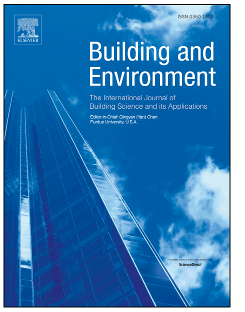
Journal Pre-proof



Methodologies for the design of Positive Energy Districts: A scoping literature review and a proposal for a new approach (PlanPED)

Louise-Nour Sassenou, Francesca Olivieri, Paolo Civiero, Lorenzo Olivieri

PII: S0360-1323(24)00509-2

DOI: https://doi.org/10.1016/j.buildenv.2024.111667

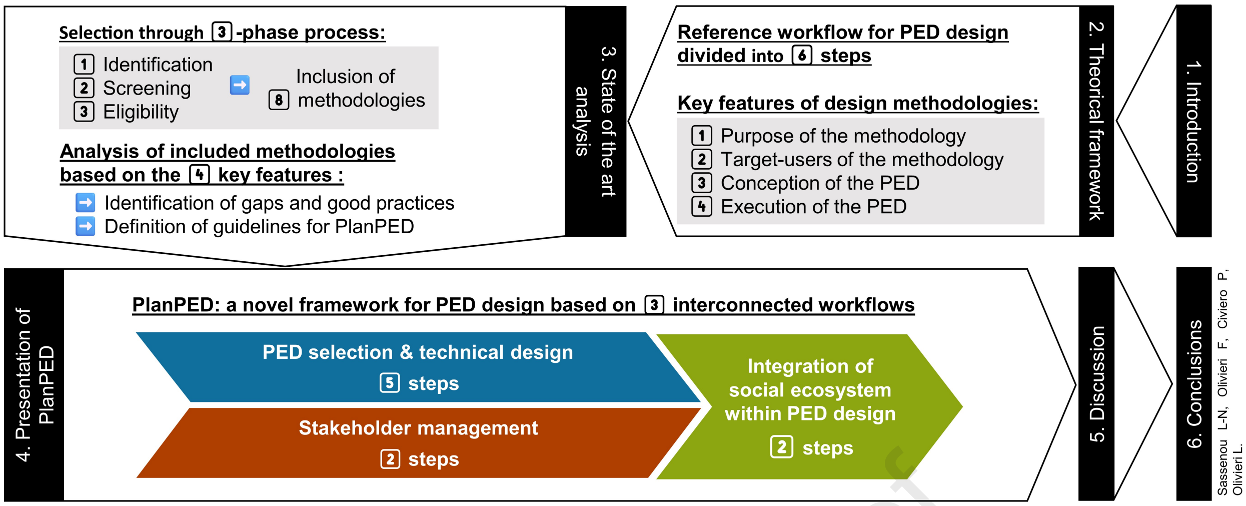
Reference: BAE 111667

To appear in: *Building and Environment*

Received Date: 30 October 2023

Revised Date: 30 April 2024

Accepted Date: 21 May 2024


Selection through 3 -phase process:
1 Identification
2 Screening
3 Eligibility
Inclusion of 8 methodologies
Analysis of included methodologies based on the 4 key features :
Identification of gaps and good practices
Definition of guidelines for PlanPED
3. State of the art analysis
Reference workflow for PED design divided into 6 steps
Key features of design methodologies:
1 Purpose of the methodology
2 Target-users of the methodology
3 Conception of the PED
4 Execution of the PED
2. Theorical framework
1. Introduction
4. Presentation of PlanPED
PlanPED: a novel framework for PED design based on 3 interconnected workflows
PED selection & technical design
5 steps
Stakeholder management
2 steps
Integration of social ecosystem within PED design
2 steps
5. Discussion
6. Conclusions
Sassenou L-N, Olivieri F, Civiero P, Olivieri L.

Title: Methodologies for the design of Positive Energy Districts: A scoping literature review and a proposal for a new approach (PlanPED)

Authors names and affiliations:

Louise-Nour Sassenou - Corresponding author

Department of Construction and Technology in Architecture, Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid, Av. de Juan de Herrera 4, 28040 Madrid, Spain.

Instituto de Energía Solar, Universidad Politécnica de Madrid, Av. Complutense 30, 28040 Madrid, Spain.

Phone: +34622820698 - E-mail address: l.sassenou@upm.es

Francesca Olivieri

Department of Construction and Technology in Architecture, Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid, Av. de Juan de Herrera 4, 28040 Madrid, Spain.

Phone: +34910674890 - E-mail address: francesca.olivieri@upm.es

Paolo Civiero

Department of Architecture, Roma Tre University, Largo Giovan Battista Marzi 10, 00153 Rome, Italy.

Phone: +390657339710 - E-mail address: paolo.civiero@uniroma3.it

Lorenzo Olivieri

Department of Construction and Technology in Architecture, Escuela Técnica Superior de Arquitectura, Universidad Politécnica de Madrid, Av. de Juan de Herrera 4, 28040 Madrid, Spain.

Instituto de Energía Solar, Universidad Politécnica de Madrid, Av. Complutense 30, 28040 Madrid, Spain.

E-mail address: lorenzo.olivieri@upm.es

Abstract

Cities can substantially contribute to European Green Deal targets by accelerating their transition towards smarter, more efficient, and renewable-based energy models. In that context, European cities need to increase their self-sufficiency and the resilience of their energy system especially through the promotion of district and neighbourhood scale energy projects such as positive energy districts (PEDs). Despite the increasing interest for PEDs experienced in the last years, their deployment is currently hindered by the absence of an energy planning culture and the lack of adequately skilled personnel in cities. Indeed, there is a strong need for practical tools and guidelines that support practitioners in the design and implementation of PEDs. In that context, the present paper introduces PlanPED, a framework for the conception of methodologies for PED planning, design, and implementation, to support municipalities in their energy transition. PlanPED aims at providing a multiple perspective approach based on the most important elements from existing methodologies. In that sense, the paper begins with an overview of the state of the art, leading to the identification of trends, gaps, and good practices of current research. Then, based on this analysis, the novel framework PlanPED is introduced. It consists of three interconnected workflows that, if followed, enables to know which steps and resources need to be put in practice to initiate the transition towards PED, while recognizing the variability of contexts and necessities. By doing so, PlanPED seeks to facilitate the elaboration of tailored and practical roadmaps for the deployment of PEDs in cities.

Keywords: Cities Mission; Design methodology; European green deal; Integrated energy planning; Positive energy district; Urban energy transition.

Nomenclature

EB	energy balance
EBC	Energy in Buildings and Communities
EcoP	economic performance
EnerP	energy performance
EnviP	environmental performance
EU	European Union
GIS	geographic information system
GHG	greenhouse gases
HUB	historic urban block
IEA	International Energy Agency
ID	identification
IPCC	Intergovernmental Panel on Climate Change
KPI	key performance indicator
MCDM	multi-criteria decision-making
PEBlock	positive energy block
PED	positive energy district
PRL	positive energy district readiness level
RES	renewable energy sources
SPEN	sustainable plus energy neighbourhood
SPQ	social performance and quality of life
UESM	urban energy system model
UBEM	urban building energy model
UWF	urban water front
ZED	zero energy districts

1. Introduction

While occupying less than 2% of the Earth's surface, cities produce more than 60% of global greenhouse gases (GHG) emissions -including CO2 and CH4- [1]. On its path to reach climate neutrality by 2050, Europe Union (EU) is acknowledging this pivotal role through initiatives, such as the EU mission “Climate-Neutral and Smart Cities”, also called “Cities Mission” [2]. The Cities Mission is the Horizon Europe research and innovation programme for the years 2021-2027 that focuses on the green and digital transformation of cities [3]. To do so, a two-step process has been defined: first to achieve 100 climate-neutral cities by 2030, then to ensure that these cities act as experimentation fields to enable all European cities to follow suit by 2050 [4]. As outlined by Ulpiani et al. [5], cities can substantially contribute to EU climate targets by accelerating their transition towards smarter, more efficient, and renewable-based energy models. In that context, European cities need to increase their self-sufficiency and increase the resilience of their energy system through the promotion of initiatives, such as district and neighbourhood scale energy projects [6–8].

Among the different concepts existing to refer to local-level energy transition in cities, positive energy district (PED) currently constitutes a reference terminology within EU policies and programs. PEDs are defined as energy efficient urban areas that achieve a positive energy balance on an annual basis and net zero GHG emissions [9–11]. By addressing the challenge of the energy transition from a local basis, they enable to find tailored solutions that boost advances in terms of energy efficiency, energy security, energy production, and flexibility [12]. Therefore, PEDs have gained increased attention in the academic literature [13,14] and policies strategies [9,15]. However, the interest for PEDs is hardly going beyond the conceptual level as there is still a reduced number of case studies and practical experiences [16–18].

According to the reference framework on PEDs, one clear barrier to their effective deployment in Europe is the lack of an energy planning culture and of specially qualified staff resources in cities [9]. Therefore, to bridge that gap between theory and practice, there is a strong need for practical tools and guidelines that support practitioners in the design and implementation of PEDs [10,13]. The development of those instruments is not an easy and linear task as the transformation of a district implies creating pathways for transition over time, which depends on several general and contextual factors that vary across cities [9]. Therefore, there is no one-fits-all strategy regarding the design and implementation of PEDs [19,20]. On the opposite, PED is a flexible concept destinated to evolve and be adapted to local necessities and limitations [14].

The present paper aims to contribute to address those multiple challenges, by introducing PlanPED, a supportive framework for the conception of methodologies for PED planning, design, and implementation. PlanPED constitutes one of the outcomes of several synergic projects dedicated to the development of instruments that fosters the conversion of existing districts into PEDs, by combining solutions that address energy, environmental and social aspects of district sustainability. In that sense, PlanPED proposes an approach based on three interconnected workflows that, if followed, enables to know which steps and resources need to be put in practice to initiate the transition towards PED, while recognizing the variability of contexts and necessities.

The remainder of the paper is organized as follow. First, section 2 introduces the theorical framework of methodologies for PED design. Then, section 3 gives an overview of existing methodologies and exposes their main features and limitations. The framework PlanPED is introduced in section 4 and discussed in section 5. Finally, conclusions are drawn in section 6. This structure of the work is presented on figure 1.

