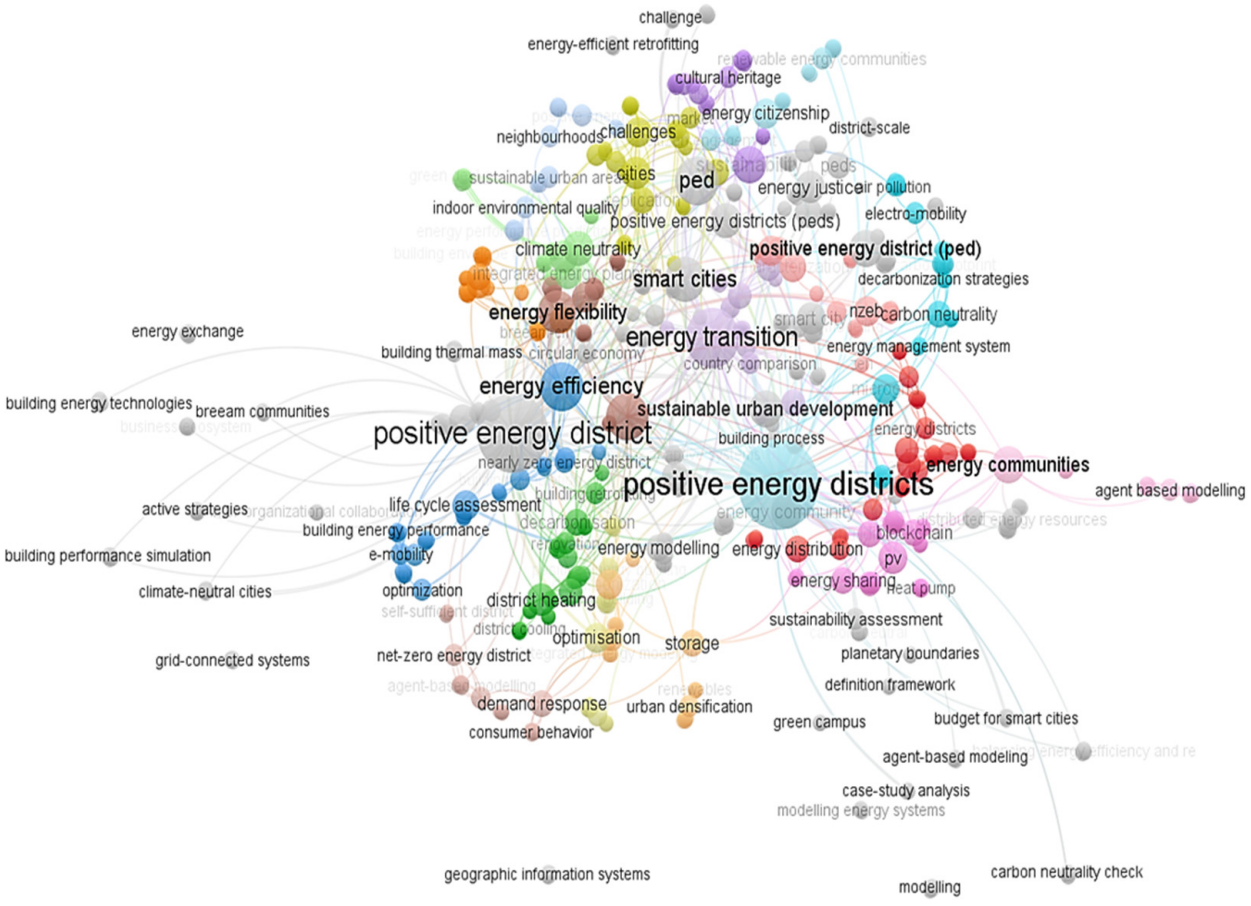


Figure 4. Main overview of authors' keywords co-occurrence of scientific literature.

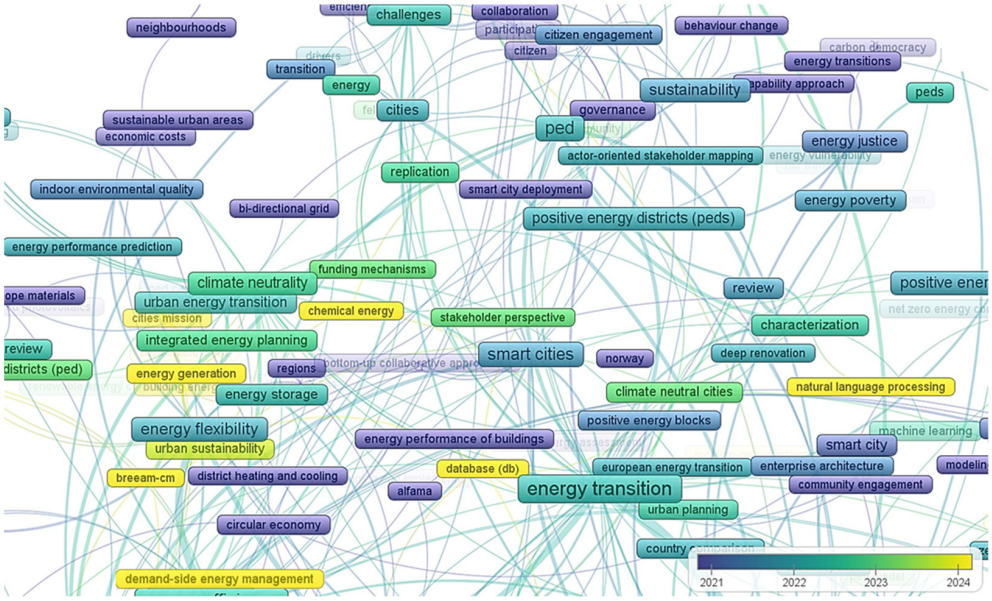


Figure 5. Temporal distribution of the co-occurrence of relevant authors' keywords within the scientific literature.

As it turns out, the concept of PED is a complex concept around which the interest of different research sectors and stakeholders is focused, and which therefore requires an integrated multi-sectoral and multi-criteria approach. Indeed, the concept of PED is linked through robust connections to several aspects of eco-compatible design, business models, and optimisation of multisource and novel energy systems. For this reason, an integrated and systemic approach towards PEDs is at the basis of an effective roadmap. As per the bibliometric analysis, some studies address this need, as confirmed by the strength of the connections of the PED concept with that of "integrated energy planning" and "collaborative approach". On this line, authors pay attention to the definition of a collaborative and integrated approach between the various parties involved in the planning stage according to a "urban living-lab vision" in order to overcome thematic and sectoral silos and identify the key drivers for the PED diffusion. Furthermore, tools aimed at harmonising the perspectives of different stakeholders, such as "stakeholder perspective" and "stakeholder mapping", could be used in order to facilitate project management.

From this perspective, the adoption of systematic roadmaps can promote the diffusion of PEDs both by supporting municipalities in the planning phase and by facilitating cooperation between corporate stakeholders, citizens, and the interdisciplinary research team. Furthermore, the definition of a systematic planning horizon is essential for sustainability objectives to be fully achieved in the long term and for fostering the replication potential of PEDs. However, some authors highlight the need for further research efforts to identify holistic solutions and tailor-made roadmaps.

Within this context, an effective sustainability assessment framework is crucial to achieve and maintain the project objectives even in the long term in accordance with the Sustainable Development Goals. Some authors focused on the definition of an overall assessment framework that combines elements of socio-economic sustainability with concepts of environmental sustainability according to an "integrated sustainability perspective". This vision could require the integration of different skills, techniques, and analysis, such as life cycle costing (LCC) and cost benefit analysis (CBA)/multiple benefit analysis, multi criteria decision analysis (MCDA), life cycle assessment (LCA), or KPIs-based approaches. It is worth noting that the approach should be user-oriented as suggested by the close combination between the concept of PED and that of "energy justice", "energy poverty", "social innovation", etc., which represents the research efforts towards the social sustainability of PEDs and similar novel urban areas. On the other hand, as highlighted by some other

keywords (i.e., "energy citizenship", "behaviour change", and "community engagement"), citizens play a key role in the success of the project. Therefore, as demonstrated by several project outputs on the topic, the organisation of events, information campaigns, and actions (such as the definition of social aggregation hubs for promoting social identity and cohesion) aimed at involving and empowering citizens are essential enabling factors.

As for the environmental sustainability and as per the linkage between the concept of PED and that of the "life cycle assessment" shown in Figure 4, some research trends are oriented towards the eco-design of buildings and energy infrastructures in order to take into consideration the entire life cycle. This is particularly relevant considering that some novel materials and technologies have higher embodied impacts than traditional systems. Furthermore, strategic thinking for circularity could complement the eco-design framework while avoiding fragmentation in planning and considering iterativeness to the processes.

Another aspect recently analysed is the definition of energy efficiency measures and business ideas appropriate for historical buildings, "cultural heritage" and "PEDs", which preserve their cultural value. This suggests the need for systematic roadmaps towards the PED implementation that maintain characteristics of adaptability to various contexts. In general, factors that influence design and political choices depend on the use of the buildings, climate, characteristics of energy networks, availability of renewable sources, territorial welfare, social challenges, and regulations.

While on the one hand, PEDs can be seen as bulwarks of the concept of sustainable development and growth, on the other hand, PEDs are also hubs of energy and technological innovation. Therefore, the topic is attracting several efforts in the search for innovative energy management solutions on the one hand, and in novel technologies on the other. As per the bibliometric analysis, one line of research focuses on the development of robust and reliable energy demand forecasting models using solid tools and/or machine learning techniques.

As shown in Figure 4 (brown cluster of keywords), the concept of PED is frequently connected to that of energy flexibility and demand side management (DSM) through keywords such as "energy flexibility", "demand response", "energy management systems", etc. The concept of energy flexibility is at the centre, together with that of sustainability, of the definitions on PEDs, as it contributes to the load match between local generation of renewable energy and the load through load shifting and peak shaving. As can be seen from Figure 5, the field is receiving considerable scientific interest but is rather recent (some research is from 2023 to 2024), and further research efforts are required to define and test-tailored flexibility approaches made for PEDs. This is particularly relevant considering that most experiences on flexibility focus on the single building scale, while there is a gap in the research of systematic approaches at the district scale. Most of these applications within innovative urban concepts, such as PEDs, are related to the flexible control of the HVAC system, e.g., through the use of the thermal mass of the building envelope and to the integration of electricity storage batteries in the energy layout of the district and electric vehicles. On the other hand, further attention should be paid to optimising aggregate flexibility and thermal comfort.

Furthermore, there is a research gap in the integration of novel thermal energy storage (TES) systems in the overall energy framework of the district, i.e., phase change material (PCM) and thermochemical storage material (TCM)-based storage devices, even if some keywords (i.e., "chemical energy", "thermal energy storage") and studies focus on them.

Some research highlights the need for "business models" and "financing schemes" for the valorisation of flexibility revenues, especially if demand response services and/or ancillary services for the electricity grid are also provided.

As follows from this brief description of the main research trends on PEDs, the topic summarises notable research efforts from different fields. However, comprehensive planning frameworks for PEDs and clear roadmaps were not presented in previous research.

In this regard, thirty-six of the reviewed articles do not focus on the modelling and methodological approaches, but rather address the recurring need for roadmaps, pathways,

or guidelines for PEDs. This need arises from several critical factors according to the analysis of the publications included in the review. These scientific studies are related to several aspects, e.g., the replication of successful strategies and lessons learned [59,60]; policy-maker engagement through informed and collaborative decision-making [61]; addressing the growing but uneven attention to PEDs [62]; definition of an environmental framework for PEDs and the main challenges towards overall sustainability [57]; identification of enabling factors, opportunities, and gaps towards the diffusion of PEDs [19]; and reviewing practical examples to identify best practices [2].

Furthermore, structured planning and design frameworks are essential for managing the complexity of PED implementation [28], aligning legislative frameworks [26], and identifying barriers [22]. Comprehensive guidelines also facilitate stakeholder engagement, providing clear steps and resources for initiating and sustaining PED transitions, thereby ensuring effective and scalable outcomes.

4.2. Overview Analysis: PED-TAs

This section analyses the set of publications classified as PED-TAs according to the matrix shown in Table 1, i.e., scale of application (Section 4.2.1), scopes (action areas) (Section 4.2.2), key features (Section 4.2.3), target stakeholder (Section 4.2.4), and phases of application (Section 4.2.5).

Figure 6 illustrates the continuous increase in this type of publication in recent years. It should be noted that the publications for the year 2024 are up to June (mid of the year), which is when the search was conducted. This focus on methodologies and applicative cases is due to their significant rise, highlighting their growing importance and relevance in the field.

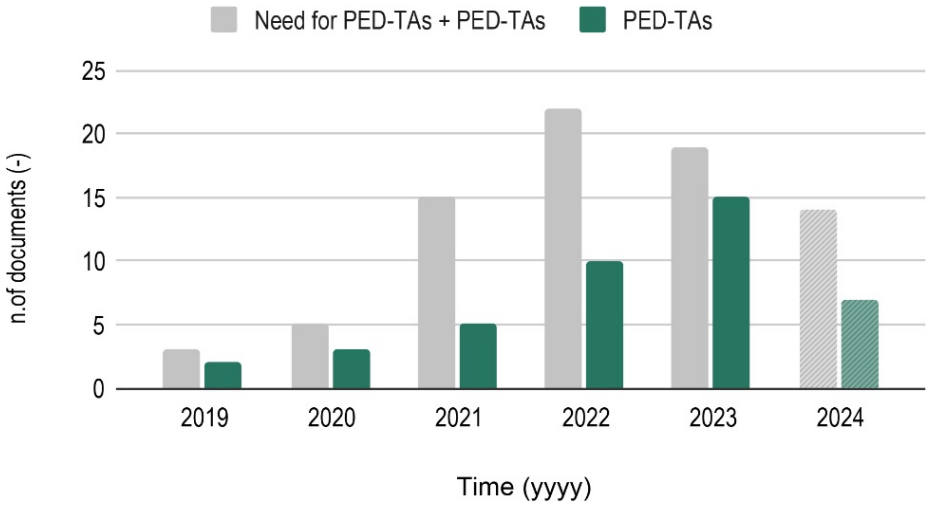
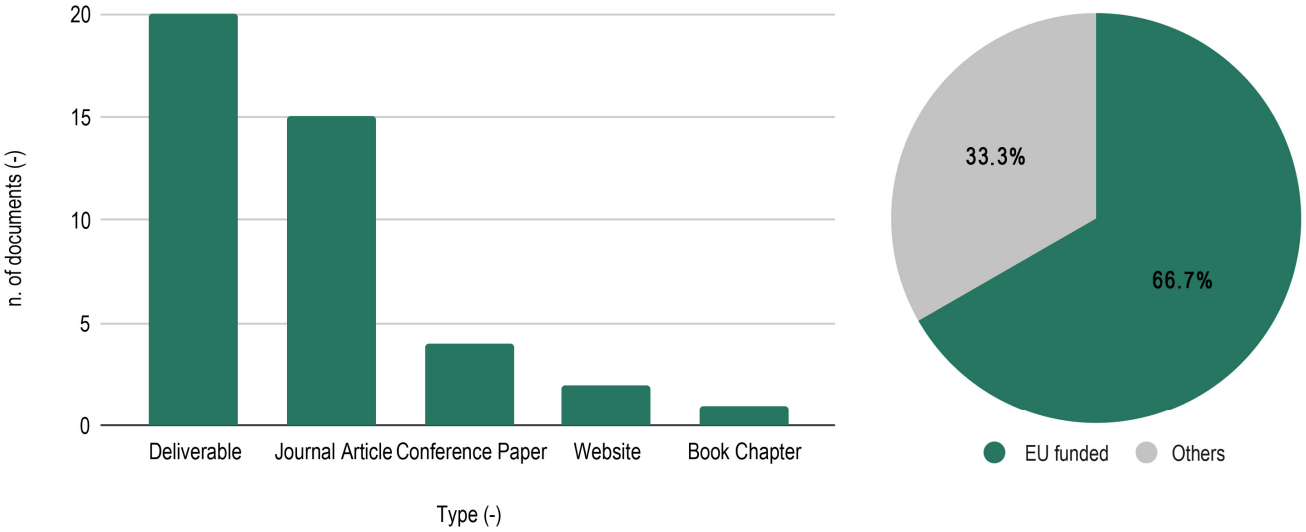


Figure 6. Trend in PED-TAs publications.

In analyzing the PED-TA methodologies and applicative cases, 42 documents were identified and analysed in depth from the literature review: 26 of the mentioned approaches focus on the PED concept [13,63–87], while the remaining 16 refers to some PED-similar assets, such as energy communities [53,88–91], climate positive community [92,93], green and solar neighbourhoods/cities [23,94,95], district-scale renewal [96–98], and net-zero energy and carbon districts [99–101]

Focusing the attention on the type of documents, they mainly belong to two categories: 20 over 42 are categorised as deliverable or research reports, directly funded by EU projects or national initiatives [68,74], while 15 over 42 are classified as journal articles. The remaining are divided into four conference papers, two websites, and one book chapter (Figure 7a). This ranking highlights the predominant role of national and EU-funded projects in driving research and reporting on the PEDs, which account for almost half of the documents.

Journal articles, almost as numerous, provide crucial peer-reviewed information, while the smaller contribution of conference papers, websites, and book chapters suggests a more limited dissemination through these formats.



(**a**) (**b**)

Figure 7. Document categorisation: (**a**) PED-TAs by type of document; (**b**) PED-TAs funded by EU projects/initiative.

Finally, most of the analysed approaches, i.e., 66.7%, are connected to EU-funded projects and initiatives (Figure 7b). In particular, seven of them were specifically developed in the frame of the smart cities and communities projects focused on the PED concept and funded under the topic 'LC-SC3-SCC-1-2018-2019-2020—Smart Cities and Communities' [66,67,71,73,78,79,87]. This demonstrates the significant impact of European funding programs in shaping PED research and development, underscoring the EU's strategic role in promoting them.

4.2.1. Scale of Application

The majority of the documents, 64.3%, focus on the district scale either through a focus on the PED concept [77,80] or related concepts [95,96]. This emphasis on the district level reflects the PED's goal of achieving energy efficiency across multiple buildings and public spaces within a defined urban area, making it a practical and impactful scale for energy transformation.

The remaining papers focus on methodologies at the upper and lower scales. Specifically, 26.2% of the documents focus on the city scale [101], including related concepts such as smart cities [26], carbon-neutral cities [65], or climate-positive cities [92]. Additionally, 9.5% of the documents concentrate on the building block scale [84], covering concepts such as energy communities [53] and building renovation [97]. The focus on city and building scales complements the district-level analysis, showing that while PEDs are primarily applied at a district level, similar principles can be adapted to both larger urban systems and individual building blocks. Including these perspectives provides a comprehensive review of the methodologies and roadmaps relevant to PED across different but closely related scales (Figure 8).

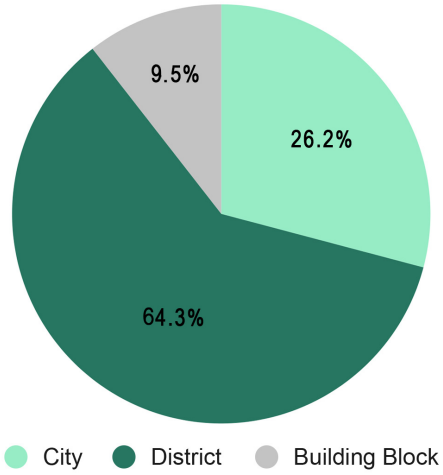


Figure 8. PED-TAs Scale of application.

4.2.2. Scopes (Action Areas)

According to the transition management methodology proposed by Roorda et al. (2014) [50], the approach of PED-TAs was analysed by classifying cases according to their scope or action area (Figure 9). Of the cases analysed, 42.9% focus on activating, which prioritises the establishment of pilot projects by finding the best solutions for various intervention scenarios [69,94,97]. This approach is crucial for the practical testing and demonstration of PED concepts, allowing stakeholders to refine strategies through real-world application. Another 40.5% concentrate on orienting, involving strategic tools that facilitate the decision-making process by evaluating specific local challenges in a medium–long-term perspective [78,79,93]. Orienting tools are essential for planning PEDs with foresight, ensuring that projects are not only reactive to immediate needs, but they also contribute to sustainable, long-term urban transformation.