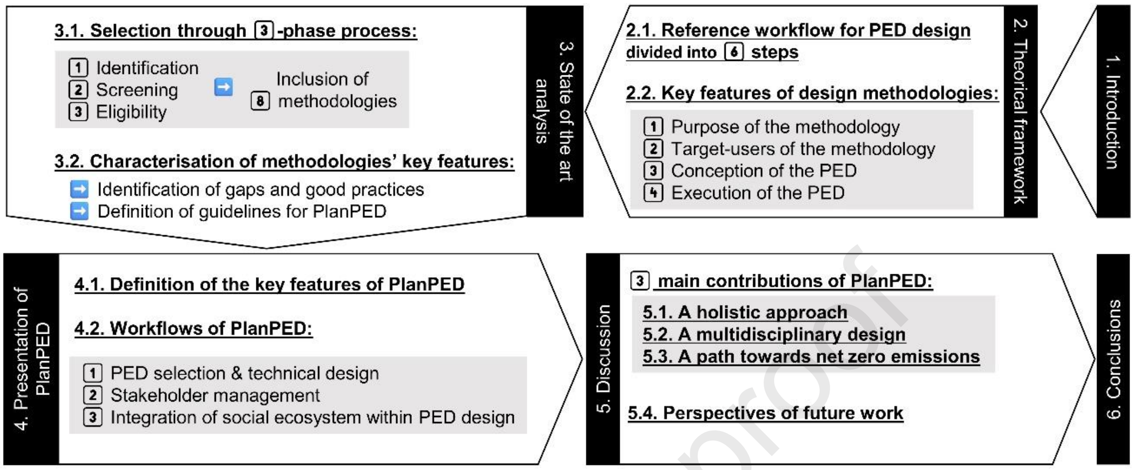


Figure 1: Structure of the paper.

2. Theorical framework

2.1. Reference workflow

Most of available methodologies for PED design follow a similar reference workflow divided into six steps and shown on figure 2. It begins with the identification of the areas of the city that are the most suitable for PEDs implementation and the selection of the district to be transformed (step 1). Once the district is selected, its baseline analysis is executed based on the collection of data that enable to characterise the initial state of the district, such as the urban form (e.g., built density, land use, buildings typologies [21]) and bioclimatic conditions (step 2). It leads to the identification and quantification of district's potentials and needs (step 3). Then, solutions that address those needs and potentials are selected and combined to form different PED designs (step 4). The resulting scenarios are modelled, simulated, and assessed (step 5). Finally, the analysis of the simulations outputs enables to select a PED design amongst the other and conceive an action plan that enable to implement it (step 6). It is worth noting that not all methodologies include the full workflow. On the contrary, the steps included, and the importance given to each of them vary depending on the purpose of the methodology. In that sense, the outlined workflow is considered a suggestion for a complete conversion of districts into PEDs.

Figure 2: Reference workflow of methodology for PED design, compiled by authors based on [14] and literature review.

2.2. Key features

The key features are defined as elements that the developers should acknowledge when elaborating the different steps of a methodology for PED design. A study of literature dedicated to energy urban planning [14,22–24] led to the identification of four main key features. The first feature is the purpose that the methodology aims to achieve, which includes both the characteristics of the district to be transformed and the specific objectives to be reached mainly in term of energy balance and GHG emissions. The second feature is related to the users of the methodology, that from now will be named the "target-users". The definition of the target-users encompasses the characteristics (e.g., interests, expertise, capacities, level of influence and impact) that must be considered to ensure that the methodology meets the needs of the practitioners and acknowledges PEDs complexity. The third feature is the conception of the PED, which encompasses the type of solutions that will be included and the way they will be combined within the PED design. The last feature is the execution of the PED which constitutes the bridge between theorical design and effective implementation, and hence comprises the measures that will ensure that the methodology will have a real impact.

3. State of the art analysis

The objective of the present section is to analysis the state of the art of methodologies for PED design. To that end, it begins with the selection of a set of existing methodologies. Then, these methodologies are studied thoroughly to determine how they currently incorporate the key features introduced in section 2. As a result, this analysis enables to identify and characterize the most important and available elements for PEDs design that will be then included within PlanPED.

3.1. Selection of design methodologies

The selection of papers has been done following the approach in three phases presented on figure 3. The search was undertaken using Scopus, the largest electronic database of peer-reviewed literature [25]. It is worth noting that the number of search results doesn't solely rely on the characteristics of the database; it also significantly dependent on the search terms and question formulation. PED is still an innovative concept under development, and, because of the reduced case studies and practical experiences [16–18], there are still very few design methodologies applied so far. Therefore, it has been considered relevant to nourish the present literature selection with other search terms related to energy transition at district scale. To take in account these different concepts, the following search phrase was created: (plus OR positive OR zero PRE/2 energy) PRE/2 (district OR neighbourhood OR block). In that sense, the articles analysed in this section also includes methodologies for the design of other similar concepts such as sustainable plus energy neighbourhood (SPEN) [26], positive energy blocks (PEBlocks) [27,28], zero-carbon energy district [29] or zero energy districts (ZED) [30].

The search was conducted in June 2023 within the search fields *Article Title, Abstract and Keywords* and using the filters *Articles and Chapters* and *Peer-reviewed*. Then, the inclusion criteria were applied. The inclusion criteria, outlined on figure 3 within the Screening and Eligibility phases, have been carefully selected following recommendations of existing methodologies for literature reviews [10,13,31,32]. They ensure the quality, accessibility, and relevance of the literature selection.

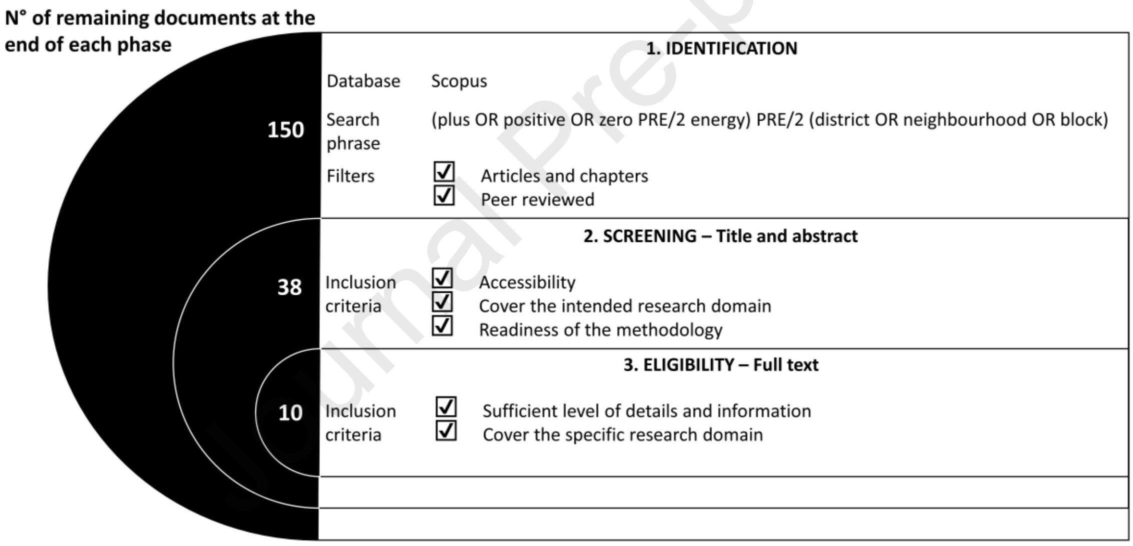


Figure 3: Flow diagram showing the number of documents identified, screened, assessed for eligibility, and included in the paper selection, compiled by authors based on [10].

The first phase enabled to identify 150 peer-reviewed articles. In the second and third phases, elements that do not fit into the scope of the review or that do not meet the inclusion criteria were removed. On the one hand, the screening, based on the analysis of papers' title and abstract, excluded 112 elements, leaving a total of 38 sources. On the other hand, in the eligibility phase, based on the study of full papers, 29 elements were removed. The 10 remained documents, gathering 8 different methodologies, were included in this analysis. The main aspects of the selected methodologies are presented in table 1.

ID Name*	**Concept & Purpose**	**Used method/tools****	**Reference(s)**
PathPED	Concept: PED Purpose: - Define urban transition pathways with milestones in 2030 and 2050. - Assess designs in terms of the Paris agreement's commitments. - Provide a decision support system for the delivery of feasible PEDs.	- Agent Based Modelling. - Dynamic simulations tool [MATLAB & Simulink].	[33]
Syn.ikia	Concept: SPEN Purpose: - Design SPEN located in different climate zones in Europe. - Analyse the robustness of the designs with respect to different scenarios. - Define key performance indicators (KPIs) that acknowledge the multidimensional nature of SPEN.	- Dynamic simulations tool for energy use (IDA-ICE, TRNSYS 18, City Energy Analyst). - Dynamic simulations tool for energy generation [Grasshopper, TRNSYS 18, Archelios, City Energy Analyst].	[26,34]

PEDRERA	Concept: PED Purpose: - Set and analyse a reliable prediction of potential business scenarios on large scale retrofitting actions. - Evaluate the overall co-benefits resulting from the renovation process of a cluster of buildings. - Define KPIs according to stakeholder and phase.	- Dynamic scenarios simulations tool: novel multidimensional urban building energy model (UBEM) programmed in Python to be integrated in open planning tools [e.g., urbanZEB].	[35,36]
UWF	Concept: PED Purpose: - Design the optimal district configuration that aligns with the definition and objectives of a PED. - Focus on the specific characteristics of the studied urban water front (UWF). - Support the decision-making thanks to a sensitivity analysis.	- Strategic project planning for project management. - Procedure for energy audits. - Dynamic simulations [HOMER].	[37]
MCDM	Concept: PEBlock Purpose: - Provide a workflow structure for PEBlock organization. - Assess different positive energy scenarios through a multi-criteria decision-making (MCDM) optimisation framework.	- PROMETHEE procedure. - Dynamic simulations [TermoNamirial v5.0].	[38]

UBEM- UESM	Concept: Zero-carbon districts Purpose: - Dynamically predict the heating and cooling demand of the district. - Automatically size different energy system configurations based on the calculated demands.	- Dynamic simulations: novel automated framework combining a Python-based UBEM [EnergyPlus] with an urban energy system model (UESM) [INSEL 8.2.].	[29]
HUB	Concept: PEBlock Purpose: - Transform historic urban block (HUB) into positive energy block. - Assess scenarios considering the impact on cultural heritage.	- Double multi-criteria analysis. - Preliminary calculations for energy and CO_2 savings.	[28]
Panama	Concept: ZED Purpose: - Assess the potential of an existing district to be defined under near-zero energy limits in the context of Panama. - Develop a reference plan for ZED applications in countries like Panama.	- Bioclimatic methodology [WRPLOT ViewTM, Climate Consultant, Bioclimarq 2016]. - Dynamic simulations [DesignBuilder w. EnergyPlus].	[30]

**Identification (ID) Name: enable to identify methodology. If the methodology has not a name, it has been chosen using the name of: related project, type of studied district or used method/tools.*

***Software and models indicated between square brackets*

Table 1: Main characteristics of the selected methodologies.

3.2. Characterisation of methodologies' key features

The objective of the present section is to analyse how the eight methodologies above mentioned incorporate each key feature in their process, to identify gaps and good practices, and define guidelines to include within PlanPED framework that is then presented in section 4).