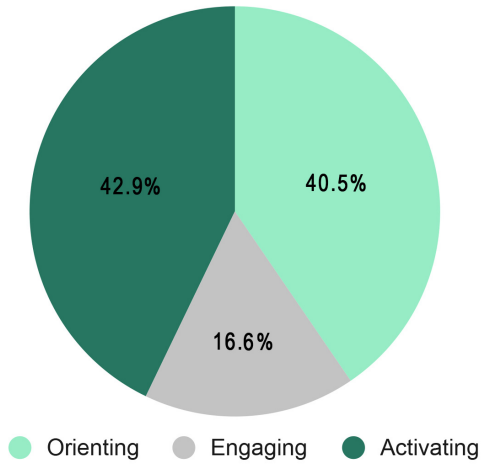


Figure 9. PED-TAs scopes (action areas).

The remaining 16.6% focus on engaging, prioritising stakeholder participation throughout all stages of PED [23,82]. While less prevalent, the focus on the engagement topic highlights the importance of involving local communities, businesses, and other key actors from the very beginning to ensure that the PED is socially accepted and tailored to the needs of those it will affect. However, some Tas, even with a deeper scope in activating or orienting, integrate the engagement component inside the proposed workflow [23,87].

4.2.3. Key Features

Focusing on the content of the documents, a series of key features of interest for developing a PED-TA roadmap were identified, as detailed in Table 1. These key features include a step-by-step approach (SSA) [65], focus on renovation (R) [80], KPIs calculation (KPI) [64], scenario simulations (SS) [77], digitalisation (D) [99], context-based strategies (CB) [63], stakeholder participation (SP) [70], and customer orientation (CO) [73]. Each of these features appears in at least 15 documents, with context-based strategies highlighted in 38 documents, followed by the step-by-step approach in 35 documents (Figure 10). This highlights the importance of customising PED approaches to the specific socio-economic, environmental, and geographical context of each district, recognising that one-size-fits-all solutions are rarely effective.

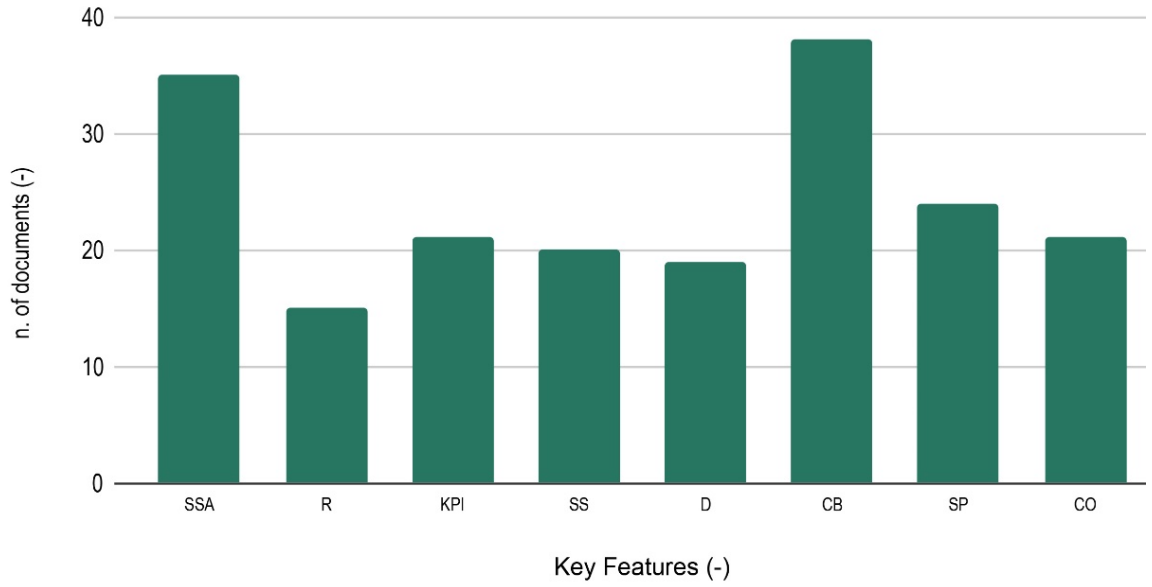


Figure 10. PED-TA key features.

Following this, 35 documents highlight a step-by-step approach (SSA), which suggests that implementing PEDs requires a structured, phased approach. This method allows for incremental progress, ensuring that each phase of development builds on the previous one, making it easier to manage complex transitions.

Notably, the focus on renovation (R) is the least represented feature, suggesting that many of the papers focus more on renewable energy systems than on energy efficiency or building retrofitting. This indicates a possible gap in the literature, where more attention could be paid to the integration of energy efficiency measures in PED projects, especially in older urban areas where renovation is crucial to achieve sustainability goals.

4.2.4. Target Stakeholders

The four types of stakeholders identified (Table 1) are highlighted in Figure 11, with the public sector most frequently noted as the primary promoter or initiator of PEDs [73,78,93]. The involvement of the public sector is crucial, as it typically provides the necessary regulatory frameworks, funding, and policy support to foster the growth and integration of PEDs. Moreover, public sector initiatives often pave the way for collaboration with other stakeholders, including private companies, research communities, citizens, and non-profit organisations. Therefore, although the Public Administration is frequently seen as the primary promoter or initiator of PEDs, private sector stakeholders, academia, and citizens also repeatedly appear as key target stakeholders.

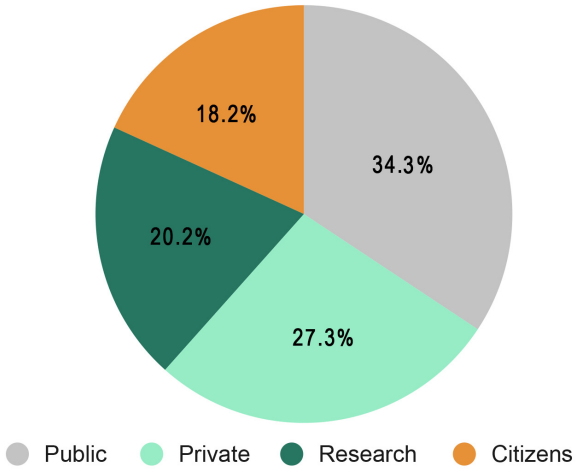


Figure 11. PED-TA target stakeholders.

4.2.5. Phases of Application

Regarding the phases included based on the classification obtained for the PED Database [18,21,28], most of the documents included the pre-implementation phases, 36 publications include the planning phase, such as [13,82], and 25 include the design and demand aggregation phase [80,84] (Figure 12). This reflects the current focus of PED research on establishing a solid foundation for projects before moving on to the more advanced stages of construction and operation. Planning and design are essential to set clear basis and objectives and to ensure stakeholder involvement before implementation starts.

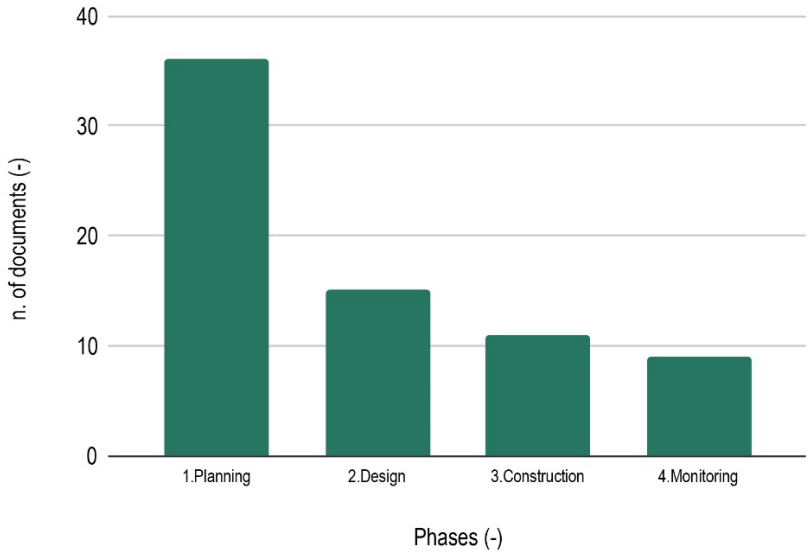


Figure 12. PED-TA phases of application.

The subsequent phases appear less frequently in the review, with 11 documents including the construction and implementation phase [85], and 9 covering the monitoring, operation, and management phase [90]. This result suggests a gap in the literature and practice, where less attention is given to how PEDs are built, operated, and managed once the planning and design are completed. Greater focus on these later phases could help to validate the whole process implementation, and to ensure the long-term success and scalability of PEDs.

4.3. In-Depth Analysis: Selected Relevant Transition Approaches (R-TAs) on PEDs

Following the comprehensive review of the transition approaches (TAs), a detailed analysis of some inspirational examples and related practical use cases, hereafter named as relevant-transition approaches (R-TAs),was conducted. Starting from the 42 analysed approaches, 7 of them [63,66,70,73,75,87,96] were considered the most responding to the research questions (RQ) and aligned with the identified key features of the roadmap. Hence, these 7 R-TAs were categorised and analysed (Table 2) according to the transition management methodology proposed by Roorda et al., 2014 [50]. It is important to clarify that their categorisation is based on the predominant approach observed; however, it does not exclude that all the identified categories, i.e., orienting, engaging and activating, were addressed or can be considered as an integral part of the overall methodology.

4.3.1. Orienting

Orienting R-TAs are decision-support tools designed to create a comprehensive vision for developing positive energy districts (PEDs). These approaches address specific local challenges by assessing the environment, stakeholder needs, and existing infrastructure. They outline a series of sequential, interconnected actions within a precise timeline, ensuring that each step builds on the previous one. This methodical planning aligns resources, streamlines efforts, and enhances the efficiency and effectiveness of PED implementation, facilitating a smoother, more coordinated transition to sustainable energy districts.

R-TA01—In the SPARCS project [102], the roadmapping approach supports the realisation of a 'bold city vision' to effectively guide urban transformation [66]. Each participating city, including Espoo, Leipzig, Kifissa, Kladno, Lviv, Maia, and Reykjavik, develops a context-specific roadmap that graphically outlines the transition pathway and identifies specific milestones divided according to key strategic areas (KSA) such as urban energy solutions, mobility, land use, green-blue infrastructure, governance, circular economy, education, and climate initiatives. Methodological steps include: (1) forming a task force in each city, (2) aligning with the 'Bold City Vision 2050', (3) involving key stakeholders, (4) allocating resources for workshops, and (5) designing city-level workshops.

The roadmap template features a structured table with KSAs analysed from the current status (left) to the city vision (right), showcasing milestones and workshop outcomes for effective implementation and progress monitoring.