3.2.1. Purpose of the methodology

The general purposes of the methodologies have been indicated in table 1. Hereafter, those purposes are further defined, translated into specific objectives, and quantified by means of KPIs according to four categories (table 2).

On the one hand, the definition of the purpose depends on the characteristics of the district to be transformed into PED, that from now will be named "PED candidate". Because of the variability of urban contexts, methodologies for PED design must consider a wide range of diverse needs and challenges depending on districts characteristics. According to Sassenou et al. [10], the key characteristics to acknowledge are: the surface of the district within physical boundaries, the built density, the uses, and the year of construction of the buildings. In that sense, several authors suggest that if design methodologies were tailored to representative patterns of districts, they could increase their efficiency and performance [11,19,39,40]. The study of the characteristics of PED candidates enables to identify three levels of tailoring within selected methodologies: 1) methodologies for all types of districts (syn.kia, MCDM, UBEM-UESM), 2) methodologies not tailored to any type of district but validated thanks to application to specific case studies (PathPED, PEDRERA), and 3) methodologies for well-defined types of districts (UWF, HUB, Panama). These latest are all aimed at supporting the energy transition of existing districts. While UWF and HUB methodologies focus on a specific area of the cities -respectively the coastal area and the historic urban centre -, the Panama methodology is tailored for a specific location, climate, and use.

On the other hand, the general purpose can be translated into different types of specific objectives that usually come with a quantifiable target (table 2). While the energy balance (EB) idea is present in all methodologies, with targets associated to different levels of ambition -neutrality (0) or positivity (+) -, specific objectives related to GHG emissions are much less considered and defined. Indeed, rather than aiming at reaching a defined target, the methodologies tend to only mention a reduction (↘) of GHG emissions. Otherwise, methodologies include specific objectives related to other aspects of district sustainability and quality of life, which act as criteria to compare different scenarios and are not aimed at reaching a defined target value (e.g. improvement of indoor comfort, minimization of costs). The progress towards the specific objectives' targets is measured by means of KPIs that encompass the multidimensional nature of district sustainability. Among the literature, some frameworks have been developed to support the selection and definition of relevant indicators to assess urban energy project in all their complexity [34,41]. The application of those frameworks enables to identify four main categories of KPIs for the evaluation of PED projects: energy performance (EnerP), environmental performance (EnviP), economic performance (EcoP), and social performance and quality of life (SPQ). KPIs are essential to guide, quantify and monitor improvements, evaluate the designs, and support decision-making [42]. Within the included methodologies, while the category EnerP is used to monitor the EB objective with KPIs related to the three pillars that PEDs should rely on -production, efficiency, and flexibility- [9], the category EnviP enables to quantify the reduction of GHG emissions from different scopes of activities [43]. The evolution of the other aspects of district sustainability are tracked thanks to EcoP and SPQ KPIs. It is worth noting the approach of PEDRERA which targets each KPI to potential stakeholder, based on their perspective and needs.

When applied to cases studies, only two methodologies (UBEM- UESM and HUB) fail in reaching their specific objectives' targets, e.g. positive energy balance, zero GHG emissions. The main reasons outlined by both methodologies are the difficulty to cover the energy demand of buildings and infrastructures with high-consumption profiles and the lack of renewable energy resources within the district area. Furthermore, HUB mentions the additional constraints deriving from the historical value of the studied area.

ID Name	Specific objectives		Categories of KPIs				Target reached
	Type	Target	EnerP	EnviP	EcoP	SPQ	
PathPED	EB	+	- Production - Efficiency				Yes
	GHG	0		Scope 1&2			Yes
	Others						-
Syn.ikia	EB	+	- Production - Efficiency - Flexibility				Yes
	GHG	No					
	Others				Costs	Indoor comfort	-

PEDRERA	EB	+	- Production - Efficiency				Not specified
	GHG	↘		Scope 2&3			Yes
	Others				- Costs -Cashflow	Welfare & security	-
UWF	EB	+	- Production - Efficiency				Yes
	GHG	↘		Scope 2			Yes
	Others				- Costs - Cashflow		-
MCDM	EB	+	- Production - Efficiency				Yes
	GHG	No					
	Others				Costs	Indoor comfort	-
UBEM- UESM	EB	+	Production				No
	GHG	0		Scope 2			No
	Others				Costs		-
HUB	EB	+	- Production - Efficiency				No
	GHG	↘		Scope 2			Yes
	Others						-
Panama	EB	0	- Production - Efficiency				Yes
	GHG	No					

	Others				Indoor comfort	-

Table 2: Specific objectives and KPIs of the selected methodologies.

3.2.2. Target-users of the methodology

PEDs are complex urban projects that involve a large number of actors and contributors. The stakeholders' ecosystem of a PED usually includes municipalities, building owners and tenants, research institutes and universities, urban services providers, industry and companies, non-profits or non-governmental organizations, and, last but not least, citizens and their organisations [44,45]. All the types of stakeholders from this diverse ecosystem could make use of a methodology for PED design.

When designing a methodology, it is essential to bear in mind who are going to be its target-users to ensure that their needs and priorities are adequately addressed, in terms of both content and form. Indeed, even if the methodology is operational, accurate, and enable to design a suitable PED, if it is not developed considering its target-users, it is likely that it will not be correctly used nor adopted by practitioners. Therefore, the selection and analysis of the target-users must be introduced at the beginning of the conceptualization of the methodology, along with the definition of its purpose and to be adopted in the implementation process. This target-users analysis contributes to the design of a strategy for stakeholder management within PED projects presented on figure 4. The central purpose of this stakeholder management is to engage the target-users, facilitate the dialogue between the stakeholders, and ensure that their diverse interests and priorities are taken into consideration [11,45]. As outlined on figure 4, the characterization of the target-users also enables to define and adapt several aspects of the methodology for PED design.

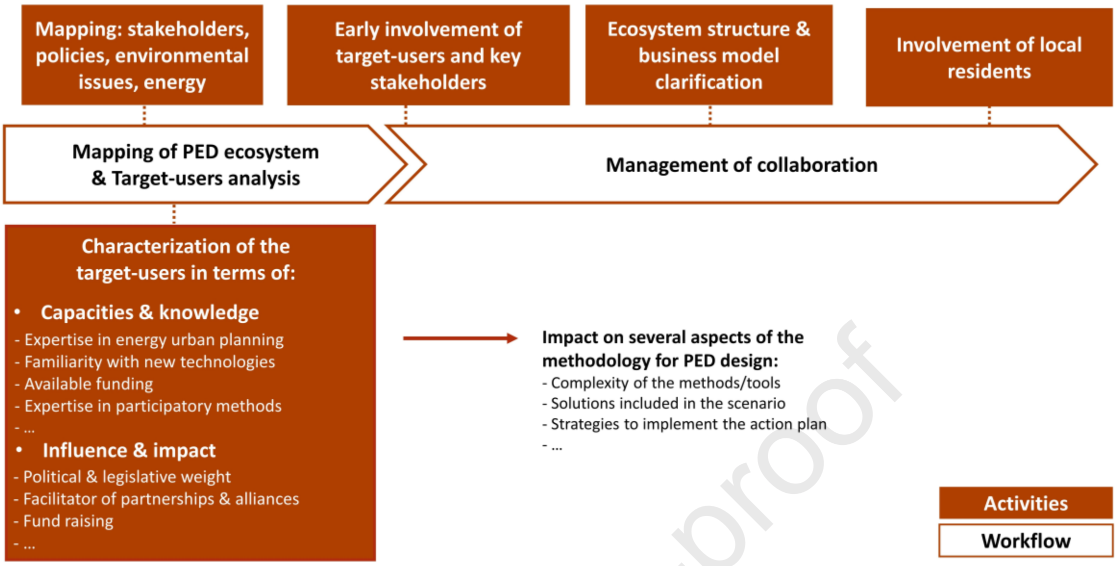


Figure 4: General workflow and main activities of stakeholder management for PED project, compiled by authors based on [45,46].

The review of the literature selection demonstrates that activities aimed at supporting cooperation among stakeholders are usually not included in PED design methodologies [47]. Consequently, in the absence of a structured framework, stakeholders tend to only collaborate and exchange through narrowly defined and established networks [11]. Concerning target-users analysis, even if several methodologies acknowledge that PED projects involve multiple stakeholders, only the PEDRERA methodology addresses the needs of three different groups of target-users (end-users, the public sector, and private parties). The other studied methodologies are developed for a unique and undefined target-user, i.e., the urban planner responsible for PED implementation. Indeed, the term urban planner does not refer to a specific type of PED stakeholder that could be defined in term of capacities and influences. This lack of target-users definition within the literature selection confirms that there is a need for methodologies tailored to the real pains, needs and objectives of specific practitioners.

3.2.3. Conception of the PED

This feature consists in reflecting on which kind of solutions should be included within PED design and how they should be combined in a way that enhance the efficiency of the whole district. So far, most research on PEDs have focused on the transition and decentralisation of the energy system, while other key aspects such as social and microclimatic considerations have received less attention [13].

An analysis of the types of solutions considered in the literature selection, demonstrates that the included methodologies follow this trend. First, the methodologies mainly look at PED design from a technical point of view. Indeed, only two of them contemplate actions based on non-technical solutions such as business model (PEDRERA) and behavioural energy-savings measures (HUB). Then, a thorough analysis of the technical solutions, shown on figure 5, demonstrates that the selected methodologies tend to focus on the installation of renewable energy sources (RES) - sometimes coupled with mobility and storage solutions for energy flexibility - and the improvement of district efficiency. However, they mainly focus on buildings and solutions related to the efficiency in the outdoor spaces, defined as the ratio between the energy services provided within the outdoor spaces (thermal comfort, lighting, etc.) and the amount of energy required to provide those services, are only present in the Panama methodology. Furthermore, only the syn.ikia methodology includes smart solutions aimed at improving energy flexibility and optimizing energy uses and exchanges. Finally, as showed in table 1, this approach, based on technical solutions only, is also present in the way the design of the PED is executed. Indeed, all selected methodologies rely on energy models, calculations, or dynamic simulations.

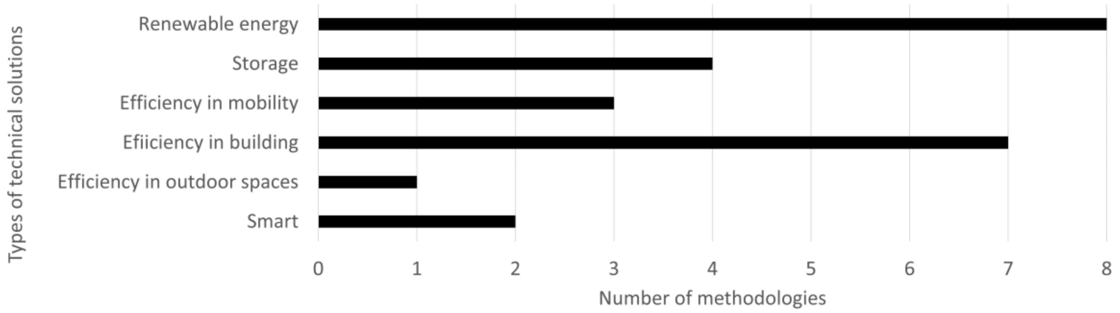


Figure 5: Types of technical solutions considered in selected methodologies, based on the classification of the morphological map of technics for PED by Heller [48].

3.2.4. Execution of the PED

This last feature refers to all the measures that enables to convert the design into an operational PED. Currently, this point constitutes a major constraint for practitioners, who struggle to translate theorical designs into concrete actions. Three main types of measures have been identified, based on the analysis of the state of the art of guidelines for PEDs deployment by Neumann et al. [49] and the framework for Urban Energy Masterplanning presented in [22]. First, the measures that establish a direct connection between conception and implementation and enable to translate PED design into a roadmap of energy interventions and actions. Then, the measures aimed at building a supportive framework for PED implementation. This second type uses to address barriers of the context that currently restrain PED development, such as lack of funding, complex ownership structure, conflicts of interests between stakeholders, or citizens' mistrust. Finally, the last type includes the measures that facilitate and promote the inclusion of PED within strategic urban planning and energy plans e.g., Sustainable

Energy and Climate Action Plans. This alignment of PEDs strategies with local and regional plans is essential to ensure the coherence of the whole, create synergies with current initiatives, promote cross-sectoral collaborations, and contribute to wider and more complex challenges.

The selected methodologies do not include any type of the above-mentioned measures. It confirms the identified gap between theory and practice. However, several methodologies do include components that help pave the way towards implementation such as non-technological solutions aimed at supporting PEDs implementation and deployment (PEDRERA, HUB) and studies to test and improve the feasibility of the design (syn.ikia, UWF). By doing so, these methodologies aim to connect the design with practical aspects of the PED implementation and support decision-making.

4. Presentation of PlanPED: a framework for PED design

The present section introduces PlanPED, a framework for holistic PED design, to be further defined depending on local needs and motivations. As argued in section 1, PlanPED stems from the postulate that the definition of a general framework constitutes a preliminary step that will facilitate the conception of efficient and tailored methodologies for PED design. Furthermore, PlanPED has been built following the workflows for PED design (figure 2) and stakeholder management (figure 4), considered as reference methodologies for the definition and implementation of holistic urban energy strategies. Finally, the main characteristics of PlanPED have been defined thanks to the analysis of the four key features introduced in section 2. In that sense, the following definition of PlanPED is based on assumptions from reference literature on urban planning, energy systems and stakeholder management, and the deepened analysis of selected methodologies for PED design performed in section 3. Section 4 begins with the definition of PlanPED's key features, offering some preliminary reflexions, decisions, and recommendations, to address current challenges and needs of practitioners. Once the features defined, the resulting workflows of PlanPED are presented.

4.1. Definition of the key features of PlanPED

4.1.1. Purpose of PlanPED

Three aspects define the purpose and potential of the PlanPED approach: the characteristics of the PED candidate, the specific objectives and their associated KPIs. First, in respect to the characteristics of PED candidate, several authors consider that priority should be given to districts with higher potential to achieve PED objectives considering economic, social, political, legal, environmental, and technical criteria (e.g., sufficient space available for RES generation, low payback time, existing energy infrastructures, presence of energy communities) and/or urgent need for energy transition (e.g., vulnerability to climate change, low level of thermal comfort, high rate of energy poverty) [10,50–52]. There is consensus that the biggest challenge of urban energy transition lies in renovating the existing building stock [9,53]. Therefore, PlanPED focuses on the conversion of existing districts into PEDs. The methodologies deriving from PlanPED would further restrain their scope to specific patterns of district (e.g., with specific urban form, area, building typologies, or climatic zone), to improve their performance and impact.

Then, the specific objectives and associated KPIs of PlanPED should be aligned with PED definition as stated in PEDs reference document [9]. Therefore, PlanPED acknowledges the two main objectives outlined in the reference definition, of achieving a positive energy balance and of reducing GHG emissions to net zero. Indeed, according to section 3, existing methodologies use to focus on the positive energy balance and consider GHG emissions neutrality as a secondary and minor aspect that should be improved when possible. Within literature and projects, several terminologies are used to refer to this target, the most common being “carbon neutrality”, “net zero/zero emission” and “climate neutrality”. However, these terminologies are not interchangeable [54]: while a carbon neutral goal refers to carbon dioxide only, a net-zero target includes all GHG, and a climate-neutral objective extends to all causes of radiative forcing [55,56]. PlanPED aims to address these simplification and confusion regarding GHG emissions, by attaching a special care to this objective.

Furthermore, as PEDs should ensure a “good life for all in line with social, economic and environmental sustainability” [9], it is recommended that methodologies deriving from PlanPED include additional specific objectives that refer to aspects such as thermal comfort, quality of life, biodiversity, or circularity, depending on district priorities. The task of monitoring all these diverse objectives may result challenging for practitioners, as it implies the selection over a catalogue of hundreds of available KPIs. Instruments, such as the previously mentioned step-by-step processes for evaluating, selecting, and defining KPIs for PEDs monitoring presented in [34,41], are emerging to support them in this task.

4.1.2. Target-users of PlanPED

A PED is the results of a dynamic and complex process, and consequently, there is no single stakeholder management model for all PED projects and phases [47]. In that sense, the mapping of PED ecosystem must be actualized as often as local context and conditions change [45,47]. In particular, the relevance of the different PED stakeholders and opportunities for collaboration depend on the phase of the project [47,57,58]. For the planning and design phase, which is the focus of the present paper, various authors recognise the key role of local public authorities [11,59].

However, despite their importance for urban energy planning, local authorities are not alone in this journey [2,11]. PEDs cover a wide range of activities and their design and implementation necessitate the collaboration of multiple stakeholders among sectors such as construction, energy services, real estate, and the built environment [47]. As outlined on figure 4, there is a consensus concerning the importance of including PED local residents within this multi-actor perspective [11,14,19,60]. Indeed, even if citizens and local stakeholders are not vital for PED project implementation, they certainly are for reaching positive energy balance and zero GHG emissions during PED operation [45]. In that context, PlanPED focuses on addressing the needs of target-users from municipalities and includes an efficient stakeholder management workflow that pursues a human-centric and collaborative governance approach [11]. By doing so, PlanPED aims to ensure the use of the methodology, facilitate multi-stakeholder interactions and involvement, and implement bottom-up perspectives that prioritise human and ecosystems well-Being and lived experiences in PEDs design [60].

4.1.3. Conception of the PED

One of the main innovations of PEDs is that they combine a large variety of solutions [61] so they can address energy, environmental and social aspects of urban sustainability, and tackle both buildings and public spaces issues [11]. First, PEDs must be energy efficient in terms of buildings, installations, mobility, and urban spaces. To that end, the integration of passive strategies and the interoperability of solutions, defined as their ability to "seamlessly integrate, effectively communicate, and undertake tasks to achieve desired outcomes" [62], are fundamental. Therefore, PlanPED includes and connects the six main types of technical solutions (figure 5), with a special focus on "efficiency in outdoor spaces" and "smart", two types of solutions that are essential to improve district's efficiency and enhance its interoperability. Furthermore, PlanPED enables the selection and design of governance and business models for the PED, two non-technical solutions that enhance target-users involvement, attract investments, and support the correct operation of technical solutions. It is worth noting that the selection and design of the solutions is highly dependent on the characteristic of the district. In that sense, the focus on a specific pattern of district, as suggested in section 4.1.1, would also enable to facilitate and improve this process.

Another key aspect of PED design relies on how it will be realized, i.e., with which tools or methods. As highlighted in the section 3.2.3, most methodologies include energy modelling and dynamic simulations to assess their designs. To do so they use tools and models that are selected among the many available on the market, based on target-users' needs in term of accuracy, level of details or type of solutions [63–65]. PlanPED aims to enable the integration and combination of a wide range of solutions, and therefore requires a model that simulate several aspects of the urban system at once [65–67]. Software tools such as 'CitySim', 'SynCity', 'City Energy Analyst', 'Integrated Environmental Solutions Virtual Environment IES VE', or 'Solemma Open Studio' are considered adequate to execute integrative PED designs [65,67,68]. However, when more detailed modelling is required, this integrating approach may become too complex and difficult to manage using a single tool. In that case, another approach consists in combining several models, each one addressing specific aspects of the district design [64].

Finally, even if those tools and methods are decisive to ensure accurate evaluation and selection of PEDs scenario, it cannot be forgotten that cities are places governed and shaped by several socio-economic, political, and environmental factors [65,69]. Therefore, it would be simplistic and superficial to base PED design only on technological tools that do not enable to assess the impact of non-technical solutions, neither take into consideration crucial parameters such as national regulations, mobility flows or social habits. To fulfil these multiple requirements, PlanPED connects the modelling and simulations of the PED with urban planning, economic, environmental, and social studies.

4.1.4. Execution of the PED

PlanPED aims to support municipalities in the craft and execution of their pathway to PEDs by providing them the needed knowledge, guides, and tools [11,70]. The translation of conceptual design into real implementation strategy constitutes a complex challenge for practitioners, that currently no design methodology is effectively addressing [14]. PlanPED aims to contribute to fill that gap, by helping municipalities in the design of practical measures from the three types introduced in section 3.2.4.: 1) measures that establish a direct connection between design and implementation, 2) measures aimed at building a supportive framework for PED implementation, and 3) measures that facilitate and promote the inclusion of PED within strategic local urban planning and energy plans.

First, one key element for PED implementation belongs to the last step of the reference workflow for methodology design (figure 2): the design of the action plan. Indeed, an implemented PED project can be seen as the outcome of a well-harmonised and strategic planning of actions that enables to convert an existing district into an energy efficient and GHG-neutral urban area [23]. Therefore, PlanPED includes a well-defined action plan that translates the theoretical design into a roadmap of actions and make PED project a reality. Furthermore, in practice the lack of a communication and agreements between different stakeholders are often preventing the correct implementation of planning strategies [19]. Therefore, the action plan also involves a co-creation process in the conceptual phase, aimed at selecting and promoting strategies that consider the different stakeholder's perspectives [36].

Then, the second and third types of measures are intended to support the execution of the action plan. PlanPED enables the achievement of both objectives thanks to its target-users. Indeed, municipalities are considered particularly relevant for implementing supportive legislative, economic, and social framework, as they have both the legitimacy and tools to implement regulatory mechanisms, open space of dialogues, create incentives, find synergies, and unlock co-benefits [11,71]. Furthermore, municipalities constitute key stakeholders to implement coherent and effective PED strategies, as they can ensure their integration into local urban plans and connect them with ongoing city's initiatives.