R-TA02—The methodology developed within the MAKING-CITY project [103] provides a structured framework for planning and designing PEDs in urban areas [73]. It emphasises citizen participation, economic viability, technical feasibility, political support, regulatory compliance, and spatial considerations. The systematic decision-making process aims to assess city conditions and identify priorities, objectives, and solutions. The methodology unfolds in six phases: (1) analyzing city characteristics using a diagnostic approach, (2) prioritising city needs and defining PED boundaries, (3) engaging citizens through participatory approaches, (4) conducting technical studies on PED solutions and technologies, (5) calculating annual energy balances to verify surplus energy generation, and (6) compiling a detailed catalogue of proposed solutions.

R-TA03—The PED Solution Booklet [87] adopts a questioning approach to guide the establishment of PEDs within urban contexts. It addresses critical aspects such as defining district boundaries, optimising energy systems, integrating ICT applications, emphasising social considerations, exploring business models and finance mechanisms, and urban planning and design. Real use cases and applicable tools are included for each section, alongside practical advice on initiating PED projects in cities, e.g., stakeholder mapping, assessing current planning practices, creating a PED vision and roadmap, etc. The booklet also delves into strategies for upscaling and replication, underlying the importance of scalability and adaptability to diverse urban forms. It covers governance structures, legal and regulatory aspects crucial for PED implementation success, and provides guidance on navigating regulations, establishing governance frameworks, and managing energy system decentralisation.

4.3.2. Engaging

Engaging R-TAs prioritise comprehensive stakeholder participation throughout all stages of PED planning, design, implementation, and monitoring process. These approaches employ various techniques to sustain stakeholders' active involvement in order to leverage their value and expertise. By fostering a collaborative environment, these types of RTAs aim to ensure stakeholder commitment throughout the whole project lifecycle. Their continuous engagement facilitates the consideration of diverse perspectives, builds consensus, and ensures that developed solutions are robust and widely supported.

R-TA04—Cities4PED [104] introduces an innovative approach aimed at guiding municipalities and stakeholders through a coherent workflow for PEDs, while emphasising robust community participation across various phases. The report [70] focuses on achieving two main objectives: (a) firstly, understanding neighbourhood dynamics, including institutional, economic, physical, and regulatory structures, cultural elements such as shared beliefs and values, and networks involving local actors, and (b) secondly, outlining strategies to promote PED co-ownership, defined as "greater inclusion, participation and democratic control of diverse publics and communities in the energy system" [70] (p. 23). The report highlights six impactful tactics supported by practical examples: active outreach, trust building, boundary objects, problem framing through storytelling, capacity building, and governance dynamics. In conclusion, the report proposes a step-by-step approach to enhance community involvement in PED initiatives: (1) examining neighbourhood structures, cultures, and networks, (2) framing problems based on local needs, (3) assessing current levels of district co-ownership and stakeholder collaboration, and (4) implementing inclusive tactics and strategies to foster greater inclusion and participation.

R-TA05—the PED-ID project [105] proposes a knowledge-based guidance to facilitate decision-makers engagement in the early phases of PED status, while considering multiple scenarios perspectives and their long-term impacts [75]. According to the guidance, the PED project entails four essential early steps: (1) inception—identifying potential implementation areas for the PED; (2) planning—gathering comprehensive data crucial for subsequent assessments; (3) consultation—evaluating technical concepts, energy requirements, and available resources to devise transition scenarios; and finally, (4) decision—presenting key indicators to select optimal solutions. The approach is accompanied by a series of canvases and templates that progressively support the decision-making process, ensuring that PED initiatives are strategically planned from the beginning. In particular, the PED-ID project recognises stakeholder involvement as the crucial element for PEDs and therefore, it provides a practical engagement model to establish a long-term strong collaboration [106].

4.3.3. Activating

Activating R-TAs prioritise the grounding of pilot projects by identifying optimal solutions tailored to diverse intervention scenarios. These scenarios encompass multiple domains, i.e., buildings, open spaces and infrastructures, and involve a thorough analysis to determine the most effective strategies for each specific context. Activating R-TAs place particular emphasis on specific key performance indicators (KPIs) that need to align with project goals, such as energy efficiency, economic affordability, thermal comfort, multimodal mobility, etc. By focusing on these critical indicators, R-TAs ensure that pilot projects not only address immediate community needs, but also contribute to broader sustainability goals.

At the same time, these approaches incorporate iterative testing and refinement processes, enabling adjustments based on real-world feedback and performance data.

R-TA06—The purpose of the PEDRERA model [63,107,108] is to support the activation and implementation of renovation actions at the district level, according to a wider PED approach. Indeed, the PEDRERA project deals with specific objectives: (a) set and analyse a reliable prediction of potential business scenarios on large scale retrofitting actions, (b) evaluate the overall co-benefits resulting from the renovation process of a cluster of

buildings, and (c) define multiple KPIs according to stakeholder perspective and each phase of the implementation process.

The PEDRERA methodology supports data-driven and georeferenced databases (PostGresSQL + PostGis), and thanks to computational models (programmed in Python), performs interactive simulation of renovation actions based on specific local context and stakeholder interest KPIs. The tangible outcome of the PEDRERA project is the design of the PEDRERA Renovation Model that allows for simulating the co-benefits and economic outcomes of different scenarios in large-scale renovation actions.

The main KPIs adopted in the financial appraisal are: (1) monthly payments (monthly payments that each type of user should pay); (2) end-user savings (the percentage of investment an end-user can save); (3) public sector operational costs; (4) the revolving funds (the investment amount granted to the inscription user type that will be recovered when the property is transferred to a new user); (5) private parties operational costs (the operational cost assumed, considering both direct and indirect costs); (6) gross benefits and earnings before taxes (EBT), expressed as value and % of operational costs; (7) financial costs (estimated financial costs according to the loan rate and its duration); (8) financial needs (the loan capital necessary to cover operation costs); and (9) cash flow (based on the economic model's calculation of the operation-related cash flow return of investment).

R-TA07—The Decision Support Platform (DSP) by Paia and Frighi, 2022 [96] focuses on renovation strategies and proposes a methodological approach to guide effective district-scale renewal interventions. The DSP serves as a comprehensive ecosystem of data, tools, and information, leveraging a digital twin model. This approach integrates crucial elements such as buildings, infrastructures, networks, transport systems, and green areas within a specific case-study. Implemented via the digital twin, the DSP employs a balanced scorecard approach anchored to KPIs. These KPIs facilitate the measurement and simulation of alternative scenarios across intervention areas such as mobility, buildings, green spaces, and intermediate zones. By providing quantifiable metrics, the KPIs ensure the effective evaluation of scenario performance against strategic objectives. The methodology consists of six consequential steps: (1) Case Study—analyse the baseline (Input data), (2) Urban Digital Twin—build the baseline case model (input and sensor data), (3) Simulation—test and monitor different design scenarios using strategic KPIs and best practices, (4) Decision Making Collaboration Training, (5), Multi-Criteria Decision Analysis (MCDA), and (6) Guideline for Energy Transition.

Table 2. Comparison analysis among the most Relevant Transition Approaches (R-TA) on PEDs.

	Approach	Scale	Key Features *								Target Stakeholders	Phases
			SSA	R	KPI	SS	D	CB	SP	CO		
ORIENTING	R-TA01 [66,102]	City	•			•		•	•		- Public sector - Private sector - Research sector - Citizens and civil society	- Planning
	R-TA02 [73,103]	District	•				•	•	•	•	- Public sector - Private sector - Research sector - Citizens and civil society	- Planning - Design - Construction - Monitoring
	R-TA03 [87]	District	•	•	•	•	•	•	•	•	- Public sector - Private sector - Research sector - Citizens and civil society	- Planning - Design - Construction - Monitoring

Table 2. *Cont.*

	Approach	Scale	Key Features *								Target Stakeholders	Phases
			SSA	R	KPI	SS	D	CB	SP	CO		
ENGAGING	R-TA04 [70,104]	District	•					•	•	•	- Public sector - Private sector - Research sector - Citizens and civil society	- Planning
	R-TA05 [75,105,106]	District	•		•	•		•	•	•	- Public sector	- Planning
ACTIVATING	R-TA06 [63,107,108]	District	•	•	•	•	•	•	•	•	- Public sector - Private sector - Citizens and civil society	- Planning - Design - Construction
	R-TA07 [96]	District	•	•	•	•	•	•		•	- Public sector - Citizens and civil society	- Planning - Design

* Key features are abbreviated as follow: step-by-step approach (SSA); focus on renovation (R); KPI calculation (KPI); scenario simulation (SS); digitalisation (D); context-based (CB); stakeholders participation (SP); and customer oriented (CO).

5. Discussion of Results

Starting from the research questions (RQs) identified in Section 3 and building on the results of the performed analysis in Section 4, the discussion aims at: (1) depicting the main needs and features of PED relevant transition approaches (R-TA) following a questions and answer (QA) approach (Section 5.1, then summarised in Table 3) and (2) providing general recommendations and suggesting practical future steps toward designing the PED roadmap (Section 5.2).

Table 3. Resume of RQs in connection with the analysed PED-TA literature and projects.

RQs		References
RQ1	RQ1.1	[12,19,22,24,26,30,59,60,64,91,93,108–121]
	RQ1.2	[53,63–67,69,70,72–75,81,82,88,92,96–98]
RQ2	RQ2.1	[53,63,68,70–72,75,80,84,92,94–97,101,102,106,107,113,122]
	RQ2.2	[53,60,68,70–72,75,80,84,92,94–97,101,106,113,122,123]
RQ3	RQ3.1	[23,67,71,73,75,78,87]
	RQ3.2	[67,69–71,76,82,87,109,113,122]
RQ4	RQ4.1	[28,75,124]

5.1. Characteristics, Gaps and Challenges in PED-TAs

5.1.1. RQ1—Why Is a PED-TA Needed

RQ1.1 Which are the trends to be considered?

By addressing technical, economic, social, and regulatory dimensions and considering the latest trends and innovations, a PED-TA can provide a comprehensive step-by-step process that guides stakeholders through the complexities of planning sustainable and energy-efficient urban environments. According to the analysed documents, the development of PED-TAs strictly relies on the following recurring trends:

1. Adoption of user-centric and local-based strategies [12,19,59,109–113]
    - Co-Creation and Co-Design: Actively involve and empower local residents, businesses, and other stakeholders in the planning, design, and implementation processes. This ensures that the solutions developed are tailored to the specific needs and preferences of the community.
    - Public Awareness: Implement educational programs and sensibilisation campaigns to inform citizens about the benefits of PEDs, renewable energy technologies, and energy efficiency practices.