4.2. Workflows of PlanPED

PED design roadmap is covered by PlanPED framework and combines three different workflows, each one with specific aims: 1) for PED selection and technical design, 2) for stakeholder management, and 3) for integration of social ecosystem within PED design. The social ecosystem is defined as the framework of individuals, networks, and organizations of the district. As previously outlined, this approach has been drawn from reference workflows (figures 2 and 4). A significant contribution of PlanPED to these existing guidelines is the connection established between the technical design and the stakeholder management of the PED, first separately along the project timeline and then merged within a unique final workflow. These connections as well as the different steps of the three workflows are shown on figure 6 that introduces PlanPED framework.

The stakeholder management (in brown) facilitates and ensures the effective and informed participation of key stakeholders in the selection and conception of the PED (in blue). Therefore, the simultaneous execution of these two workflows enables to design solutions that consider and address the real challenges and needs of the local context. The final integrative workflow (in green) enables to concretise the PED design by executing participatory planning activities in which stakeholders are invited to directly contribute to the PED design. All these three workflows are further defined in the following sections. It results that PlanPED encompasses several dimensions of the urban transition and requires different knowledge, capacities, and collaborations to be executed. In that sense, to ensure the correct adaptation and execution of PlanPED, the municipality that leads the process should count on the support of a multidisciplinary team of experts.

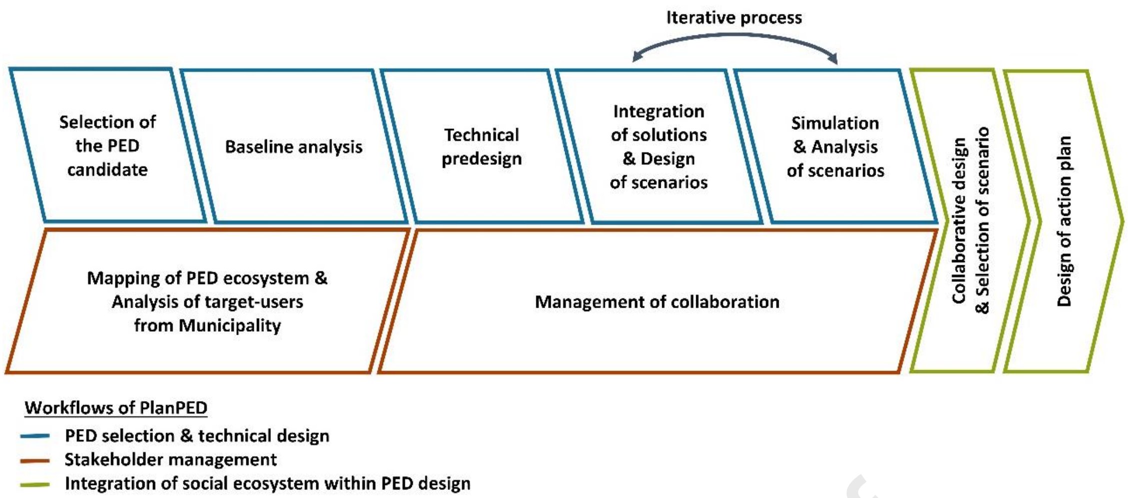


Figure 6: Workflows of PlanPED, compiled by authors.

4.2.1. PED selection and technical design

The PED selection and technical design workflow begins with the identification of the urban areas that are most appropriate for the implementation of PEDs, thanks to the determination of their positive energy district readiness level (PRL). The aim of this novel concept -that was first introduced in a report for the Spanish Technological platform on energy efficiency [72]- is to evaluate the degree of maturity of cities or urban areas for the deployment of the PEDs. The PRL is a criterion of analysis which combines a multi-criteria analysis and an overlay analysis with geographic information system (GIS) software. In that sense, this combination provides the strengths of both approaches: a robust assessment based on multiple criteria and very visual results from the different lays of the GIS software.

Hence, this step, based on the method presented in [50], consists of collecting city data (e.g., resource availability, land-use context, urban macroform and development, energy infrastructure, energy services and social structure), assessing it by means of criteria that encompass economic, social, political, legal, environmental, and technical aspects, then determining the resulting PRL, and finally identifying PED concepts boundaries. However, the method of Alpagut et al. [50] mainly focuses on identifying areas with higher potential to achieve PEDs objectives. This workflow enriches these assessments by including more criteria related to the needs of districts for urban sustainability and resilience, e.g., considering the impacts of climate change and vulnerability to extreme weather events.

The second step is the baseline analysis which consists in the collection of data to characterise the initial state of the district and complements the information retrieved in the first step at city scale. Indeed, the focus on a lower scale enables to use other means for data collection (e.g., interviews with citizens, energy bills of buildings and equipment, on-site measurements) that facilitate the access to more detailed and specific information. In that sense, the design workflow combines top-down and bottom-up perspectives.

The third step slightly differs from the reference framework (figure 2). Indeed, even if it includes the identification of needs and prioritization, it goes a little further by proposing a preliminary design of the PED. In that sense, once the current state and needs of the district are defined thanks to the baseline analysis, those are associated to a selection and rough quantification of technical solutions to implement. Based on those estimations, urban planners can work on the integration of the solutions within the physical space of the district, considering national and municipality directives. This preliminary technical design would result from the collaboration of a multidisciplinary team of local experts (e.g., engineers, urban planners, and architects) from or hired by the municipality.

The fourth and fifth steps are part of an iterative process leading to a proposal for PED design. It consists in alternating successively: the design and incorporation of the selected solutions within the district (step 4) and the energy modelling and simulation of the PED (step 5). The iterative process is a novelty in comparison with the reference framework. Ideally, both steps can be repeated several times until impacts comply with PEDs targets and city priorities. By doing so, PlanPED aims to address the complex challenges that occur within the district, by connecting energy and urban planning considerations. For the execution of that process, the multidisciplinary team of local experts would work together with relevant urban stakeholders (e.g., private investors, urban services provider, design and construction companies), to ensure that the resulting design acknowledges their different perspectives [73]. The final outcome is thus a design that achieves PED targets both in terms of energy balance and GHG emissions, while acknowledging agendas principles, local regulations, strategies and investments.

4.2.2. Stakeholder management

The stakeholder management workflow begins with PED mapping and target-users analysis. The objective of the target-users analysis is to identify and characterize the municipality staff that will be involved in the next steps of the workflow. Based on these analysis and mapping, the strategy for management of collaboration is established. This strategy consists in defining: 1) the different form of participation and engagement of the target-users along the design process; and 2) a governance model that describes the relationships and modes of collaboration, as well as business models (public-private partnerships, turnkeys, one-stop-shops, among others), between municipality and PED ecosystem using a quadruple helix approach [74–76]. Then, in the second step the strategy management of collaboration is executed. It involves activities for the involvement of target-users, the engagement and capacity building of local actors, and the creation of stable relationships between them. By doing so, the stakeholder management workflow aims to enable the effective and informed participation of different stakeholders in PED design, and hence support the execution of the two other workflows. One reference tool for the design and execution of the stakeholder management workflow is the 'Community Transition Pathway' built in the framework of the project GRETA – GReen Energy Transition Actions, financed by the H2020 programme [77].

4.2.3. Integration of social ecosystem within PED design

The last workflow consists in the union between the two previous ones, and thus combines the technical and non-technical aspects of the PED into an integrative design. The first step emanates from the need to build public consensus on the PED design to ensure its feasibility and sustainability [78]. It consists in the organization of a participatory planning process - involving activities such as interviews and surveys, cognitive mapping, or serious game - that enables to gather impressions and feedback of local stakeholders and citizens concerning PED design [73]. Taking suggestions into account, the technical design is then adapted, in a way that includes the perceptions, values, assumptions, expertise and experiences of diverse actors. The participatory process is also used to gather opinions and interest on implementation strategies, that will serve as input for the design of the action plan. Furthermore, as previously outlined, the work previously done within the stakeholder management workflow is key for all this process: it ensures that district's inhabitants and local stakeholders are well-informed, willing to participate and prepared to cooperate for the sake of the PED project.

In the second step, the final PED design is translated into an action plan. This action plan includes a roadmap that enables the transition of the districts into PEDs. Concretely, it consists in the chronological implementation of the different technical solutions and a proposal of funding mechanisms, business models, and governance schemes that could support the effective operationalization of the PED.

5. Discussion

PlanPED is a novel framework for PED design, built following the reference workflows of design methodology and stakeholder management (figure 2 and 4) and deepening the four key features characterised in the section 2.2. The present section aims to further discuss the three main contributions of PlanPED to the current pitfalls of PED design and implementation. In that sense, the following describes these contributions, the remaining aspects to be addressed, and finally suggests perspectives for future work.

5.1. A holistic approach

One of the main novelties of PlanPED is its division into three interconnected workflows, that enable to address the complexity of challenges that practitioners currently face in PED design process. PlanPED begins with the simultaneous execution of two complementary workflows, one for PED design, the other for stakeholder management, that are then merged into one focusing on the integration of the social ecosystem into PED design. Indeed, even if there is strong evidence that involving citizens can result in the planning and execution of urban projects that are more innovative and ambitious

[77,79–81], this concern has not yet been translated into dedicated actions within PED design methodologies. PlanPED addresses that gap with the inclusion of stakeholder management since the beginning of the process, which enables to connect PED design with concrete challenges of the local context - beyond technical considerations only - and therefore opens the way for more holistic solutions and strategies.

5.2. A multidisciplinary design

The creation of a PED requires the combination of innovative solutions to be implemented both in the indoor and outdoor spaces of the district. Thus, the success of PED execution relies on a high number of parameters and can be hindered by technical, socio-economic, administrative, cultural, and legislative features of the existing context. PlanPED addresses this complexity with the combination of tools, methods, and strategies from multiple disciplines, in the PED design process. In that sense, this workflow includes specific activities (e.g., technical predesign and the iterative approach) that facilitate the dialogue and collaboration between experts with different background and knowledge. PlanPED argues that rather than looking for the perfect expert or tool that encompass all requirements, municipalities should opt for collaborations among disciplines and methods. This approach enables the municipality to lead and implement the process with its existing staff resources and capacities, finding the best combination of expertise among its different units and categories of workers (e.g., councillor, urban planning unit, project manager). Hence, if municipalities identify that they may need additional competences, they would only subcontract or hire new staff to fulfil well-defined tasks. In that context, universities constitute key partners for municipalities, as they can provide them missing knowledge and train their workers, so they acquire the needed skills [75].

5.3. A path towards net zero GHG emissions

PlanPED has been built with the conviction that ambitious challenges can only be addressed with ambitious and well-defined objectives. Indeed, GHG emissions is an indicator that not only gives an overall vision of district sustainability, but also can act as a bridge between different scales of action. This second aspect is particularly relevant in the framework of the Cities Missions, that pursues the same neutrality purpose as PED but at a city scale. In that sense, the inclusion of the GHG neutrality objective in PlanPED enables to outline the potential and opportunity that PED projects represent for the achievement of broader goals. Therefore, to facilitate the recognition of this contribution, it results crucial to align the GHG emissions calculations with reference framework such as the Global Protocol for Community-Scale Greenhouse Gas Emission Inventories [82] or the Global Covenant of Mayors Common Reporting Framework [83]. Thus, further research should be dedicated to the definition of common norms and rules for GHG calculations applied to PED, to foster transparency among calculations, deliver clarity, limit misunderstanding, avoid potential greenwashing, and support truly transformative projects [84].

In their guidelines for cities aiming at going neutral by 2030, the European Commission recommends the inclusion of the six main GHG in terms of carbon dioxide equivalent and of the three scopes of activities [85]. Like for carbon footprint, the scope 1 and 2 of GHG calculations refer to energy related emissions, and the scope 3 enables to encompass other aspects of district sustainability [86], such as consumers habit not energy related, or greening of public spaces.

5.4. Perspectives of future work

PlanPED gives a baseline proposal that cannot be applied as-it-is but instead must be further defined depending on local needs and motivations. In that sense, a future perspective for PlanPED is its application to different urban contexts, leading to further definitions of its three workflows according to local requirements that encompass political, legal, ownership, environmental, social, and technical aspects. Once fully designed, the tailored versions of PlanPED would be validated through their application to real case studies. Throughout this tailoring process, there may appear cities with similarities in their PED roadmaps due to common characteristics regarding aspects such as urban density, type of buildings, access to RES, lifestyle, or energy regulation. The analysis of the relation between cities characteristics and PEDs roadmaps could then enable the identification and definition of patterns of cities regarding PEDs planning, design, and implementation, and contribute to further define the PRL indicator.

In particular, one key challenge to be addressed among this definition of tailored methodologies is their appropriation and use by the municipalities. Indeed, PlanPED aims to build on the existing resources of the municipality, in terms of staff, expertise and knowledge. In that context, one key challenge lies on the way these different resources will be managed, optimized, and connected, within the different PlanPED's workflows. Future research should focus on the identification and adaptation of innovative instruments that can facilitate this task, such as methods to enhance collaboration among different municipal units [2], capacity building formation for municipality workers, or user-friendly interface for tools combination [64,88].

6. Conclusions

The objective of this paper was to present PlanPED, a new approach for the conception of methodologies for PED planning, design, and implementation. It began with a presentation of the theorical framework of methodologies for PED design, followed by an overview of the state of the art based on the selection of a set of eight existing methodologies. This analysis led to the identification of trends, gaps, and good practices of current research. On the one hand, two reference workflows for PED projects were identified, one dedicated to the planning and design, the other to the stakeholder management. On the other hand, the four key features of design methodologies were deepened: the purpose of the methodology, the target-users of the methodology, the design of the PED and the execution of the PED. Then, based on this analysis, the novel framework PlanPED was introduced.

PlanPED is aimed at providing a multiple perspective approach based on the most important and available elements from existing methodologies and according to the reference workflows. That framework has been designed to support municipalities in their transition towards more sustainable and GHG-neutral models. Indeed, as settled above, PlanPED moves from a collection of best practices and methods to the building of an approach framed in a novel and effective way, that describes the PRL baseline of the different urban areas [72], and then guides and engages public authorities and other stakeholders in the transformation of existing districts into PEDs. Its framework covers the main topics (technical, administrative, social, economic, etc.) required to overcome the PED planning, design, and implementation pitfalls as it is enough flexible to be tailored to the specificities of each transformation process, business model and stakeholders involved.

By doing so, PlanPED aims to deliver tailored and practical roadmaps enabling to accelerate the deployment of PEDs in cities. The resulting increase of real PED experiences may have a multiplier effect, as it would enrich the theory, contribute to further define existing conceptual framework, and allow the testing and validation of instruments within various contexts [34]. It is worth noting that this wide impact would only be achieved with the alignment of research and practice efforts and the fluid exchange of knowledge and experience, through networks such as the COST Action Positive Energy Districts European Network [89], the International Energy Agency (IEA) Energy in Buildings and Communities (EBC) Annex 83 on Positive Energy Districts [90], and the European Energy Research Alliance Joint Programme Smart Cities [74].

Funding

The research leading to these results has received funding from the Spanish Ministry of Science and Innovation via a doctoral grant to the first author [FPU20/07591]; from the Comunidad de Madrid through the call Research Grants for Young Investigators from Universidad Politécnica de Madrid [APOYO-JOVENES-21-LI6SVQ-77-664ZUQ]; and from the project [PCI2023-145997-2] funded by MICIU/AEI/10.13039/501100011033, under the Driving Urban Transitions Partnership, which has been co-funded by the European Commission. This publication is based upon work from COST Action Positive Energy Districts European Network [PED-EU-NET, CA19126], supported by COST (European

Cooperation in Science and Technology); and from the IEA EBC Annex 83 "Positive Energy Districts" work program.

References

[1] United Nations, Generating power - cities and pollution 2022, (n.d.). https://www.un.org/en/climatechange/climate-solutions/cities-pollution (accessed September 30, 2023).

[2] M. Soberón, I. Ezquerra-Lázaro, T. Sánchez-Chaparro, J. Moreno-Serna, G. Dóci, O. Kordas, Supporting municipalities to develop collaboration capability to facilitate urban transitions and sustainability: Role of transition intermediaries in madrid, J Clean Prod (2023) 138964. https://doi.org/10.1016/J.JCLEPRO.2023.138964.

[3] M. Salvia, F. Pietrapertosa, V. D'Alonzo, P. Clerici Maestosi, S.G. Simoes, D. Reckien, Key dimensions of cities' engagement in the transition to climate neutrality, J Environ Manage 344 (2023) 118519. https://doi.org/10.1016/J.JENVMAN.2023.118519.

[4] European Commission, EU Mission: Climate-Neutral and Smart Cities, (n.d.). https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/climate-neutral-and-smart-cities_en (accessed October 18, 2022).

[5] G. Ulpiani, N. Vetters, D. Shtjefni, G. Kakoulaki, N. Taylor, Let's hear it from the cities: On the role of renewable energy in reaching climate neutrality in urban Europe, Renewable and Sustainable Energy Reviews 183 (2023) 113444. https://doi.org/10.1016/J.RSER.2023.113444.

[6] G. Ulpiani, N. Vetters, C. Maduta, Towards (net) zero emissions in the stationary energy sector: A city perspective, Sustain Cities Soc 97 (2023) 104750. https://doi.org/10.1016/J.SCS.2023.104750.

[7] M. Amado, F. Poggi, Cities Energy Transition, Sustainable Energy Transition for Cities (2022) 19–29. https://doi.org/10.1016/B978-0-12-824277-3.00004-9.

[8] M. Amado, F. Poggi, Net-Zero Energy City, Sustainable Energy Transition for Cities (2022) 31–44. https://doi.org/10.1016/B978-0-12-824277-3.00003-7.

[9] JPI Urban Europe, SET-Plan 3.2, White Paper on PED Reference Framework for Positive Energy Districts and Neighbourhoods, 2020. https://jpi-urbaneurope.eu/ped/ (accessed August 11, 2022).

[10] L.N. Sassenou, L. Olivieri, F. Olivieri, Challenges for positive energy districts deployment: A systematic review, Renewable and Sustainable Energy Reviews 191 (2024) 114152. https://doi.org/10.1016/J.RSER.2023.114152.

[11] S. Sareen, V. Albert-Seifried, L. Aelenei, F. Reda, G. Etminan, M.B. Andreucci, M. Kuzmic, N. Maas, O. Seco, P. Civiero, S. Gohari, M. Hukkalainen, H.M. Neumann, Ten questions concerning positive energy districts, Build Environ 216 (2022) 109017. https://doi.org/10.1016/J.BUILDENV.2022.109017.

[12] V. Todeschi, P. Marocco, G. Mutani, A. Lanzini, M. Santarelli, Towards energy self-consumption and self-sufficiency in urban energy communities, International Journal of Heat and Technology 39 (2021) 1–11. https://doi.org/10.18280/IJHT.390101.

[13] J. Brozovsky, A. Gustavsen, N. Gaitani, Zero emission neighbourhoods and positive energy districts – A state-of-the-art review, Sustain Cities Soc 72 (2021) 103013. https://doi.org/10.1016/J.SCS.2021.103013.

[14] S. Koutra, J. Terés-Zubiaga, P. Bouillard, V. Becue, 'Decarbonizing Europe' A critical review on positive energy districts approaches, Sustain Cities Soc 89 (2023) 104356. https://doi.org/10.1016/J.SCS.2022.104356.

[15] Joint Programming Initiative Urban Europe, SET-Plan ACTION n°3.2 Implementation. Plan Europe to become a global role model in integrated, innovative solutions for the planning, deployment, and replication of Positive Energy Districts, (2018).

[16] G. Turci, B. Alpagut, P. Civiero, M. Kuzmic, S. Pagliula, G. Massa, V. Albert-Seifried, O. Seco, S. Soutullo, A Comprehensive PED-Database for Mapping and Comparing Positive Energy Districts Experiences at European Level, Sustainability 2022, Vol. 14, Page 427 14 (2021) 427. https://doi.org/10.3390/SU14010427.

[17] Urban Europe, Europe towards Positive Energy Districts , 2020. https://jpi-urbaneurope.eu/ (accessed June 11, 2021).

[18] X. Zhang, S.R. Penaka, S. Giriraj, M.N. Sánchez, P. Civiero, H. Vandevyvere, Characterizing Positive Energy District (PED) through a Preliminary Review of 60 Existing Projects in Europe, Buildings 2021, Vol. 11, Page 318 11 (2021) 318. https://doi.org/10.3390/BUILDINGS11080318.

[19] E. Derkenbaeva, H.K. Yoo, G.J. Hofstede, K. Galanakis, R. Ackrill, Positive Energy Districts in Europe: one size does not fit all, ISC2 2022 - 8th IEEE International Smart Cities Conference (2022). https://doi.org/10.1109/ISC255366.2022.9921835.

[20] E. Derkenbaeva, S. Halleck Vega, G.J. Hofstede, E. van Leeuwen, Positive energy districts: Mainstreaming energy transition in urban areas, Renewable and Sustainable Energy Reviews 153 (2022) 111782. https://doi.org/10.1016/J.RSER.2021.111782.

[21] S. Chakraborty, J. Novotný, I. Maity, R. Lemoine-Rodríguez, A. Follmann, Same planet but different worlds! Diverging convergence pattern of urban form typologies across 413 cities with million+ inhabitants and their sustainability trade-offs, Habitat Int 145 (2024) 103024. https://doi.org/10.1016/J.HABITATINT.2024.103024.