- Tailored Solutions: Adopt innovative solutions that are specifically tailored to the local climate, morphology, renewable sources availability, energy networks requirements, and socio-economic conditions.

2. Analysis on the main recurring PEDs barriers and enabling factors [22,24,26,28]
   - Technical Challenges vs. Technological Innovations: On the one hand, there is difficulty in integrating new technologies with existing infrastructure, limitations in current energy storage solutions, and inadequate grid infrastructure to support advanced technologies; on the other hand, there is development of advanced smart grid technologies, improved methods for integrating renewables and technologies such as building integrated photovoltaics (BIPV), wind turbines and towers, rainwater collection tanks, etc. [114,115].
   - Energy Balance vs. Energy Flexibility: PED tools navigate complex urban aspects beyond energy balance—although energy efficiency measures are necessary to meet energy standards and energy savings goals, the concept of energy flexibility is a key enabling factor for the diffusion of PEDs. Energy flexibility strategies and demand-side management (DSM) allow a greater load match between local renewable energy generation and energy demand on the one hand; on the other hand, flexibility approaches can balance energy flows inside and outside PEDs by providing ancillary services and demand response (DR) [30,64,116–118].
   - Social Challenges vs. Community Engagement: On the one hand, there are low levels of public awareness and understanding, resistance from local communities due to lack of engagement, and unequal distribution of benefits and opportunities; on the other hand, there is implementing educational initiatives to increase public understanding, engaging all relevant stakeholders in the planning process, and ensuring fair distribution of benefits and policies to combat green gentrification is perceived as central [57,108,110].
   - Ecodesign Frameworks vs. Environmental Challenges: On the one hand, although some projects are based on the assessment of operational emissions, eco-design frameworks inspired by the life cycle assessment (LCA) are needed to avoid shifting impacts from the operational phase of the life cycle to others; on the other hand, environmental frameworks for PEDs should integrate circular economy principles from a strategic vision perspective [93]. Such assessments should be carried out in the early stage of the project on the basis of trade-off analyses between design alternatives.
   - Disaggregated Sustainability vs. Holistic Thinking: The sectoral approach towards environmental, social, and economic sustainability limits the overall performance of the project, highlighting issues that should be addressed according to an integrated sustainability vision. Along this line, the mutual impacts of environmental vs. socio-economic sustainability measures are assessed not in successive and fragmented steps but according to a holistic perspective [30,57,91,108].

3. Promotion of legislative frameworks and financial schemes [12,22,110,111]
   - Supportive Policies and Certification Protocols: These advocate regulatory frameworks that facilitate the development and operation of PEDs according to a multi-level perspective, i.e., local, regional, national, and international [22,60,119–121], and facilitate the adoption of standards and certification schemes to ensure the quality and performance of PED technologies during the whole lifecycle.
   - Innovative Financing and Economic Incentives: Exploring financing models such as public-private partnerships, green bonds, and energy performance contracts and leveraging on economic incentives, fundings possibilities, and subsidies to support the adoption of PED technologies [19,59]. Further efforts are necessary for the quantification of the economic revenues from flexibility services as well as the definition of strategic business models and cost–benefit analysis.

RQ1.2 Which is the final scope?
PED-TA final scope can be considered three-fold:

1. Strategic Planning (Orienting) [53,64,66,67,72–74]
   - Roadmap Development: designing pathways and action plans with clear timelines, milestones, and responsible parties to guide the transition process.
   - Policy and Regulation Alignment: ensuring that the PED strategies are in line with city vision, existing policies, and regulations at local, regional, and national levels.
2. Stakeholder Participation (Engaging) [70,75,81,82,88,92]
   - Inclusive Governance: establishing governance structures that facilitate collaboration among public authorities, privates, academia, and civil society.
   - Community Engagement: actively involving local communities in the planning and implementation processes to ensure buy-in and address social implications.
3. Comprehensive Assessment and Scenario simulation (Activating) [63,65,69,96–98]
   - Technical Feasibility: analysing technical requirements and integration of renewable energy sources, smart grids, and energy storage systems.
   - Techno-Economic Analysis: detailing cost –benefit assessment to ensure financial sustainability and viable business models, solutions, and technologies.

5.1.2. RQ2—What Are the Main PED-TA Recurring Features

RQ2.1 Which are the principal contents, steps and elements to weight?

The study identifies eight critical recurring features essential for a holistic and systemic approach to PED development:

- Step-by-Step Approach [53,94]: this includes (1) evaluating the current situation through assessment and baseline analysis, (2) setting specific targets and objectives, and (3) developing a detailed process diagram, such as a roadmap, a blueprint or a flowchart, with clear actions, timelines, and responsibilities.
- Focus on Renovation [84,97]: Emphasising building retrofitting to prioritise energy deep renovations and upgrades in existing buildings is essential. Additionally, implementing energy management systems to monitor and optimise energy use in renovated buildings is crucial.
- Key Performance Indicators (KPIs) Calculation [68,92]: Defining KPIs to measure actions impact and overall district performance is necessary. Establishing mechanisms for ongoing monitoring and reporting of these KPIs helps track progress towards the established goals.
- Scenario Simulations [80,101]: Using scenario analysis and modelling tools to assess different pathways and strategies for achieving PED ambition is important. Identifying optimal scenarios based on cost-effectiveness, environmental impact, and social acceptance aids in decision-making process.
- Digitalisation [95,96]: Implementing digital platforms and tools for data collection, analysis, and integration enhances efficiency. Utilising smart technologies, such as IoT, sensors, and smart meters, allows for real-time monitoring and management of technological systems.
- Context-Based Strategies [71,72,122]: Considering climate, geography, socio-economic factors, and existing infrastructure is vital when developing local strategies. Customising solutions to fit the specific needs and conditions of the district and its stakeholders needs ensures relevance and effectiveness.
- Stakeholder Involvement [70,106,113]: Developing strategies to engage and involve diverse stakeholders, including residents, businesses, local authorities, and utilities, is crucial. Encouraging participatory planning fosters collaboration and co-creation among stakeholders, ensuring buy-in and support for PED initiatives.
- Customer Orientation [70,75]: Prioritising the needs and expectations of end-users, such as residents and businesses, in the design and implementation of PED solutions

is key. Additionally, raising awareness and educating customers about the benefits of PEDs empowers them to participate in energy-saving behaviours.

RQ2.2 Which are the main gaps?

The main emerging gaps, intended as areas that may lack detail or coverage, from analysed PED-TAs can be summarised as follows:

- Interdisciplinary Integration [70,123]: The PED-TA mentions various steps, domains, and strategies, but in general, they lack emphasis on interdisciplinarity. Ensuring collaboration between different fields of competencies (e.g., engineering, urban planning, social sciences, urban governance, etc.) is crucial for effective solutions and for taking advantage of actions' co-benefits. In this sense, it seems fundamental that PEDs are supported by an interdisciplinary teamwork, building on a strong sense of co-ownership, collaboration, and increased trust.
- Actors' perspective (Area of Interest) [63,102,107]: The identification, commitment and integration of stakeholders at the national, regional, and local level are essential steps for the development and success of PEDs, as well as to ensure that the main actors can participate and join potential transition projects. The stakeholder engagement is strictly connected to the capacity of an actor to stress his/her decision within the process, according to the specific need and its prioritisation. Therefore, each KPI sometimes reflects the potential interest in a decision to be taken in the co-creation process during the planning and design phases, where there is often disagreement, or where it is difficult to find acceptance or convergence among actors.
- Social Acceptance and Behavioural Changes [60,88,113]: While stakeholder involvement and customer orientation are mentioned, there is insufficient focus on fostering social acceptance and encouraging behavioural changes in the community. Enhancing these TAs with strategies for building trust, addressing resistance, and promoting long-term behavioural changes is crucial for a conscious and citizen-centred energy transition.
- Resilience and Adaptability [12,31,108]: In most of the approaches, there is no explicit focus on climate adaptation and resilience to unforeseen changes such as climate impacts, economic shifts, or technological advancements. PED-TAs still predominantly focus on building and energy infrastructure, a comprehensive vision that also includes outdoor spaces, and their climate-adaptive design is urgently needed.
- Data Availability [13,93,94,99]: Multiple approaches rely on a series of structured and open accessible data. Insufficient or not reliable datasets is a very common issue. It is important to combine data from various sources or public administration depts., enhance technologies for data collection and analysis, e.g., smart energy metres, the building modelling system (BMS), as well as platforms for data integration and transparency.

5.1.3. RQ3—Who Are the Key Stakeholders for a PED-TA

RQ3.1 Who should be the target user?

Some studies [67,71,73,78] emphasise that the primary target user of a PED-TA is the public sector, specifically represented by local government entities such as municipalities. Municipalities are pivotal in shaping urban development policies and strategies that incorporate energy efficiency and sustainability goals into city long-term strategic vision and infrastructure renovation. According to this primary target, the following points for a municipal-targeted PED-TA should be considered:

- Flexible Decision-Supporting Frameworks: Outlining the process of transitioning towards a PED (e.g., flowcharts, check lists, canvas, etc.). Guiding documents are fundamental to kick-off the PED implementation process [23,67] and should include best practices, case studies, and regulatory requirements, as well as a good level of usability to be adapted in the different contexts and user needs.

- Financing Options and Resource Mobilisation: Tailored to PED projects, including public–private partnerships, grants, and EU funding opportunities. This can be integrated in an action plan securing resources necessary for infrastructure and investments towards PEDs development in a medium–long-term perspective [71].
- Effective Communication Strategy: Explaining in a quite immediate and visually catchy way key vision, overall strategies, timelines, and planned actions and solutions towards PED development [75]. This communication strategy should create user-friendly materials, such as brochures, fact sheets, and infographics that explain PED concepts, its goals, and potential impact in a catchy way.
- Coordination and governance: To include the various stakeholders and their perspectives [87]. Different stakeholders have different agendas, interests, and constraints. Given the complexity, scale, and character of PEDs as urban transformation projects, local authorities have an obvious lead role in facilitating the PED process. Project initiators must facilitate and coordinate with other actors, ensuring strong support from stakeholders and solid political backing from the city.

RQ3.2 How can the local partnership towards PEDs be constituted?

Constituting a local partnership towards PEDs to involve all the relevant stakeholders along the process is fundamental [67,70,76]. This involves bringing together relevant actors to collaborate on planning, implementing, and managing complex large-scale intervention. Considering the municipality as the initiator of the PED planning process, the partnership can be structured as follows:

- Public Sector—[71,87]: Overcome silos-based municipal organisational structure by involving technicians from different sectors, allowing a broad range of competencies coverage and a wider and specific knowledge of the territory. At the same time, stakeholders beyond municipal boundaries, such as district councils, in-house municipal societies, local agencies, one-stop-shops etc., need to be involved. This collaboration ensures a holistic approach to PED development, considering long-lasting impacts and broader opportunities.
- Private Sector—[69,82]: Include real estate developers, construction companies, energy utilities, and technology providers in the team. Their expertise in building design, infrastructure development, and energy management is crucial to assure the techno-feasibility and economic-affordability of the whole intervention.
- Research Sector—[76,109]: Create continuative collaboration with universities and research centres can provide support in conducting feasibility studies and in the testing of innovative solutions. At the same time, this collaboration can open new funding opportunities for cities to secure applied research on the territory and the experimentation of pilot interventions and innovative solutions.
- Community and Civil Society—[113,122]: Actively involve local residents, community groups, and non-governmental organisations (NGOs) in the planning and implementation process. Their input can enhance project acceptance, address local concerns, and promote social equity within PEDs.

The governance structure of the PED local partnership can include the following key components: (1) a steering committee composed by the representatives from each stakeholder group to oversee the partnership and decision-making processes, (2) working groups focusing on specific aspects of PED development (e.g., energy management, building standards, and community outreach), and (3) a coordination task force to establish regular meetings, workshops, and communication channels to facilitate collaboration and information sharing among all stakeholders.

5.1.4. RQ4—When Can the PED-TA Be Applied

RQ4.1 Which are the key phases to prioritise?

In PED-TAs, as in other urban sustainability initiatives, effective implementation involves some recurring key phases: planning, design, construction, and monitoring [28,124]. However, from a municipality perspective, especially considering the innovative nature of PEDs and their potential long-term impacts on the whole urban system, the planning phase needs to be prioritised [75]. Key steps of this initial phase, i.e., planning, are the following:

- Setting a strategic vision: definition of goals and aspirations of the municipality regarding energy efficiency, renewable energy integration, carbon neutrality, ecodesign, and overall district liveability.
- Supporting capacity building among key actors: involving municipal officials, urban planners, architects, engineers, energy experts, community representatives, etc., in the planning and implementation process to ensure they can effectively contribute to the PED project's success.
- Facilitating cross-cutting cooperation within the municipality and with external stakeholders, e.g., utilities, developers, researchers, and residents, and multilevel collaboration with regional, national, and EU energy policies.

The planning phase also encompasses the need to program the other process phases: design—focuses on developing detailed plans and specifications for infrastructure, buildings and open spaces within the PED; construction—once plans are finalised, construction activities commence to implement the designed infrastructure and buildings. This phase emphasises the use of sustainable construction practices, materials, and technologies to minimise environmental impact and maximise energy performance; and monitoring—throughout the implementation and operational phases of the PED, continuous monitoring and evaluation are essential. This ensures that performance targets are met, identifies areas for improvement, risks, and provides feedback to refine future planning and design strategies.

5.2. Future Researches and Recommendation for PED-TA

The concept of PED is evolving towards a holistic approach that encompasses direct and transversal activities to prepare energy systems for climate-neutral transition. This approach emphasises the development of technologies, products, processes, infrastructure, and production systems. The focus on energy is intricately linked to integrated urban planning, governance structures, and citizen engagement, aiming to facilitate the replication and mainstreaming processes to impact urban transitions.

While the general definition of PED is under review within the PED Programme [38], it is clear that customised guidelines must be provided, with specifications and implementation occurring at local and regional levels. However, the overarching vision is common and targets climate neutrality by prioritising energy efficiency, flexibility, sustainability, and renewable generation. On this line, PEDs should be contextualised within the entire energy system, considering different angles and stakeholders' perspectives and roles.

PED projects require a matrix view, integrating thematic areas such as social, economic, legal, technological, political, and spatial dimensions with specific enablers such as markets, funding, feasibility, business models, and information transfer. This structure aids in mainstreaming actions, ensuring that project results have tangible impacts and keep strong alignment with the PED vision [125].

Effective mainstreaming of PED results involves identifying strategies to integrate project outcomes into the broader urban context of climate-neutral cities [36]. This requires dismantling silo structures in energy transition issues through clear identification of project results, stakeholder involvement, and shared communication. Achieving long-term impact necessitates positioning projects and specific deliverables to facilitate their integration into urban settings.

Given the complexity and numerous aspects involved in the development of PED-TA, designating a single stakeholder as the initiator of the process is advantageous. The review of target stakeholders indicates that the public sector, particularly local public administrations (PA), often assumes this leading role. However, the PA, as the initiator, needs to understand which stakeholders will intervene throughout the entire process of forming the PED and how to involve them.

Regarding the review of key features, the context-based approach stands out as the most recurrent aspect among those analysed. Part of the complexity in establishing a PED-TA lies in the varying characteristics that districts can exhibit in terms of urban planning, renewable resources, socio-economic factors, stakeholders, and more. Another key feature highlighted in the review is the step-by-step approach and stakeholder involvement. To facilitate the implementation of PEDs, a roadmap should provide a phased guide of actions to be developed, enabling the initiator of the PED to systematically plan the activities. Additionally, it is essential to identify the stakeholders involved in each action and define their roles.

Therefore, a roadmap can be considered an effective tool that includes common guidelines to facilitate PED promotion and ensure their replicability, while also maintaining the flexibility to adapt to the specific context of each district and the iterativeness of the process.

Taking these factors into consideration and based on the conducted analysis, the proposed structure for the roadmap is as follows: Firstly, establish a process diagram delineating the various phases for implementing a PED, incorporating barriers and drivers specific to each phase. While common barriers and drivers can be identified, attention should also be devoted to location-specific and district-based aspects. Subsequently, define the primary categories of actions, ranging from goal definition to monitoring and evaluation, encompassing communication and digitalisation. These action categories may manifest across phases through more specific actions, such as establishing KPIs or assessing renewable energy integration and flexibility potential. These actions should encompass a comprehensive system, addressing socio-economic benefits, social engagement, environmental sustainability, integrated governance, digitalisation, and technological innovations. However, delineating these phases and actions constitutes only a part of the process. Moreover, it should be explicitly stated whether the nature of these actions involving stakeholders is informative, consultative, collaborative, or co-creative. Figure 13 provides a summary of the key categories to be included in the PED roadmaps.

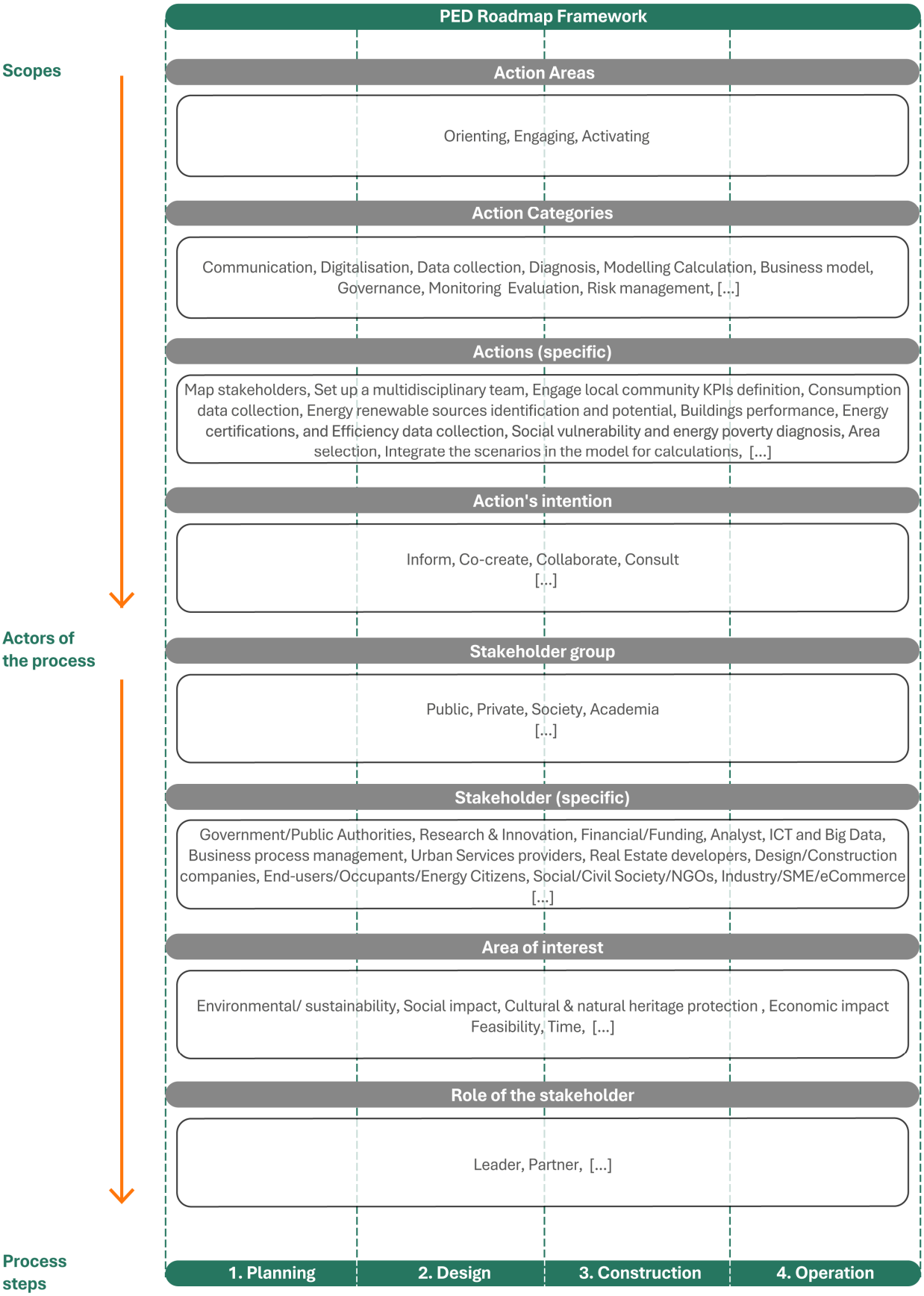


Figure 13. PED roadmap tentative categories.