[22] A. van den Dobbelsteen, R. Roggema, N. Tillie, S. Broersma, M. Fremouw, C.L. Martin, Urban Energy Masterplanning—Approaches, Strategies, and Methods for the Energy Transition in Cities, Urban Energy Transition (2018) 635–660. https://doi.org/10.1016/B978-0-08-102074-6.00045-0.

[23] B. Polly, S. Pless, S. Houssainy, P. Torcellini, W. Livingood, S. Zaleski, M. Jungclaus, T. Hootman, M. Craig, A Guide to Energy Master Planning of High-Performance Districts and Communities, (2020). https://doi.org/10.2172/1734654.

[24] S. Charani Shandiz, B. Rismanchi, G. Foliente, Energy master planning for net-zero emission communities: State of the art and research challenges, Renewable and Sustainable Energy Reviews 137 (2021) 110600. https://doi.org/10.1016/J.RSER.2020.110600.

[25] J.F. Burnham, Scopus database: A review, Biomed Digit Libr 3 (2006) 1–8. https://doi.org/10.1186/1742-5581-3-1/TABLES/2.

[26] I. Andresen, T. Healey Trulsrud, L. Finocchiaro, A. Nocente, M. Tamm, J. Ortiz, J. Salom, A. Magyari, L. Hoes-van Oeffelen, W. Borsboom, W. Kornaat, N. Gaitani, Design and performance predictions of plus energy neighbourhoods – Case studies of demonstration projects in four different European climates, Energy Build 274 (2022) 112447. https://doi.org/10.1016/J.ENBUILD.2022.112447.

[27] M. Sibilla, F.H. Abanda, Multi-Criteria Decision Making Optimisation Framework for Positive Energy Blocks for Cities, Sustainability 2022, Vol. 14, Page 446 14 (2022) 446. https://doi.org/10.3390/SU14010446.

[28] A. Blumberga, R. Vanaga, R. Freimanis, D. Blumberga, J. Antužs, A. Krastiņš, I. Jankovskis, E. Bondars, S. Treija, Transition from traditional historic urban block to positive energy block, Energy 202 (2020) 117485. https://doi.org/10.1016/J.ENERGY.2020.117485.

[29] B. Samadzadegan, S. Samareh Abolhassani, S. Dabirian, S. Ranjbar, H. Rasoulian, A. Sanei, U. Eicker, Novel Energy System Design Workflow for Zero-Carbon Energy District Development, Frontiers in Sustainable Cities 3 (2021) 23. https://doi.org/10.3389/FRSC.2021.662822/BIBTEX.

[30] L. De León, D. Mora, C. Carpino, N. Arcuri, M.C. Austin, A Reference Framework for Zero Energy Districts in Panama Based on Energy Performance Simulations and Bioclimatic Design Methodology, Buildings 2023, Vol. 13, Page 315 13 (2023) 315. https://doi.org/10.3390/BUILDINGS13020315.

[31] V. Oquendo-Di Cosola, F. Olivieri, L. Ruiz-García, A systematic review of the impact of green walls on urban comfort: temperature reduction and noise attenuation, Renewable and Sustainable Energy Reviews 162 (2022) 112463. https://doi.org/10.1016/J.RSER.2022.112463.

[32] M. Gayoso Heredia, C. Sánchez-Guevara Sánchez, F.J. Neila González, Integrating lived experience: Qualitative methods for addressing energy poverty, Renewable and Sustainable Energy Reviews 189 (2024) 113917. https://doi.org/10.1016/J.RSER.2023.113917.

[33] T. Castillo-Calzadilla, R. Garay-Martinez, C.M. Andonegui, Holistic fuzzy logic methodology to assess positive energy district (PathPED), Sustain Cities Soc 89 (2023) 104375. https://doi.org/10.1016/J.SCS.2022.104375.

[34] J. Salom, M. Tamm, I. Andresen, D. Cali, Á. Magyari, V. Bukovszki, R. Balázs, P.V. Dorizas, Z. Toth, C. Mafé, C. Cheng, A. Reith, P. Civiero, J. Pascual, N. Gaitani, An Evaluation Framework for Sustainable Plus Energy Neighbourhoods: Moving Beyond the Traditional Building Energy Assessment, Energies 2021, Vol. 14, Page 4314 14 (2021) 4314. https://doi.org/10.3390/EN14144314.

[35] P. Civiero, J. Pascual, J.A. Abella, A.B. Figuero, J. Salom, PEDRERA. Positive Energy District Renovation Model for Large Scale Actions, Energies 2021, Vol. 14, Page 2833 14 (2021) 2833. https://doi.org/10.3390/EN14102833.

[36] P. Civiero, J. Pascual, J. Arcas Abella, J. Salom, Innovative PEDRERA Model Tool Boosting Sustainable and Feasible Renovation Programs at District Scale in Spain, Sustainability 2022, Vol. 14, Page 9672 14 (2022) 9672. https://doi.org/10.3390/SU14159672.

[37] I. Aparisi-Cerdá, D. Ribó-Pérez, I. Cuesta-Fernandez, T. Gómez-Navarro, Planning positive energy districts in urban water fronts: Approach to La Marina de València, Spain, Energy Convers Manag 265 (2022) 115795. https://doi.org/10.1016/J.ENCONMAN.2022.115795.

[38] M. Sibilla, F.H. Abanda, M.M. Sesana, R. Lollini, Multi-Criteria Decision Making Optimisation Framework for Positive Energy Blocks for Cities, Sustainability 2022, Vol. 14, Page 446 14 (2022) 446. https://doi.org/10.3390/SU14010446.

[39] A. Bruck, S. Díaz Ruano, H. Auer, One piece of the puzzle towards 100 Positive Energy Districts (PEDs) across Europe by 2025: An open-source approach to unveil favourable locations of PV-based PEDs from a techno-economic perspective, Energy 254 (2022) 124152. https://doi.org/10.1016/J.ENERGY.2022.124152.

[40] A. Bruck, S. Diaz Ruano, H. Auer, Values and implications of building envelope retrofitting for residential Positive Energy Districts, Energy Build 275 (2022) 112493. https://doi.org/10.1016/J.ENBUILD.2022.112493.

[41] K. Angelakoglou, K. Kourtzanidis, P. Giourka, V. Apostolopoulos, N. Nikolopoulos, J. Kantorovitch, From a Comprehensive Pool to a Project-Specific List of Key Performance Indicators for Monitoring the Positive Energy Transition of Smart Cities—An Experience-Based Approach, Smart Cities 2020, Vol. 3, Pages 705-735 3 (2020) 705–735. https://doi.org/10.3390/SMARTCITIES3030036.

[42] C. Becchio, M.C. Bottero, S.P. Corgnati, F. Dell'Anna, Decision making for sustainable urban energy planning: an integrated evaluation framework of alternative solutions for a NZED (Net Zero-Energy District) in Turin, Land Use Policy 78 (2018) 803–817. https://doi.org/10.1016/J.LANDUSEPOL.2018.06.048.

[43] M. Sotos, Chapter 5 - Identifying Scope 2 Emissions and Setting the Scope 2 Boundary, in: World Resources Institute (Ed.), GHG Protocol Scope 2 Guidance, U.S.A., 2015: pp. 32–41. https://ghgprotocol.org/sites/default/files/standards/Scope 2 Guidance_Final_Sept26.pdf.

[44] C. Clemente, P. Civiero, Report di analisi del potenziale delle soluzioni SCC funzionali allo Smart Urban District nella filiera delle costruzioni finalizzata alla definizione dei network e degli stakeholder di sistema, Roma, 2016.

[45] J.A. Rankinen, S. Lakkala, H. Haapasalo, S. Hirvonen-Kantola, Stakeholder management in PED projects: challenges and management model, International Journal of Sustainable Energy Planning and Management 34 (2022) 91–106. https://doi.org/10.54337/IJSEPM.6979.

[46] S.O.M. Boulanger, B. Ruggieri, S. Pagliula, M. Massari, D. Longo, Roadmap for Community Transition Pathways. Guidelines, D5.3 of the Horizon 2020 project GRETA, EC grant agreement n°101022317, Bologna, Italy, 2022.

[47] C. Cheng, V. Albert-Seifried, L. Aelenei, H. Vandevyvere, O. Seco, M.N. Sánchez, M. Hukkalainen, A Systematic Approach Towards Mapping Stakeholders in Different Phases of PED Development—Extending the PED Toolbox, Smart Innovation, Systems and Technologies 263 (2022) 447–463. https://doi.org/10.1007/978-981-16-6269-0_38/COVER.

[48] R. Heller, Positive energy in the city: innovation for a sustainable transition, Eburon Academic Publishers (2022). https://research.hva.nl/en/publications/positive-energy-in-the-city-innovation-for-a-sustainable-transiti (accessed July 24, 2023).

[49] H.M. Neumann, S.D. Garayo, N. Gaitani, D. Vettorato, L. Aelenei, J. Borsboom, G. Etminan, A. Kozlowska, F. Reda, J. Rose, P. Tuominen, Qualitative Assessment Methodology for Positive Energy District Planning Guidelines, Smart Innovation, Systems and Technologies 263 (2022) 507–517. https://doi.org/10.1007/978-981-16-6269-0_42/COVER.

[50] B. Alpagut, A.L. Romo, P. Hernández, O. Tabanoğlu, N.H. Martinez, A GIS-Based Multicriteria Assessment for Identification of Positive Energy Districts Boundary in Cities, Energies 2021, Vol. 14, Page 7517 14 (2021) 7517. https://doi.org/10.3390/EN14227517.

[51] A. Bruck, S. Díaz Ruano, H. Auer, A Critical Perspective on Positive Energy Districts in Climatically Favoured Regions: An Open-Source Modelling Approach Disclosing Implications and Possibilities, Energies 2021, Vol. 14, Page 4864 14 (2021) 4864. https://doi.org/10.3390/EN14164864.

[52] T. Binda, M. Bottero, A. Bisello, Evaluating Positive Energy Districts: A Literature Review, Lecture Notes in Networks and Systems 482 LNNS (2022) 1762–1770. https://doi.org/10.1007/978-3-031-06825-6_170/COVER.

[53] U. Kınay, A. Laukkarinen, J. Vinha, Renovation wave of the residential building stock targets for the carbon-neutral: Evaluation by Finland and Türkiye case studies for energy demand, Energy for Sustainable Development 75 (2023) 1–24. https://doi.org/10.1016/J.ESD.2023.04.014.

[54] IPCC, Summary for Policymakers In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, Cambridge University Press, Cambridge, UK and New York, NY, USA, 2018. https://doi.org/10.1017/9781009157940.001.

[55] S. Erba, L. Pagliano, Combining Sufficiency, Efficiency and Flexibility to Achieve Positive Energy Districts Targets, Energies 2021, Vol. 14, Page 4697 14 (2021) 4697. https://doi.org/10.3390/EN14154697.