6. Conclusions

The development of the PED roadmap, guided by the CA 'PED-EU-NET' Memorandum of Understanding, aims to contribute to the following overarching objectives: (1) share progress in PED research across diverse stakeholders, such as academia, cities, and communities, and across various domains, including technological, social, economic, financial, legal, and regulatory sectors; (2) develop tools that optimise the PEDs planning and design; and (3) support activities and develop operational tools that bridge the gap between science, policy makers, and society by aligning the interests and needs of multiple stakeholders.

The literature review provided a comprehensive overview of the PED-Tas, including roadmaps, pathways, and guidelines towards PED/PED similar experience development.

In addition, the literature review and the results emerging from the QA analysis offer new impetus to the work developed so far in the CA PED Database, reiterating its strategic role for the mapping, implementation, storytelling, and mainstream of PEDs. Indeed, much of the information collected in Table 1 and Figure 13 is the result of what was in depth-analysed in the literature review; nevertheless, this information is already available and can be easily extracted from the case studies collected in the PED Database 'https://pedeu.net/map/ (accessed on 20 June 2024)'. In fact, the PED Database serves dual purposes: it enhances ongoing dialogue on positive energy districts by providing comprehensive and reliable data and insights, but also supports the decision-making process. This information empowers stakeholders to make informed decisions based on a deep understanding of the complexities and opportunities within PED experiences. In doing so, the database promotes collaboration among diverse stakeholders, facilitating synergies and collective action towards shared sustainability goals. Therefore, the literature review validates the progress made by the CA WG1 group and provides valuable insights for the future development of a practical tool to support the widespread implementation of PEDs.

As discussed, PED planning is a complex topic and this complexity translates into the need for a holistic, integrated, and comprehensive analysis and design framework both in terms of thematic areas, i.e., social sustainability, environmental compatibility and economic profitability, governance, and technological-energy innovation on one side, and sectoral policies on the other, i.e., sectors coupling between energy networks or building typologies, standardisation, and certification processes, interaction between cities, public bodies, private stakeholders, and academia, tackling affordability of housing and energy poverty along with improving energy efficient behaviours, etc. However, research on the topic is still limited and fragmented thinking limits the potential of PEDs. Based on these research needs, and as conceived in this study, a roadmap can boost the diffusion of PEDs and their replicability, guiding the plurality of stakeholders step by step according to a systematic and collaborative approach.

The collaborative vision from a living-lab perspective should focus on users' needs, a user-oriented approach, so that sustainability goals can be achieved in the long term; and the roadmap should have the flexibility to adapt to different contexts while maintaining the systematic approach.

The planning phase should be prioritised, as it significantly impacts the sustainability of PEDs in the long horizon. In this phase, a life cycle perspective for sustainability can guide design choices more effectively as well as tailored-made business models and financing schemes. Furthermore, the energy flexibility potential of the district should be studied in detail through trade-off analyses in the early stage phase, as it can significantly contribute to the mitigation of impacts.

In this transition path, the energy aspect is crucial to identifying the transformation strategy to be implemented, but it is the new way of conceiving the implementation process in a circular and incremental manner that is still inefficient (programming, planning, design, construction, management/use, and reuse/disposal). Therefore, the application of the circularity concept also to the transformation process means that the process is both iterative (circular somehow) and incremental in achieving all the PEDs objectives and over

time. Although not universally applicable, the roadmapping activity, deriving from the analysis of the transition approaches, suggests a structure tailored to the circumstances and dynamics emerging along the certain process in the specific local context.

A wide list of actions and stakeholders engagement along the process can support each iterative process; however, data availability and capacity building can be considered the main challenging gaps that public administrations have to plan to ensure that social and economic feasibility are ensured along the transition process.

Future studies will focus on developing practical approaches designed as a circular sequential path or workflow to facilitate the implementation of PEDs. This tool will include specific guidelines for each phase of the PED process, with particular emphasis on the planning phase. Key priorities include: (1) adopting a user-centric approach, considering the intended users of the roadmap and their roles in each phase of the implementation process; (2) defining actions (accordingly to orienting, engaging, and activating scopes) and their sequential execution for PED implementation; (3) involving the entire 'PED community' in the implementation process; (4) customising the roadmap considering the intervention context, such as whether it involves new construction or renovation, and the regional differences (e.g., northern countries versus Mediterranean areas); and (5) incorporating a multi-layered system that integrates buildings, environment, people, and other relevant components.

In the short term, the PED roadmap could serve as a robust tool to assist municipalities and private investors in planning and designing PED implementations in urban areas. Looking ahead, in the mid-long term, the PED roadmap could potentially be integrated into cities' planning instruments to facilitate their transition towards climate neutrality targets.

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Nomenclature

BIPV	Building Integrated Photovoltaics
BMS	Building Modeling System
CA	Cost Action
EPBD	Energy Performance in Buildings Directive
DR	Demand Response
DSM	Demand Side Management
DSP	Decision Supporting Platform
DUT	Driving Urban Transition
EBF	Earnings Before Taxes
EU	European

FP	Framework Programme
IEA EBC	International Energy Agency Energy in Buildings and Communities
IoT	Internet of Things
IT	Information Technology
KPI	Key Performance Indicator
LCA	Life Cycle Assessment
MaaS	Mobility as a Service
MMSA	MultiModal System Analysis
MoU	Memorandum of Understanding
NGO	Non-Governmental Organisation
PCED	Positive Clean Energy District
PED	Positive Energy District
PED-EU-NET	Positive Energy Districts European Network
PED-TA	Positive Energy District Transition Approach
RQ	Research Question
R-TA	Relevant-Transition Approach
R&I	Research and Innovation
SET	Strategic Energy Technology
ToC	Theory of Change
WG	Working Group

Appendix A. List of Reviewed PED Projects

N.	Acronym	Full Title	Funding (Programme and Call)	Duration (from–to)	Website (accessed on 20 June 2024)	PED-TA*
01	CityxChange	Positive City ExChange	Horizon 2020 LC-SC3-2018-ES-SCC	2018–2023	https://cityxchange.eu/	[Y]
02	MAKING-CITY	Energy efficient pathway for the city transformation: enabling a positive future	Horizon 2020 LC-SC3-2018-ES-SCC	2018–2024	https://makingcity.eu/	[Y]
03	POCITYF	A POsitive Energy CITY Transformation Framework	Horizon 2020 LC-SC3-2019-ES-SCC	2019–2024	https://pocityf.eu/	[N]
04	ATELIER	AmsTErdam BiLbao cItizen drivEn smaRt cities	Horizon 2020 LC-SC3-2019-ES-SCC	2019–2024	https://smartcity-atelier.eu/	[Y]
05	SPARCs	Sustainable energy Positive and zero cARbon CommunitieS	Horizon 2020 LC-SC3-2019-ES-SCC	2019–2024	https://sparcs.info/en/	[Y]
06	RESPONSE	integRatEd Solutions for POsitive eNergy and reSilient CitiEs	Horizon 2020 LC-SC3-2020-EC-ES-SCC	2020–2025	https://h2020response.eu/	[Y]
07	TECNIOspring PLUS	ACCIÓ programme to foster mobility of researchers with a focus in applied research and technology transfer	Horizon 2020 MSCA-COFUND-2015	2016–2022	https://catalonia.com/services-for-investors	[Y]
08	syn.ikia	Sustainable Plus Energy Neighbourhoods	Horizon 2020 NMBP-EEB-2019	2020–2024	https://www.synikia.eu/	[Y]
09	Smart-BEEjS	Human-Centric Energy Districts: Smart Value Generation by Building Efficiency and Energy Justice for Sustainable Living	Horizon 2020 MSCA-ITN-2018	2020–2023	https://smart-beejs.eu/	[Y]
10	ARV	Climate Positive Circular Communities	Horizon 2020 LC-GD-2020-7	2022–2025	https://greendeal-arv.eu/	[Y]
11	oPEN Lab	Open innovation living labs for Positive Energy Neighbourhoods	Horizon 2020 LC-GD-2020-7	2021–2026	https://openlab-project.eu/	[Y]
12	PROBONO	The Integrator-centric approach for realising innovative energy efficient buildings in connected sustainable green neighbourhoods	Horizon 2020 LC-GD-2020-7	2022–2026	https://www.probonoh2020.eu/	[Y]

N.	Acronym	Full Title	Funding (Programme and Call)	Duration (from–to)	Website (accessed on 20 June 2024)	PED-TA*
13	CRAFT	Creating Actionable Futures	Horizon Europe MISS-2021-CIT-01	2022–2025	https://craft-cities.eu/	[Y]
14	CapaCITIES	Building Capacities for the Climate Neutral and Smart Cities Mission	Horizon Europe MISS-2021-CIT-01	2022–2024	https://dutpartnership.eu/capacities/	[A]
15	ASCEND	Accelerate poSitive Clean ENergy Districts	Horizon Europe MISS-2021-CIT-02	2023–2027	https://www.ascend-project.eu/	[A]
16	NEUTRALPATH	Pathway towards Climate-Neutrality through low risky and fully replicable Positive Clean Energy Districts	Horizon Europe MISS-2021-CIT-02	2023–2027	https://www.ascend-project.eu/	[A]
17	BIPED	Building Intelligent Positive Energy Districts	Horizon Europe MISS-2023-CIT-01	2024–2026	https://www.bi-ped.eu/	[A]
18	ExPEDite	Enabling Positive Energy Districts through a Planning and Management Digital Twin	Horizon Europe MISS-2023-CIT-01	2024–2026	https://expedite-project.eu/	[A]
19	TIPS4PED	Turning cIties Planning actionS for Positive Energy Districts into success	Horizon Europe MISS-2023-CIT-01	2024–2027	/	[A]
20	InterPED	INTERoperable cloud-based solution for cross-vector planning and management of Positive Energy Districts	Horizon Europe CL5-2023-D4-01	2024–2026	/	[N]
21	PEDvolution	Interoperable solutions to streamline PED evolution and cross-sectoral integration	Horizon Europe CL5-2023-D4-01	2024–2026	/	[A]
22	TRANS-PED	Transforming Cities through Positive Energy Districts	JPI Urban Europe Pilot Call I	2021–2022	https://trans-ped.eu/	[Y]
23	Cities4PEDs	Research, Exchange and Collaboration on City Levels to Enable PEDs across Diverging Contexts	JPI Urban Europe Pilot Call I	2021–2022	https://energy-cities.eu/project/cities4peds/	[Y]
24	INTERACT	Integration of Innovative Technologies of Positive Energy Districts into a Holistic Architecture	JPI Urban Europe Pilot Call I	2021–2022	https://www.ped-interact.eu/	[Y]
25	PED-ID	Holistic assessment and innovative stakeholder involvement process for identification of Positive-Energy-Districts	JPI Urban Europe Pilot Call I	2021–2022	https://jpi-urbaneurope.eu/project/ped-id/	[Y]
26	Citizen4PED	Citizen inclusive PEDs in existing urban areas: diversification, standardisation and reflexive replication	JPI Urban Europe PED for Climate Neutrality	2022–2025	https://citizens4ped.eu/index.php/about/	[A]
27	DigitalTwin4PEDs	Dialogue and Quality Assurance Support for PEDs by Digital Twin District Energy Models	JPI Urban Europe PED for Climate Neutrality	2022–2025	/	[A]
28	FLEXPOSTS	FLEXible energy POSitivity districTS	JPI Urban Europe PED for Climate Neutrality	2022–2025	/	[A]
29	KINETIC	Knowledge Integration for Neighbourhoods in Energy Transition led by Inclusive Communities	JPI Urban Europe PED for Climate Neutrality	2022–2025	https://kinetic-project.eu/	[A]

N.	Acronym	Full Title	Funding (Programme and Call)	Duration (from–to)	Website (accessed on 20 June 2024)	PED-TA*
30	PED-ACT	Auto characterisation of PEDs for digital references towards iterative process optimisation	JPI Urban Europe PED for Climate Neutrality	2022–2025	https://ped-act.com/	[A]
31	PED4ALL	Positive Energy Districts for All: Energising Neighbourhoods through Fair Strategies	JPI Urban Europe PED for Climate Neutrality	2022–2025	https://ped4all.eu/	[A]
32	PROPEL	Development of innovative PEDs in systems of city-district systems—a transnational comparative study	JPI Urban Europe PED for Climate Neutrality	2022–2025	/	[A]
33	SIMPLY POSITIVE	Supporting innovative and ambitious cities and municipalities on their pathway to Positive Energy Districts	JPI Urban Europe PED for Climate Neutrality	2023–2024	http://simplypositive.eu/	[A]
34	CO2PED	Collective Agency and Co-evolution towards Inclusive Energy Transitions	DUT—PED Call Theme: Energy Community and Energy Efficiency in existing urban structures	2024–2026	/	[A]
35	COPPER	Creating, Optimising, and Planning Positive EneRgy Districts: Connecting Citizens' Energy at Different Geographical Levels	DUT—PED Call Theme: Energy Community and Energy flexibility strategies	2024–2026	/	[A]
36	ENERGY4ALL	Energy as a Common Pool Resource	DUT—PED Call Theme: Energy Community	2024–2026	/	[A]
37	HeatCOOP	Residents-Owned Heat Cooperatives to Push Urban Decarbonisation	DUT—PED Call Theme: Energy Community	2023–2026	/	[A]
38	Making PEDs	Decision-Making Digital Twins for Climate Neutral PEDs	DUT—PED Call Theme: Energy Community and Energy Efficiency in existing urban structures	2023–2026	/	[A]
39	OPEN4CEC	Service-Oriented Open Platform for Citizen Energy Communities (CEC)—A Collaborative Platform	DUT—PED Call Theme: Energy Community and Energy Flexibility strategies	2023–2026	https://open4cec.ase.ro/	[A]
40	PERSIST	Positive EneRgy diStrIctS driven by ciTizens	DUT—PED Call Theme: Energy Community Energy Flexibility strategies and Energy Efficiency	2023–2026	/	[A]
41	V2G-QUESTS	Vehicle to Grid for Equitable Zero-Emission Transitions in Positive Energy Districts	DUT—PED Call Theme: Energy Community and Energy Flexibility Strategies	2023–2026	https://v2g-quests.eu/	[A]
42	DigiTwins4PEDs	Utilisation of Urban Digital Twins to Co-create Flexible Positive Energy Systems for Districts	DUT—PED Call Theme: Energy Flexibility Strategies	2024–2026	https://digitwins4peds.eu/	[A]

N.	Acronym	Full Title	Funding (Programme and Call)	Duration (from–to)	Website (accessed on 20 June 2024)	PED-TA*
43	FLEdge	A Novel Hierarchical EdgeBased Flexibility Management Ecosystem at Both Building and City Level	DUT—PED Call Theme: Energy Flexibility Strategies	2024–2026	/	[A]
44	JUST PEPP	Just Positive Energy Planning Processes in Disadvantaged Urban Areas	DUT—PED Call Theme: Energy Flexibility strategies and Efficiency in Existing Urban Structures	2024–2026	/	[A]
45	PED StepWise	Participatory Step-by-Step Implementation Process for Zero Carbon District Concepts in Existing Neighbourhoods	DUT—PED Call Theme: Energy Efficiency in Existing Urban Structures	2024–2027	/	[A]
46	POSEIDON	POSitive Energy Initiatives in Districts fOr Neutral mediterranean cities	DUT—PED Call Theme: Energy Efficiency in Existing Urban Structures	2023–2026	/	[A]

* [Y] PED-TA is available; [N] PEDs-TA is NOT foreseen; [A] PED-TA is NOT yet available, but planned to be developed during the project.

Appendix B. List of Analysed Literature

Document	Reference	Scale	EU Funded	Categorisation	
				Need for PED-TAs	PED-TAs
Literature search (Scopus and Google Scholar databases)					
Ahlers et al., 2023 °	[67]	district	Yes		•
Akhatova et al., 2020 °	[72]	district	Yes		•
Alpagut et al., 2019 °	[73]	district	Yes		•
Aparisi-Cerdà et al., 2022	[77]	district	No		•
Becchio et al., 2021	[84]	district	No		•
Borsboom et al., 2021	[122]	city	Yes	•	
Borsboom et al., 2023	[23]	city	Yes	•	
Bossi et al., 2020	[19]	district	No	•	
Brozovsky et al., 2021	[56]	district	Yes	•	
Bruckner et al., 2022	[85]	district	Yes		•
Castillo-Calzadilla et al., 2023	[13]	district	Yes		•
Civiero et al., 2021	[63]	district	Yes		•
Civiero et al., 2024	[28]	district	Yes	•	
Clemente et al., 2019	[124]	district	No	•	
Clerici Maestosi et al., 2021	[109]	district	Yes	•	
Clerici Maestosi et al., 2024	[59]	district	Yes	•	
Derkenbaeva et al., 2022a	[111]	district	Yes	•	
Ferrante et al., 2023	[76]	district	No		•
Gohari et al., 2022	[19]	district	Yes	•	
Gohari et al., 2024	[29]	district	Yes	•	
Hajduk et al., 2022 °	[113]	district	Yes		•
Han et al., 2024	[83]	district	Yes		•
Hearn et al., 2021	[110]	district	Yes	•	
Jradi et al., 2023	[80]	district	Yes		•

Document	Reference	Scale	EU Funded	Categorisation	
				Need for PED-TAs	PED-TAs
Kalms et al., 2023 °	[81]	district	Yes		•
Koutra, 2022	[12]	district	No	•	
Koutra et al., 2023	[2]	district	No	•	
Leone et al., 2023	[65]	city	No		•
Lindholm et al., 2021	[62]	district	No	•	
Manni et al., 2023	[95]	district	Yes		•
Marotta et al., 2021	[57]	district	No	•	
Natanian et al., 2024	[30]	district	Yes	•	
Neumann et al., 2022	[123]	district	Yes	•	
Piaia and Frighi, 2022	[96]	district	No		•
Sareen et al., 2022	[24]	district	Yes	•	
Sassenou et al., 2024a	[31]	district	No	•	
Sassenou et al., 2024b	[108]	district	No	•	•
Shamsi et al., 2023	[86]	district	Yes		•
Soutullo et al., 2020	[3]	district	Yes	•	
Trevisan et al., 2023	[120]	district	No	•	
Vandevyvere et al., 2022	[61]	district	Yes	•	
Zapata et al., 2024	[82]	district	Yes		•
Zhang et al., 2023	[27]	district	Yes	•	
Project search (Cordis database, JPI UE calls, DUT partnership)					
Ahlers et al., 2020	[87]	district	Yes		•
Bylund et al., 2022	[33]	city	Yes	•	
Cities4PEDs project, 2022	[70]	district	Yes		•
DUT Catalogue, 2024	[125]	city	Yes	•	
Garcia et al., 2021	[71]	city	Yes		•
Garcia Melo et al., 2023	[93]	district	Yes		•
Karásek et al., 2022	[75]	district	Yes		•
Kriikkula et al., 2022	[79]	district	Yes		•
Magnusson and Rohracher, 2022	[69]	district	Yes		•
Rouchette et al., 2022	[78]	district	Yes		•
SPARCS project, 2023	[66]	city	Yes		•
Stryi-Hipp and Steingrube, 2023	[94]	district	Yes		•
Trulsrud et al., 2023	[64]	district	Yes		•
Wiik et al., 2022	[68]	district	No		•
Wyckmans and Laschet, 2024	[92]	city	Yes		•
Further interrelated studies and projects					
Berzolla et al., 2023	[101]	city	No		•
Botzler et al., 2021	[97]	buildings block	Yes		•
Borsboom et al., 2023	[23]	city	Yes		•
Boulanger et al., 2021a	[60]	district	Yes	•	
Boulanger et al., 2021b	[88]	district	Yes		•
Civiero et al., 2020	[74]	city	No		•
Criado et al., 2019	[98]	district	Yes		•

Document	Reference	Scale	EU Funded	Categorisation	
				Need for PED-TAs	PED-TAs
Cutore et al., 2024	[53]	buildings block	No		•
De Santi et al., 2022	[118]	buildings block	Yes	•	
Di Silvestre et al., 2021	[116]	buildings block	Yes	•	
Elomari et al., 2024	[91]	buildings block	No		•
Esposito et al., 2024	[90]	buildings block	No		•
EUCityCalc, 2023	[99]	city	Yes		•
Fina and Fechner, 2021	[121]	buildings block	Yes	•	
Ghiani et al., 2022	[89]	city	No		•
Krug et al., 2023	[117]	buildings block	Yes	•	
Liu and Zoh et al., 2024	[100]	City	No		•
Magyari et al., 2022	[25]	district	Yes	•	
Noh et al., 2024	[119]	buildings block	No	•	

° identifies documents emerged both form the literature and the projects searches.

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