[56] B. Ridoutt, Climate neutral livestock production – A radiative forcing-based climate footprint approach, J Clean Prod 291 (2021) 125260. https://doi.org/10.1016/J.JCLEPRO.2020.125260.

[57] M. Kuzmic, P. Civiero, Impulse #1 Climate-neutral Districts and PEDs: "in operation vs. life cycle", a story-telling approach to address multiple stakeholders' perspectives?, Lisboa, 2023.

[58] C. McGookin, D. Süsser, G. Xexakis, E. Trutnevyte, W. McDowall, A. Nikas, K. Koasidis, S. Few, P.D. Andersen, C. Demski, P. Fortes, S.G. Simoes, C. Bishop, F. Rogan, B. Ó Gallachóir, Advancing participatory energy systems modelling, Energy Strategy Reviews 52 (2024) 101319. https://doi.org/10.1016/J.ESR.2024.101319.

[59] M. Haase, D. Baer, Implementation of positive energy district concepts and energy master plans for decarbonization of districts, Acta Polytech CTU Proc 38 (2022) 546–552–546–552. https://doi.org/10.14311/APP.2022.38.0546.

[60] M.T. Nguyen, S. Batel, A Critical Framework to Develop Human-Centric Positive Energy Districts: Towards Justice, Inclusion, and Well-Being, Frontiers in Sustainable Cities 3 (2021) 691236. https://doi.org/10.3389/FRSC.2021.691236/BIBTEX.

[61] A.X. Hearn, A. Sohre, P. Burger, Innovative but unjust? Analysing the opportunities and justice issues within positive energy districts in Europe, Energy Res Soc Sci 78 (2021) 102127. https://doi.org/10.1016/J.ERSS.2021.102127.

[62] B. Reidenbach, B. Motherway, V. Rozite, P. Henriot, J. Guyon, Towards net-zero: Improving the interoperability of technologies to transform the energy system, Paris, 2022. https://doi.org/10.1787/b613e2b8-en (accessed July 5, 2023).

[63] U. Ali, M.H. Shamsi, C. Hoare, E. Mangina, J. O'Donnell, Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis, Energy Build 246 (2021) 111073. https://doi.org/10.1016/J.ENBUILD.2021.111073.

[64] J. Allegrini, K. Orehounig, G. Mavromatidis, F. Ruesch, V. Dorer, R. Evins, A review of modelling approaches and tools for the simulation of district-scale energy systems, Renewable and Sustainable Energy Reviews 52 (2015) 1391–1404. https://doi.org/10.1016/J.RSER.2015.07.123.

[65] Z. Shi, J.A. Fonseca, A. Schlueter, A review of simulation-based urban form generation and optimization for energy-driven urban design, Build Environ 121 (2017) 119–129. https://doi.org/10.1016/J.BUILDENV.2017.05.006.

[66] G. Ricciardi, G. Callegari, Digital Twins for Climate-Neutral and Resilient Cities. State of the Art and Future Development as Tools to Support Urban Decision-Making, (2023) 617–626. https://doi.org/10.1007/978-3-031-29515-7_55/FIGURES/2.

[67] A. Sola, C. Corchero, J. Salom, M. Sanmarti, Simulation Tools to Build Urban-Scale Energy Models: A Review, Energies 2018, Vol. 11, Page 3269 11 (2018) 3269. https://doi.org/10.3390/EN11123269.

[68] S. Converso, P. Civiero, S. Ciprigno, I. Veselinova, S. Riffat, Toward a Fast but Reliable Energy Performance Evaluation Method for Existing Residential Building Stock, Energies 2023, Vol. 16, Page 3930 16 (2023) 3930. https://doi.org/10.3390/EN16093930.

[69] A. Sharifi, A.R. Khavarian-Garmsir, Z. Allam, A. Asadzadeh, Progress and prospects in planning: A bibliometric review of literature in Urban Studies and Regional and Urban Planning, 1956–2022, Prog Plann 173 (2023) 100740. https://doi.org/10.1016/J.PROGRESS.2023.100740.

[70] N. Frantzeskaki, N. Kabisch, Designing a knowledge co-production operating space for urban environmental governance—Lessons from Rotterdam, Netherlands and Berlin, Germany, Environ Sci Policy 62 (2016) 90–98. https://doi.org/10.1016/J.ENVSCI.2016.01.010.

[71] N. Maas, V. Georgiadou, S. Roelofs, R.A. Lopes, A. Pronto, J. Martins, Implementation Framework for Energy Flexibility Technologies in Alkmaar and Évora, Energies 2020, Vol. 13, Page 5811 13 (2020) 5811. https://doi.org/10.3390/EN13215811.

[72] P. Civiero, M. Sanmartí Rubén García, A. Gabaldón Manuel Andrés Chicote José Antonio Ferrer Tevar Joan Enric Ricart, P.J. Franca Guillermo Escobar, D. Escobar Flor, ITP 01-2019. Distritos de Energía Positiva (PEDs) , 2020.

[73] C. McGookin, B. Ó Gallachóir, E. Byrne, Participatory methods in energy system modelling and planning – A review, Renewable and Sustainable Energy Reviews 151 (2021) 111504. https://doi.org/10.1016/J.RSER.2021.111504.

[74] P.C. Maestosi, M.B. Andreucci, P. Civiero, Sustainable Urban Areas for 2030 in a Post-COVID-19 Scenario: Focus on Innovative Research and Funding Frameworks to Boost Transition towards 100 Positive Energy Districts and 100 Climate-Neutral Cities, Energies 2021, Vol. 14, Page 216 14 (2021) 216. https://doi.org/10.3390/EN14010216.

[75] M. Bellandi, L. Donati, A. Cataneo, Social innovation governance and the role of universities: Cases of quadruple helix partnerships in Italy, Technol Forecast Soc Change 164 (2021) 120518. https://doi.org/10.1016/J.TECHFORE.2020.120518.

[76] F. Schütz, M.L. Heidingsfelder, M. Schraudner, Co-shaping the Future in Quadruple Helix Innovation Systems: Uncovering Public Preferences toward Participatory Research and Innovation, She Ji: The Journal of Design, Economics, and Innovation 5 (2019) 128–146. https://doi.org/10.1016/J.SHEJI.2019.04.002.

[77] D. Longo, S.O. Murielle Boulanger, M. Massari, G. Turci, Energy citizenship. Tools and technologies to enable transition in districts, TECHNE - Journal of Technology for Architecture and Environment (2023) 84–92. https://doi.org/10.36253/TECHNE-13721.

[78] H. Waisman, C. Bataille, H. Winkler, F. Jotzo, P. Shukla, M. Colombier, D. Buira, P. Criqui, M. Fischedick, M. Kainuma, E. La Rovere, S. Pye, G. Safonov, U. Siagian, F. Teng, M.R. Virdis, J. Williams, S. Young, G. Anandarajah, R. Boer, Y. Cho, A. Denis-Ryan, S. Dhar, M. Gaeta, C. Gesteira, B. Haley, J.C. Hourcade, Q. Liu, O. Lugovoy, T. Masui, S. Mathy, K. Oshiro, R. Parrado, M. Pathak, V. Potashnikov, S. Samadi, D. Sawyer, T. Spencer, J. Tovilla, H. Trollip, A pathway design framework for national low greenhouse gas emission development strategies, Nature Climate Change 2019 9:4 9 (2019) 261–268. https://doi.org/10.1038/s41558-019-0442-8.

[79] L.F. Schlindwein, C. Montalvo, Energy citizenship: Accounting for the heterogeneity of human behaviours within energy transition, Energy Policy 180 (2023) 113662. https://doi.org/10.1016/J.ENPOL.2023.113662.

[80] P. Burton, J. Mustelin, Planning for Climate Change: Is Greater Public Participation the Key to Success?, Http://Dx.Doi.Org/10.1080/08111146.2013.778196 31 (2013) 399–415. https://doi.org/10.1080/08111146.2013.778196.

[81] M. Cattino, D. Reckien, Does public participation lead to more ambitious and transformative local climate change planning?, Curr Opin Environ Sustain 52 (2021) 100–110. https://doi.org/10.1016/J.COSUST.2021.08.004.

[82] W.K. Fong, M. Sotos, M. Doust, S. Schultz, A. Marques, C. Deng-Beck, Global Protocol for Community-Scale Greenhouse Gas Emission Inventories, 2021.

[83] Global Covenant of Mayors for Climate and Energy, Global Covenant of Mayors Common Reporting Framework. Version 7.0., 2023.

[84] D. Satola, M. Balouktsi, T. Lützkendorf, A.H. Wiberg, A. Gustavsen, How to define (net) zero greenhouse gas emissions buildings: The results of an international survey as part of IEA EBC annex 72, Build Environ 192 (2021) 107619. https://doi.org/10.1016/J.BUILDENV.2021.107619.

[85] European Commission, European Missions. 100 Climate-Neutral and Smart Cities by 2030. Info Kit for Cities., 2021.

[86] M. Barrow, B. Buckley, T. Caldicott, T. Cumberlege, J. Hsu, S. Kaufman, K. Ramm, D. Rich, W. Temple-Smith, Technical guidance for calculating scop 3 emissions. Suplement to the corporate value chain (Scope 3). Accounting and reporting standard, 2013.

[87] BSI (the British Standards Institute), BS EN ISO 14040:2006 - Environmental management - Life cycle assessment - Principles and framework, ISO 14000 Series. Brussels: European Committee for Standardisation (CEN). (2006).

[88] F. Ascione, N. Bianco, T. Iovane, M. Mastellone, G.M. Mauro, Conceptualization, development and validation of EMAR: A user-friendly tool for accurate energy simulations of residential buildings via few numerical inputs, Journal of Building Engineering 44 (2021) 102647. https://doi.org/10.1016/J.JOBE.2021.102647.

[89] COST Action Positive Energy Districts European Network, PED-EU-NET | COST ACTION CA19126 – Positive Energy Districts European Network, (n.d.). https://pedeu.net/ (accessed October 14, 2022).

[90] Å. Hedman, H.U. Rehman, A. Gabaldón, A. Bisello, V. Albert-Seifried, X. Zhang, F. Guarino, S. Grynning, U. Eicker, H.M. Neumann, P. Tuominen, F. Reda, IEA EBC Annex83 Positive Energy Districts, Buildings 2021, Vol. 11, Page 130 11 (2021) 130. https://doi.org/10.3390/BUILDINGS11030130.

Highlights:

- ~~A review of existing methodologies for the planning and design of PED is executed.~~
- ~~Main elements, practices, and methods are collected from these methodologies.~~
- Presentation of theorical framework of methodologies for PED design and planning.
- Analysis of eight methodologies to identify trends, gaps, and good practices.
- A framework to guide municipalities in the conception of methodologies is proposed.
- This approach for holistic PED design encompasses three interconnected workflows.
- It is baseline proposal to be further defined depending on local requirements.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: