

Article

Operationalizing Community Engagement for Positive Energy Districts: A Dual-Tier Framework and Case-Validated Roadmaps

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Abstract

This study proposes a practical manual for community engagement in Positive Energy District (PED) development. It integrates evidence from three European pilot cases (Austria, Sweden, Spain). Using a dual-tier framework, it integrates an engagement framework, the Theory-of-Change (*ToC*) sequence for dynamic stakeholder roadmaps, with an assessment framework (an eight-aspect PED Matrix). The *ToC* model clarifies the socio-organizational pathway from urgency to institutionalization while the roadmaps translate these steps into actionable involvement for public, private, civil, and academic actors across top-down, bottom-up, and hybrid approaches. The proposed *ToC* framework is further supported by the PED Matrix, covering technology, process, environmental, financial, managerial, governance, social, and legal dimensions, which aims to ensure a holistic and target-oriented assessment using a simple 0–3 maturity scale. Guided by the central research question, “How can community engagement be systematically conceptualized, implemented, and tested throughout the PED life cycle using an integrated *ToC* model, stakeholder roadmap, and multi-aspect evaluation Matrix?”, this study provides practical instruments for stakeholder profiling and adaptive participation design and demonstrates application across contrasting governance, cultural, and climatic contexts. The three use cases show how engagement strategies can be tailored to secure early wins, sustain momentum, and support long-term ownership and replication. The study thus offers decision-makers and practitioners a scalable, evidence-based approach to embed inclusive participation within technical PED delivery and to strengthen the social robustness of district-scale energy transitions.

Keywords: community engagement; positive energy districts; participatory energy transition; stakeholder roadmaps; theory of change; PED Matrix



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1. Introduction

1.1. Context and Objectives

The built environment accounts for approximately 30% of the total energy consumption and more than 55% of global electricity demand [1]. Within this context, the European Union has set an ambitious target of establishing 100 Positive Energy Districts (PEDs) by 2025, signaling a strategic shift from building-scale to district-scale energy system transition [2–4]. Over 60 PED projects had been identified across Europe by 2020 [2,5], yet the operability of most of the identified PEDs currently remains limited, with a handful emerging as being

fully functional [5,6]. This makes the target of designing 100 fully functional PEDs a highly ambitious one due to technology, social, economic, and legal challenges [6–9]. As PEDs represent a transformative approach to urban sustainability through integrated energy systems, their successful implementation is often hindered by social barriers, such as lack of either awareness or knowledge, trust issues, administrative complexity, or neglected citizen engagement [10–17]. To overcome these obstacles, targeted strategies are needed. They should focus on stakeholder collaboration, capacity building, strong policy support, and coordinated and multi-stakeholder action [18] adapted to the local context. Building on this gap, this study therefore proposes an operational, lifecycle-aligned framework for a meaningful and fair community and stakeholder engagement in PEDs.

Accordingly, this study addresses the central research question of “*how can community engagement be conceived systematically, implemented, and tested throughout the PED life cycle with an integrated ToC model, stakeholder roadmap, and multi-aspect evaluation Matrix?*”. To answer this, this study (i) operationalizes a ToC-guided, lifecycle-aligned stakeholder roadmap (in Sections 2 and 3); (ii) investigates whether the PED Matrix captures capacities, and which dimensions are most sensitive (in Sections 2.5, 3 and 4); and (iii) examines how governance models and local context condition the effectiveness and required adaptations of the framework through contextual profiles (in Section 1.2), cross-case contrasts (in Section 3), and transferability analyses (in Sections 4 and 5).

1.2. Related Works and Previous Contributions in Positive Energy Districts (PEDs)

Having positioned the gap, this section outlines the related work and contribution. When checking available early community-engagement solutions, they mainly prioritize local ownership, flexibility, and iterative learning [19–26]. To address structured, outcome-oriented planning and evaluation, there is a need for structured participatory models. However, existing approaches often remain fragmented, lacking a unified framework that systematically connects strategic planning, stakeholder participation, and evaluation across the full lifecycle of PED projects. Therefore, the authors propose a dual methodology that supports both the mobilization of community engagement and the translation of practice within complex socio-technical systems [27]. The methodologies are not prescriptive but are structured to be tailored to specific local contexts, enabling practitioners to deploy effective, sustainable engagement strategies that are both technically sound and socially resilient. Table 1 explicitly compares the early solutions and the proposed dual-tier framework in terms of timing, stakeholder role, adaptability, evaluation, communication, and integration.

Table 1. Comparison of early/community engagement and dual-framework approaches in PEDs.

Aspect	Early/Community Engagement Solutions	Dual-Tier Framework
Timing	Initiated at project’s beginning [20–22,26]	Structured across the entire lifecycle of a project
Stakeholder Role	Co-creation, empowerment, flexible roles [20,22,24,25]	Defined roles, mapped interactions
Adaptability	Highly context-sensitive, iterative [19,23,26]	Systematic, but can be adapted via ToC model
Evaluation	Feedback loops, participatory assessment [19,23,26]	Outcome-driven, explicit causal pathways
Communication	Diverse, culturally relevant, ongoing [21,22,24]	Structured, roadmap-based
Integration	Focus on local ownership and interconnected social elements [19,20,25]	Emphasizes alignment and interdisciplinary work

2. Methodology

To address these implementation barriers, this section details a methodological framework that is built upon the insights consolidated in the PED-ACT Charter & Manifesto for community engagement (D6.2). The study employs a dual-tier framework for community engagement in PEDs. The engagement framework integrates a Theory-of-Change (*ToC*) sequence with stakeholder roadmaps to guide participation across the project lifecycle. The assessment framework is provided by an eight-aspect PED Matrix, which is used to evaluate capacities and maturity over time [10–17]. The framework is designed for a Quadruple Helix (*QH*) model that integrates the fourth helix of the civil sector into the often-involved three key sectors in PEDs, which are public, private, and academic [28–31], and addresses the need for a transparent, comparable assessment of joint engagement over the project life-time [19].

2.1. Theory-of-Change (*ToC*) and Lifecycle Alignment

Firstly, the use of the *ToC* model [19] provides a strategic engagement framework for planning and an evaluation framework that clearly explains the rationale and pathway for guiding the socio-organizational transformation, which is essential for driving social change and embedding a new changed culture. It articulates eight cumulative phases. They are Phase 1: establish urgency, Phase 2: build a multi-stakeholder coalition, Phase 3: formulate a strategic vision, Phase 4: communicate the vision, Phase 5: enable concrete action, Phase 6: generate tangible wins, Phase 7: sustain acceleration, and Phase 8: institutionalize change.

The second core methodology consists of a set of dynamic stakeholder roadmaps, stemming from an urban planning and green transformation background, which are then related to the *ToC* model. It supplements the process with practical instruments that translate the strategic *ToC* framework into action pathways for engaging specific actor groups throughout the entire lifecycle of a project—from idea development to manifestation on the social lives and replication.

2.2. Stakeholder Mapping and Analysis

Building on the socio-organizational dynamics defined by the *ToC* model's phases, the stakeholder roadmaps accordingly provide concrete pathways for engaging diverse actors throughout the PED lifecycle. To effectively guide participation, it is necessary to profile actors using the six-attribute mapping framework in Table 2. This framework provides a systematic methodology for mapping and analyzing the complex ecosystem of entities involved in a PED. It goes beyond simple identification by requiring detailed analysis of six key attributes for each stakeholder or group: the specific actor identities within broader categories, core agenda and strategic objectives, the arena or jurisdictional scope of influence, existing alliances and networks, the potential role within the PED's development, and inherent limitations such as resource constraints or regulatory barriers.

Table 2. Actor profile framework required for a stakeholder roadmap.

Attribute	GUIDING QUESTIONS
1—Actor	Who are the individuals within actor categories?
2—Agenda	Which mandates, missions, and objectives do they have?
3—Arena	Where does the actor operate and what is their scope?
4—Alliances	Which relationships exist with other actors?
5—Role in PED	Which potential role can the actor play?
6—Limitations	Which constraints, challenges, and capacities do they have?

Because coalitions and capacities evolve during multi-year PEDs, stakeholder profiles are revisited at milestones or when major contextual changes occur, transforming the profiles from a static list into a dynamic diagnostic process. By answering the guiding questions for each attribute, project planners can construct a nuanced understanding of the power dynamics, incentives, and potential points of conflict or synergy long before implementation begins. This pre-emptive analysis is crucial for designing targeted engagement strategies that align with each actor's specific motivations, capabilities, and operational context, thereby increasing the efficacy of participation efforts. In this way, dynamic stakeholder management is embedded into the framework: stakeholder interests, influence, alliances, and capacities are monitored over time, and roadmaps are adjusted accordingly to maintain resilience and social sustainability across the PED lifecycle.

2.3. Roadmap Development Process

It is important to develop a well-structured methodology for a strategic roadmap, which consists of a process that translates engagement principles into an executable plan. This process is guided by a sequence of five strategic interrogatives that ensure a comprehensive and justified engagement strategy (shown in Table 3). Planners need to define who the key stakeholders are and establish engagement priorities; understand why these actors are motivated to participate and what their core collaboration needs entail; specify what types of influence they will have and the necessary multi-stakeholder constellations; determine which formal structures and governance frameworks will facilitate this interaction; and, finally, select how to implement specific participation methods and organizational approaches.

Table 3. Strategic roadmap design based on 5 key questions.

Five Key Questions	
1—Who	Potential counterparts and engagement priorities
2—Why	Motivations for participation and collaboration needs
3—What	What types of influence and engagement constellations are required?
4—Which	Which engagement structures and frameworks are appropriate?
5—How	Participation methods and organizational approaches
6—Limitations	What constraints, challenges, and capacities exist?
Roadmap applications	
Bottom-up Roadmaps	Citizen-led initiatives evolving from energy communities to comprehensive PED development
Top-down Roadmaps	Municipal or policy-driven projects requiring community integration
Technical Roadmaps	Expert-led innovation projects needing social acceptance
Hybrid Roadmaps	Combined and linked approaches adapting to local circumstances and project evolution

This systematic questioning ensures that the resulting roadmap is not a generic checklist but a bespoke, evidence-based strategy. It forces a critical examination of the underlying rationale for engagement, aligning methods with specific project goals and stakeholder characteristics. The output is a coherent plan that logically connects identified needs with defined actions, allocated resources, and expected outcomes, thereby maximizing operational efficiency and strategic impact.

To demonstrate practical utility across diverse contexts, the methodology is applied through several distinct roadmap applications. These archetypes address common development paradigms, depending on the steering actor(s) of the process. Bottom-up roadmaps

provide a pathway for citizen-led initiatives, such as energy communities, to scale into comprehensive PED project(s). A top-down roadmap is typically guided by municipal or developer-driven projects. Their roadmap needs to achieve meaningful community integration and secure a social license to operate. Technological or innovation-driven roadmaps focus on expert-led innovation projects, outlining the necessary steps to build social acceptance and adoptability for complex technological solutions.

Recognizing that real-world projects are rarely pure archetypes, the study also details the development of hybrid roadmaps. These are adaptive frameworks designed to synthesize elements from the other models, allowing project consortia to respond to shifting local circumstances, evolving power dynamics, and new opportunities throughout the project lifecycle. This flexible approach ensures that the engagement strategy remains relevant and effective from initial planning through to long-term operation and management.

2.4. Assessment Framework: Positive Energy District (PED) Matrix

Following the description of these practical approaches, a comprehensive multidimensional evaluation framework is essential to support the ongoing monitoring and systematic assessment of stakeholder engagement outcomes.

2.4.1. Purpose and Scope of the PED Matrix

To ensure comprehensive coverage beyond technology, the PED-ACT project formalizes the complexity of PED development into an integrated eight-aspect framework [32], herein termed the PED Matrix. The matrix uses a Natural Language Processing (NLP) technique that is used for text mining PED documents. By automatically extracting and analyzing key themes from unstructured data, it enables scalable insights into PED characteristics and emerging trends [32].

As the sequentially represented eight aspects [33] in Figure 1, the model serves as a foundational schema, delineating the critical, interconnected dimensions that require systematic and concurrent management throughout the energy transition process. It moves beyond a purely technical focus by establishing a holistic set of task fields that must be actively mastered by the responsible stakeholders to ensure project viability and success [24,26].

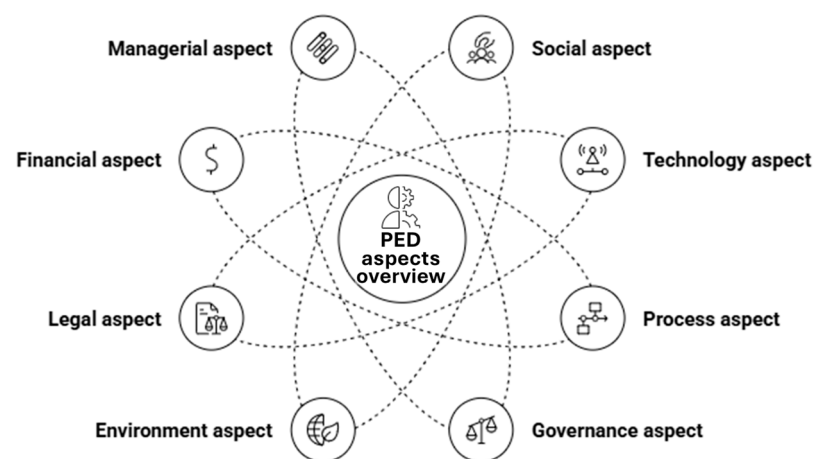


Figure 1. PED Matrix 8-aspect overview.

The framework's core technical and operational domains encompass the technical aspect, focusing on energy system design, renewable integration, and smart infrastructure. The process dimension addresses the sequencing of implementation, management of innovation, and strategies for risk mitigation. The environmental dimension emphasizes

resource optimization, lifecycle assessment, and circular economy principles. These efforts are all supported by the financial pillar, which focuses on developing viable funding models, robust business cases, and long-term investment strategies. Complementing this is the managerial function, which addresses long-term operational governance and fosters competency development and strategic partnership management.

2.4.2. Eight Dimensions and the 0–3 Maturity Scale

In each of the eight critical PED aspects, the PED Matrix is evaluated through five detailed sub-categories, employing a 0–3 rating scale. It supports systematic benchmarking of projects facilitating targeted gap analysis and the prioritization of capacity-building measures [32]. The scoring system was developed by the authors together with the whole consortium of the PED-ACT project. Then the authors tested the scoring system on 11 cases across Europe, and some results are published and selected for this study. To illustrate the process, the authors first conducted baseline studies about the cases by developing the related digital PED simulation models and PED development strategies for the cases. The scoring was then drafted by the authors based on the PED development strategies and the baseline results, with the scoring value and the reasoning behind the suggested score, which were then discussed and reviewed with the stakeholders of the cases through a series of workshops. The stakeholders gave their consent or disagreement regarding the scoring results during the workshops. The iterative discussions occurred in a collaborative way when there was a disagreement. The evaluation criteria are explicitly tailored to each aspect, assessing factors such as early stakeholder involvement (social), the PED development process within the local conditions (process), alignment of technical solutions with local potential (technology), multilevel coordination and transparency (governance), consumption optimization and environmental integrity (environmental), the advancement of innovative and community-centered legal frameworks (legal), financial stability, investment capacity, and cost transparency (financial), and long-term operational capacity through skills building and partnership development (managerial).

Crucially, the PED Matrix [32] integrates essential socio-institutional layers that underpin successful implementation. These include the governance aspect, which defines clear decision-making procedures, allocates roles, and addresses power distribution among stakeholders. Simultaneously, the social dimension prioritizes community development, inclusive participation, and continuous capacity building to foster public acceptance and agency. Meanwhile, the framework is completed by the legal component, which ensures not only regulatory compliance but also the development of innovative, community-centered legal frameworks that enable new models of ownership and participation.

By treating these eight aspects as interdependent task fields rather than siloed considerations, the PED Matrix [32] provides a comprehensive toolkit for navigating the multifaceted challenges of district-scale energy transition and steering complex stakeholder collaborations toward a common objective.

2.4.3. Need for Four Levels of Citizen and Stakeholder Participation in Energy Transition Projects

While the PED Matrix forms the assessment framework, this study further operationalizes the engagement framework through a structured four-level participation model [34]. The pyramid diagram in Figure 2 visualizes the progressive levels of stakeholder engagement across the PED lifecycle along two coupled gradients of both the level of participation and the level of influence. As one moves upwards, stakeholders shift from passive recipients of information to active co-creators and ultimately formal/informal decision-making partners, which maps to the PED Matrix scoring from the eight dimensions of technical, social, governance, financial, legal, environmental, managerial, and process. In addition,

within the model, it contains an engagement ramp that shows the intended trajectory of how projects can stimulate stakeholders from low influence into sustained collaboration.

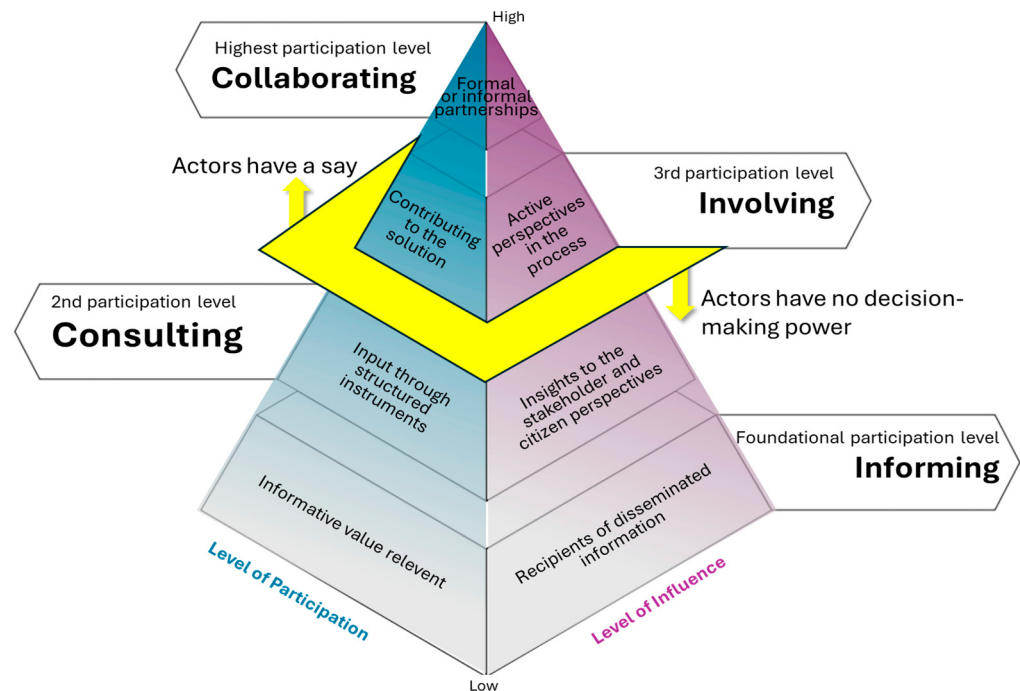


Figure 2. Four levels of PED participation with their impacts on both influence and participation.

The participation model advances to deeper participant integration with the involving stage, characterized by activating participation in the design process through workshops, charrettes, and advisory committees. In this stage, the participants contribute to the solution development, which silently promises that their contribution will have an impact on the decisions made. This type of participation is very important in enabling participants to recognize the customized nature of the developed ideas, solutions, pathways, and projects. The highest participation level, collaborating, constitutes a formal or informal partnership where stakeholders, particularly community representatives, are integrated into the core decision-making process, such as through joint steering committees, collective decision-making, or shared governance models, granting them direct agency over project outcomes.

By following this, Figures 3–6 specifically exemplify how participation can change over the process of a project. The foundational level of engagement and informing establishes essential (typical) one-way communication to disseminate data and decisions via channels such as project websites, newsletters, and public presentations. Even though this type of participation is often practiced, the informative value is often forgotten and hidden behind promotional ambitions. The subsequent level, consulting, introduces a two-way feedback mechanism to gather input through structured instruments like surveys, webinars, and focused group discussions, although the final or true decision-making authority remains internally within the project team. Regardless, consultations with local actors allow the steering teams to understand the ambitions and aims of the stakeholders and citizens and assist in engaging them over a longer period, especially if their ambitions are respected and integrated in the process and the energy transformation design.

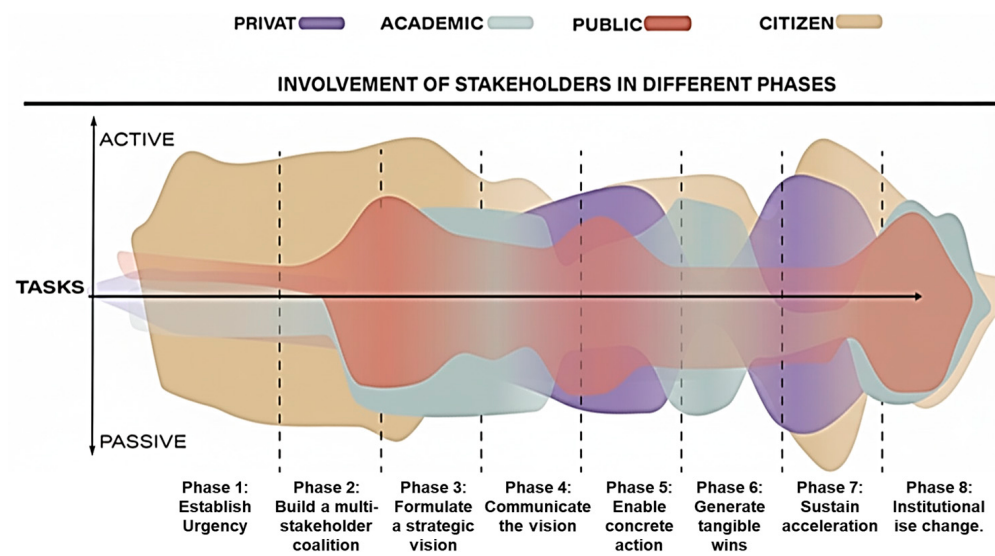


Figure 3. Quadruple helix involvement across 8 ToC lifecycles.

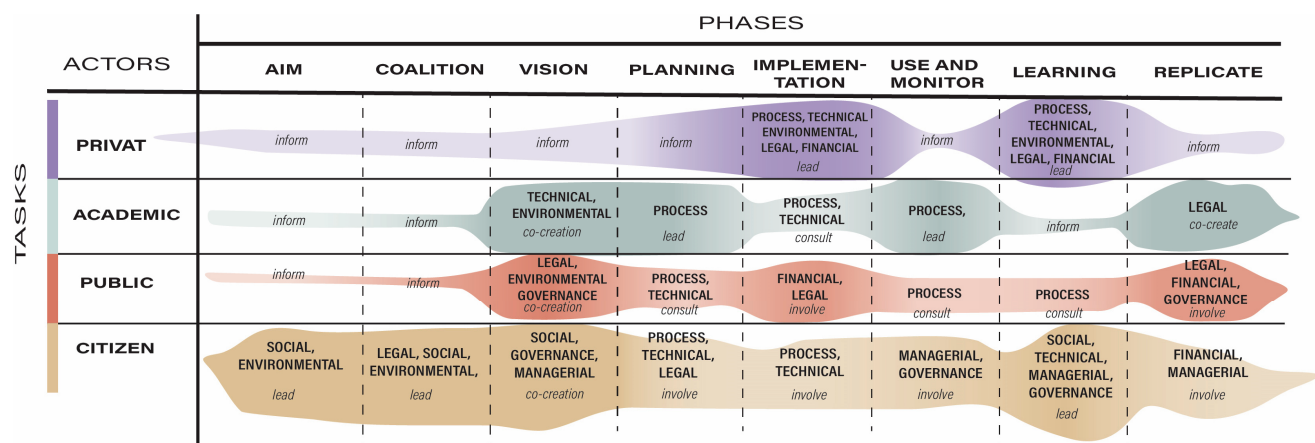


Figure 4. Actors’ tasks across each project phase in the bottom-up roadmap.

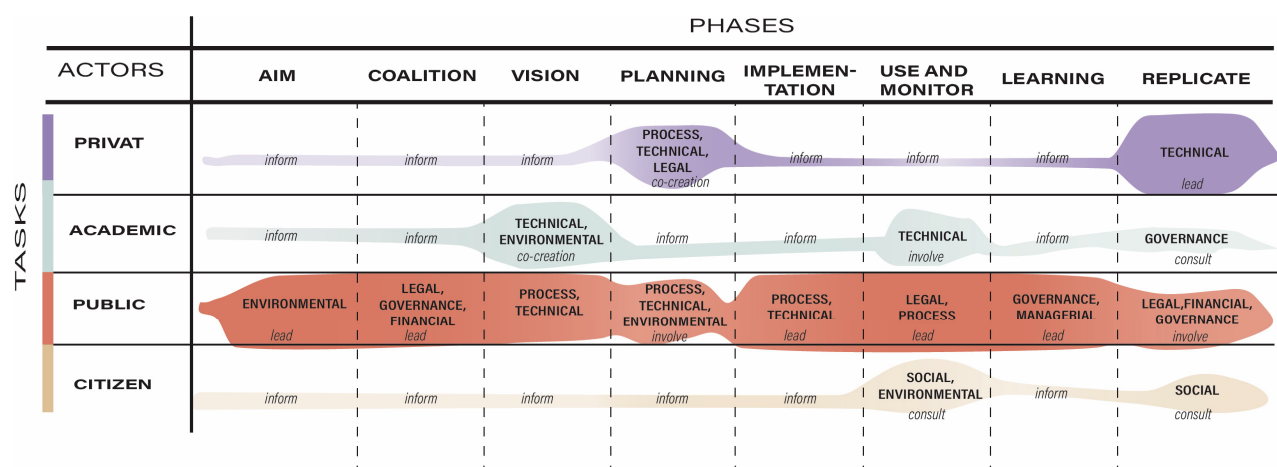


Figure 5. Actors’ tasks across each project phase in the top-down roadmap.

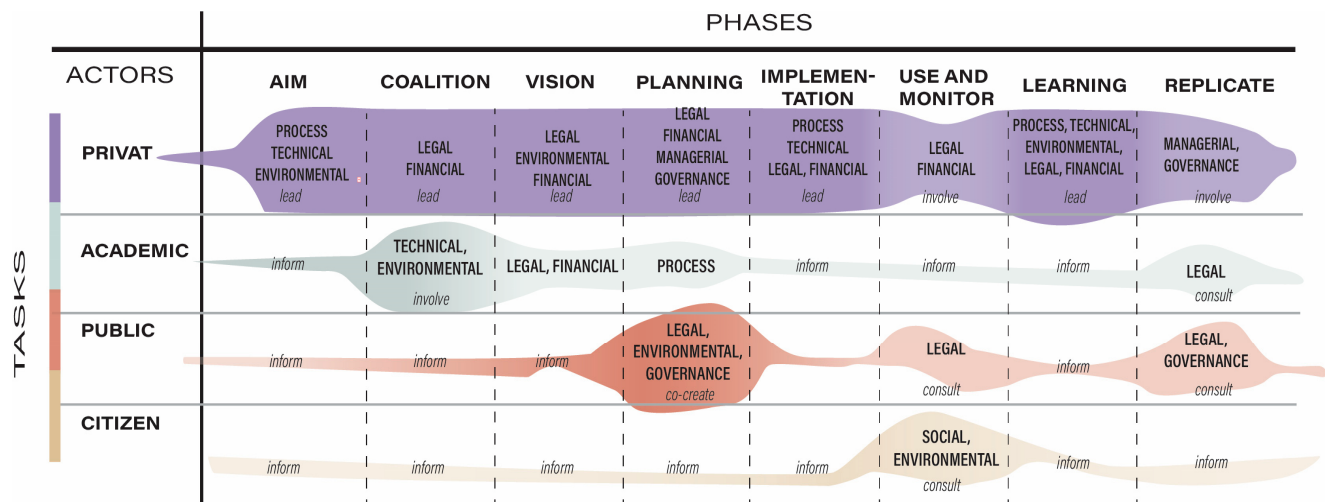


Figure 6. Actors' tasks across each project phase in the innovation-led roadmap.

The difference between experts and community is grounded (a) in the knowledge and experience and (b) in the attachment to the project. Experts, which initiate, lead, guide, decide, and implement energy projects, and have extensive knowledge about the topic, are dealing with the topic and the case professionally within the framework of their work and funding, which brings serious limitations regarding their capacity and motivation, connected to their attachment to the case or pilot. Community members in contrast and in general have less competence in energy topics, where their knowledge is fragmented but the case in development and the solutions to be developed are intervening in their living circumstances, built environment, and behavior, potentially bringing significant changes to their habits. Even though both actors seem to be synergetic at first glance, the power dynamics and asymmetry allow them to carry out different things. In the case of top-down development, the project experts often overrule all decisions to be made in a centralized manner. This can create conflictual situations, e.g., resistance from the community to the project, which may delay (financial burden for the project) or even hinder the project from implementation. Vice versa, in a bottom-up initiated and driven project, the strong advocacy of the community can be perceived as “stubbornness” and neglected by decision-makers, which delays or hinders either funding or permits for the implementation. Both conflict potentials can be handled better in a bottom-linked approach (hybrid version) with differentiated participation activities. To show the variety in how knowledge and capacity asymmetries may impact a case, three different cases were chosen in this paper to illustrate these observations. On the one hand the main drivers in the selected cases come from different backgrounds (citizens, administration, and industry); then, the cases are significantly different in context as described in Section 3. How the knowledge imbalance is unfolding in the pilot cases can be found in Sections 3.1–3.3, respectively. These frictions and asymmetries highlight the need to coordinate roles across all actor groups.

2.4.4. Quadruple Helix (QH) Across Lifecycle Phases

Within the engagement framework, effective implementation of this participation model requires the systematic inclusion of all key societal actors with varying capacities across all eight *ToC* lifecycles in PED projects, as conceptualized in the framework of the *QH* and *ToC* model (shown in Figure 3). This approach mandates the coordinated engagement of the public sector (municipalities, public agencies, regional administrations), the private sector (energy utilities, technology providers, product suppliers, developers), the aca-

demic sector (research institutions, universities), and the civil sector (citizens, community groups, NGOs).

The interdependence of these sector actors is critical. The technical, innovation-driven transformation pathways, steered by academia and industry, must be aligned with the regulatory and planning frameworks of the public sector and grounded in the social legitimacy provided by the civil sector. This integrated framework ensures that participation is not merely an exercise to tick boxes but a strategic function that enhances the robustness, financial viability, societal acceptance, and social sustainability of the developed PED. This is not merely the goodwill of the project coordinators but ensures that the cost-intensive implementation of a PED is accepted and used well by the people affected.

2.5. Implementation Approaches in PED Development (Roadmap Archetypes)

With the converted *ToC* model's phases and *QH* model's responsibilities in the roadmap framework defined, it is essential to address varied project leadership and challenges through three implementation approaches. These are engineered to accommodate diverse development approaches in this paper, including top-down, bottom-up, and hybrid models, while remaining sensitive to unique local contexts and resource capacity constraints, thus exhibiting how different approaches, partnerships, and skills can still lead to the desired outcome.

2.5.1. Bottom-up PED Development

The bottom-up approach is typically led by community groups and local stakeholders who drive grassroots initiatives. Figure 4 presents a pathway for citizen-led energy communities to grow and become a PED. The larger area representing citizen participation illustrates how grassroots initiatives can evolve into full-fledged PEDs. This trajectory typically originates with foundational renewable energy installations, such as solar PV or thermal projects and opening the energy production to share with the neighbors, which serve as a tangible starting point for community mobilization and capacity building. The evolution from this initial energy-sharing project toward a comprehensive PED is not a simple one but rather driven by a deliberate and progressive strategy of multi-stakeholder engagement and the formation of strategic partnerships at crucial phases of the project. This scaling process requires the community to systematically expand its scope beyond a one-fits-all energy generation project to integrate energy efficiency, energy mix, smart grid management, and e-mobility, thereby addressing the full spectrum of a PED's technical requirements. This necessitates a strategic shift in governance, moving from a community group toward a more structured entity, capable of managing complex contracts, regulatory compliance, multiphase and strategic investments, and long-term asset operation.

Critical to this transition are several key success factors. Primarily, the initiative must be built on a strong pre-existing social foundation that is characterized by high levels of trust, shared purpose, and active local leadership. A clear and compelling local vision co-created by the community is essential to maintaining alignment and momentum throughout the multi-year development process. Furthermore, accessing technical and legal support is paramount to bridging inherent knowledge gaps in project development, engineering, and navigating complex regulatory environments.

Finally, the long-term viability of the venture is contingent on establishing sustainable financing frameworks that move beyond initial grants to incorporate viable business models, revenue-sharing mechanisms, and access to commercial investment. The absence of any of these factors—social cohesion, vision, expert support, or sound economics—represents a significant risk that can halt the transition from a simple energy community to an integrated, citizen-driven PED.

2.5.2. Top-down PED Implementation

Top-down implementation is another approach that is primarily led by policymakers or territorial authorities guiding the strategic direction. As illustrated in Figure 5, public sector actors, particularly municipal authorities, play key roles in catalyzing PED development as a mechanism to implement ambitious urban climate and energy policies into the urban fabric. However, the technical and political complexity of these district-scale projects necessitates more than top-down implementation: it requires systematic community engagement to ensure social legitimacy, secure a license to operate, and ultimately guarantee the project's long-term effectiveness and integration into the urban fabric. This engagement transforms the municipal role from a sole director to a facilitating partner, orchestrating a multi-stakeholder process.

A primary challenge in this public-led model is mitigating the risk of community disconnection, where projects are perceived as externally imposed rather than collectively owned. This often stems from a transactional approach to participation, where communication is limited to informing rather than genuine collaboration. To counter this, municipalities must move beyond compliance-level consultation and develop meaningful participation opportunities that grant citizens and local businesses tangible influence over key design, solutions, benefits, and governance decisions.

This necessitates a commitment to long-term community capacity building. Residents and local stakeholders often lack technical literacy or procedural understanding to engage with complex energy planning on equal footing. Public sector leaders must therefore invest in educational initiatives and provide accessible resources to build this competency, ensuring that participation is informed, constructive, and equitable rather than superficial. Overcoming these challenges is a strategic imperative. Failure to do so can lead to significant project delays, financial burdens, political opposition, citizens' resistance, and underutilized infrastructure. By proactively designing engagement strategies that address disconnection, create meaningful involvement, and build local capacity, public sector leaders can de-risk PED implementation, enhance project outcomes, and foster the social capital necessary for a sustainable urban energy transition.

2.5.3. Technical and/or Innovation PED Approach

The third approach, technical or innovation-led development, characterizes a prevalent PED model that is mainly led by experts and project managers focusing on data-driven and technology-enabled participation. As illustrated in Figure 6, projects are initiated by a consortium of technology or utility providers, research institutions, and engineering firms, prioritizing the deployment of cutting-edge, integrated energy solutions. A majority of PED projects are driven and financed by research and innovation funding [35], underlining the importance of the technical innovation approach. While this approach drives innovation and demonstrates technical feasibility to innovative ideas, it inherently presents a distinct set of socio-technical engagement challenges. The main challenge lies in the significant knowledge asymmetry between project experts and the community, which often hinders effective communication and genuine dialogue.

The technical complexity of systems like multi-carrier energy grids, advanced building automation, and bidirectional power flows is often alien to laypersons, leading to potential misunderstandings, mistrust, and a perception of the technology as being opaque or imposed. Consequently, a primary risk for expert-led projects is achieving technical performance at the expense of social adoption, where a perfectly engineered system fails due to a lack of user understanding, acceptance, or ability to integrate the proposed solution in their lives effectively.

Therefore, the engagement strategy for such projects cannot be an afterthought. It must be a core, integrated component of the technical design process. The objective shifts from simply informing the community to translating technical concepts into relatable benefits and tangible user experiences. This requires experts to employ demystification tools (such as digital twins, physical demonstrators) and clear analogies, which make abstract technologies comprehensible and relevant to daily life.

Ultimately, the goal of engagement in an expert-led context is to build informed consent and active co-operation. This involves structuring participation to gather critical user insights that can refine system design for usability while simultaneously training and empowering the community to become competent operators of the new energy environment. This transforms residents from passive recipients into active partners, ensuring that the sophisticated technological solution is not only deployed but is also effectively utilized and sustained.

2.6. Case Selection and Data

The development of these frameworks was informed by a rigorous, mixed-methods research approach to ensure both scholarly robustness and practical applicability. This methodology synthesized a comprehensive review of the existing literature with an in-depth empirical analysis of the three European pilot case studies. The three cases were located in three different climate and culture zones. The process was further refined through iterative participatory workshops and subjected to systematic validation by a panel of domain experts. The experts have an academic background throughout Europe and are involved in the projects of the case study, as well as the international networks of DUT and PED-EU-NET. Consequently, the resulting tools are not theoretical constructions but are grounded in empirical evidence, consent of the local actors, and real partnership testing. The different roadmaps are connected to three cases, which were also explored in two different European projects, namely PED-ACT and POSEIDON, with a variety of partners from academia, industry, civil organizations, and public bodies. This approach ensures that the study provides evidence-based, adaptable, and scalable methodologies for embedding effective participatory processes into the technical and governance frameworks of PEDs.

3. Results: Case Applications

The following cases in this section demonstrate how the dual-tier framework was instantiated in contrasting governance and cultural contexts and the near-term wins that it enabled. The cases are summarized in Table 4 to give an overview. This paper followed the idea of elaborating a comprehensive roadmap for the potential main drivers of an enhanced PED process. The work in different groups and projects let us identify three potential main drivers, which are partially in line with the *QH* actors. For this study, the authors ruled out that the academia could be such a driver in general, as their main aim and objective is to research, innovate, and educate, and not to manage a transition or sustain an energy project per se. But since their power to innovate, contribute, and give credibility and expertise is very valuable, they are considered as very important partners in the enhanced PED development and implementation in all three roadmaps.

Table 4. Case summary.

	Bottom-Up	Top-Down	Private Sector
Location	Rural area in Austria	A midsized city, Sweden	An urban metropolitan area, Spain
Period of interaction and collaboration	2021–2025	2022–2025	2024–2025
Data types	focused interview, baseline study, PED modeling, PED Matrix self-assessment, PED case book, business canvas, co-creation reports	baseline study, PED modeling, PED Matrix self-assessment, PED case book, business canvas, co-creation reports	focused interview, baseline study, PED modeling, PED Matrix self-assessment, PED case book, business canvas, social programming
Participants	Citizens in REC board and members (prosumer, producer, consumer, multiplier members)	University researcher, municipal teams, energy sector teams, (municipal) housing company	Industrial actors in REC board, university researcher, municipal teams
Built environment	Mainly single-family homes, some multi-family homes, very limited mix of uses	Multi-family homes, housing only	Industrial area of the municipality
Specialty	The local authorities are not collaborating with the REC. The boundaries of the community reach multiple municipalities. The REC as an association performs social, cultural, and environmental activities for the community mainly as voluntary contributions	The residents of the buildings impacted (in rent) are not included in the development or upgrade to PED of the housing complex. The city has a CCC (Climate City Contract)	The REC started as an initiative of the businesses but is nowadays in close collaboration with the municipality. They have a business concept addressing private households but do not yet reach the citizens

3.1. Bottom-Up Case: Austrian Renewable Energy Community

The case of Bürgerinnen-KRAFT-werk Schönbühel-Aggsbach, Austria is a Renewable Energy Community (REC) operating within the UNESCO-protected Wachau Cultural Landscape [36]. It is a context defined by a small population and stringent heritage preservation constraints. The initiative's development process demonstrates a strategic evolution from a nature conservation focus to systemic integration of the energy transition, governed by a four-member volunteer board. Its key innovation lies in its integrated approach, synergizing community activities with cultural and environmental programming while employing heritage-compliant technology solutions to navigate strict regulatory requirements.

Analysis using the PED Matrix in Figure 7 [32] reveals a stark contrast between socio-process strengths and technical-administrative challenges. In terms of social aspects, the project scored exceptionally well for its size. Accordingly, this is evidenced by high engagement through integrated activities, strong community ownership, and effective volunteer operations. Conversely, it faced significant challenges in PED-related technology aspects, including limited in-house expertise necessitating external support and the complexity of designing renewable systems within heritage and citizens' financial constraints. Key lessons indicate that pre-existing social capital provides a foundational advantage, that bundling multiple value propositions (cultural, environmental, energy) increases commitment, and that overcoming technical and regulatory barriers requires forming strategic partnerships and developing contextually creative solutions. This case also confirms the knowledge asymmetry between energy experts and community, as described in Section 3.4. For many technical aspects related to the REC, the community learned and self-taught in order to be as operational as the REC, but in order to develop, implement, and run a more

complex energy concept like a PED they need external support, which is rather difficult to access for smaller communities in rural areas, like in this case. This conclusion confirms the necessity of the quadruple collaboration as described in Section 2.5.1.

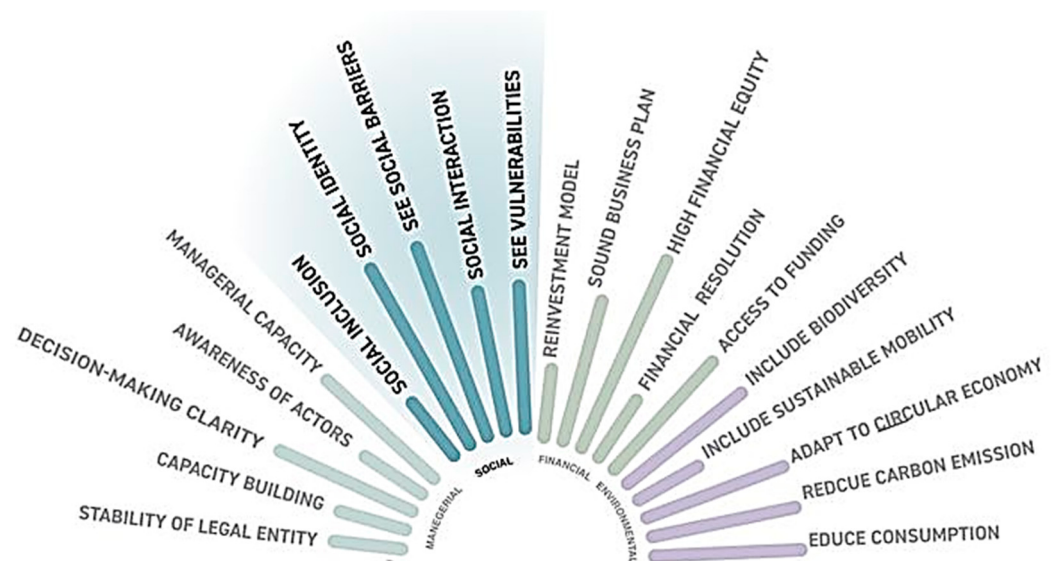


Figure 7. Strengths of the REC in Austria.

3.2. Top-Down Case: Swedish Municipal Leadership

This case examined a neighborhood in the municipality of Borlänge, Sweden. Analysis using the PED Matrix in Figure 8 reveals that this municipality prioritized the environmental aspects through a City Climate Contract (CCC), which defines goals, ambitions, and actions to achieve the climate goals. Therefore, the team's self-evaluation resulted in highest scores for this aspect. The initiative has demonstrated significant achievements in its systematic integration of biodiversity, advanced sustainable mobility planning, the adoption of circular economy principles, and measurable progress toward ambitious emission reduction targets, establishing it as a leader in municipal climate action.

Despite these operational successes regarding climate action, the PED development project encountered substantial challenges stemming from macro-level governance, including gaps in the national legal framework that limit community energy development, and a lack of clear regulations to facilitate and standardize citizen participation in energy projects. Regarding the knowledge asymmetry, the decision-makers have no room to operationalize community contribution and co-creation, which leads to top-down projects and leaves the specific community uninformed or out of the process. The primary lesson is that local environmental commitment and technical execution are necessary but insufficient; they must be supported by enabling supra-municipal legal structures. This underscores a critical expansion of municipal leadership responsibility: beyond local implementation, it must include active advocacy at higher governmental levels to reform regulations and explicitly facilitate community-owned energy models. The summary of the case underlines the importance of the QH approach for the PED process.

plementation of strategies to engage the wider community beyond commercial partners, which could be compensated with a *QH* approach. The collaboration at the current stage also shows the typical symptoms of the knowledge asymmetry as described in Section 3.4.



Figure 9. Strengths of the industrial driver in Spain.

3.4. Walkthrough of the Three Illustrative Cases

Viewing the energy transition as a *ToC* process elevates participatory activities, such as developing collective urgency and vision, to the same importance as typical urban planning phases like energy planning and solution implementation. This approach also adds significant value to the roadmap by integrating replications and up-take as phases to the process-wise organized PED. This transforms a PED project into a potent energy transition process with wider impact. However, the way that the process and phases can be served depends on the driving actor. From the perspectives of citizens, the private sector, and public administration, the process can be enriched with the contributions of the other actors and activities. The connection between the PED and *ToC* process emphasizes knowledge asymmetry and the varying needs for support and collaboration among project drivers.

The bottom-up pathway, with the case of Austrian REC, is expected to excel in social and managerial aspects. This means that the collaborative vision-finding phase of the *ToC* can be handled with the existing structure and advocacy of the citizen group. However, bottom-up initiatives need support and collaboration in planning and implementing more complex energy projects like a PED. In contrast, both the top-down and private sector actors require support and collaboration in the collective vision-finding phase, which is reflected in lower scores in social aspects. In these cases, at least an informative consultation exchange with other sectors, including citizens, is crucial to ensure alignment among all parties.

4. Discussion and Suggestions

4.1. Key Findings

By answering the central research question of “*how can community engagement be conceived systematically, implemented, and tested throughout the PED lifecycle with an integrated ToC model, stakeholder roadmap, and multi-aspect evaluation Matrix?*”, this analysis provides three critical findings structured by RQ1, RQ2, and RQ3.

Regarding RQ1—operationalizing a ToC-guided stakeholder roadmap within the engagement framework—the study demonstrates that operationalizing such a roadmap depends on dynamic stakeholder profiling, iterative engagement alignment, and transparent communication. Engagement strategies must adapt continuously to evolving stakeholder interests and capacities throughout the PED lifecycle, thereby fostering inclusive and context-sensitive participation. Community engagement is a pivotal success factor: meaningful, early-phase participation contributes to long-term success, operational sustainability, and social acceptance. This engagement correlates with increased resilience and acceptance, emphasizing the importance of deeply embedding participation from project inception.

For RQ2—the PED Matrix’s capacity to capture capacity and identify sensitive dimensions—the findings confirm the PED Matrix’s robust capability as the assessment framework to evaluate multidimensional capacities and tasks across critical project aspects, including technical, social, governance, and financial aspects. Multidimensional integration is essential: addressing all eight aspects concurrently is key for a sound and integrated PED concept. A singular focus on technology or financial dimensions, neglecting social, governance, and managerial aspects, consistently leads to suboptimal performance and implementation failure. This is underlined by the scores of the three case assessments. All scores were reviewed with project partners and finalized by consensus before analysis. It showed that sensitivities varied across contexts, with technical and social dimensions often exhibiting pronounced variability reflective of local conditions, underscoring the matrix’s effectiveness for iterative project benchmarking and capacity building.

Concerning RQ3—governance models and local context influences—the analysis underlines governance flexibility and localized adaptation as key enablers of engagement success. Despite the limited capacities (no authority in planning nor in the market) of the RECs, their strength in social aspects can, through voluntary work, support low-cost communication, advocacy, and participation activities. By contrast, the top-down and private-sector pathways often lack an established social dimension and human and financial capacities for deep community engagement. Effective governance blends transparent decision-making, multi-level coordination, and capacity building to overcome legal, cultural, and socio-political barriers unique to each PED. Context-specific adaptation is crucial: no universal blueprint exists, and strategy efficacy depends on its deliberate tailoring to the geographic, regulatory, and socio-economic context as well as to project characteristics.

These findings are interpreted considering the study’s scope and data constraints (Section 4.2) and translated into practice-oriented guidance (Section 5).

4.2. Limitations

The model used to characterize PED capacities of the cases, score cases, and identify the tasks for an enhanced PED process works with case-specific adaptations in the cases and provided actionable insights for diverse actors. However, the tools presented here need to be adapted continuously to new insights, technologies, and practices. As additional survey data and case studies become available, the roadmaps and assessments will require ongoing expansion and refinement to remain relevant and effective. This iterative improvement will deepen the understanding of PEDs and better support their initiation, development, and implementation.

This paper provides insights that enabled the current analysis, but follow-up actions are needed, including (1) further validation and adaptation of the model; (2) feedback from other PED actors; and (3) targeted research with additional sets of cases. The model represents a significant step toward a structured, multi-criteria framework that different actors can use to drive the energy transition. To be fully useful for concrete projects, it will benefit from broader public feedback and expert inputs tied to real implementation.

With these limits in view, we outline measures to sustain engagement in operations and specify the iterative use of the PED Matrix.

4.3. Sustaining Long-Term Engagement

To sustain engagement in projects' operations, the clear roles, voice, and rewards are three foundational pillars for co-created PEDs. These pillars involve meaningful responsibilities, authentic decision-making authority, and rewards beyond financial benefits.

1. Clear roles:

- Define meaningful responsibilities aligned with citizen interests and capacities.
- Provide skill development opportunities.
- Implement recognition systems.
- Establish succession planning to ensure institutional memory.

2. Clear voice:

- Grant authentic decision-making authority.
- Maintain accessible and transparent communication channels.
- Institute formal conflict resolution mechanisms to validate participant input.

3. Clear rewards:

Extending rewards beyond financial benefits to include social recognition, opportunities for personal development, and tangible, visible community improvements. These improvements collectively justify the ongoing investment of time and resources from participants.

4.4. Linking the Assessment Framework (PED Matrix) to an Iterative Engagement Process

As the application process for the PED Matrix is iterative, it requires a corresponding iterative engagement process. While the PED Matrix functions as the assessment framework, its repeated use directly informs how the engagement framework is adapted over time.

Practically, each assessment starts with stakeholders conducting a self-assessment using the matrix, identifying strengths and gaps across all eight aspects. Based on these results, engagement actions and capacity-building measures are prioritized and implemented for the most critical aspects. The matrix is then reapplied to monitor change and recalibrate the stakeholder roadmaps, ensuring that the participation formats, responsibilities, and support measures remain aligned with the evolving stakeholder landscape.

In this way, the assessment framework provides transparent evidence of progress and persistent bottlenecks. Meanwhile the engagement framework that is grounded in dynamic stakeholder profiling and roadmap adaptation as outlined in Section 2.2 further ensures that the responses to identified gaps are co-designed and context-sensitive.

5. Conclusions

The primary strength in this paper lies in the deliberate methodological synergy between its constituent frameworks. This strategic vision is operationalized through stakeholder roadmaps, which function as dynamic, adaptable pathways to systematically engage all the *QH* model's sectors across diverse development contexts and longer realization timelines. Breaking down the PED roadmap into *ToC* phases and actor-specific pathways, it clarifies how the main actors can drive the change and when they will most likely need help, consultation, support, and collaboration. The visual presentation of the process, together with the mapping of tasks across the eight PED Matrix aspects, works as a strong mental and visual map for the actors in charge.

To ensure that these engagement strategies remain effective and inclusive, the PED Matrix provides a rigorous self-assessment mechanism. The scores in each of the eight

aspects correlate with the tasks in the enhanced PED roadmap. It enables rigorous gap identification, project self-assessment, and comparative analysis across the eight critical dimensions to ensure holistic development. This is further supported by the multi-level participation framework, which provides the granular, practical mechanisms, from informing to collaborating, to design inclusive engagement strategies that respect the varied capacities and roles of all stakeholders. Together, these tools ensure that technical and social objectives are cohesively achieved.

Building on these conclusions, the authors translate the lessons into policy recommendations and stakeholder-specific guidance to support replication and scaling in other PED contexts.

5.1. Policy Recommendations

Effective enabling environments for Peer-to-Peer Energy (PPE) initiatives necessitate coordinated action across multiple governance tiers. At the macro regulatory framework level, this entails developing clear regulations that legally recognize and facilitate community energy entities. This includes creating dedicated funding streams for participatory processes, investing in large-scale capacity-building programs, and establishing formal cross-sector coordination mechanisms to align policy objectives. By rolling out the enhanced PED process and by including the initial phases and closing phases of *ToC*, the responsibilities and tasks are clearer to plan, calculate, adhere to their budget, and monitor. The visual and phase-wise differentiation (see Section 2.5) and the scoring of the capacities (in Section 3) enable the possibility to compare, measure, and quantify progress. These are all important elements of policies and can strengthen the recommendations significantly with evidence. At the municipal level, implementation must be operationalized by mandating community engagement as a compulsory component of public energy projects. Specific budgets must be allocated for these activities within municipal finance, and internal staff capacity in engagement facilitation must be built. Additionally, robust support systems are essential and must be designed to provide accessible technical assistance, tailored financial support mechanisms, specialized legal advisory services, and structured peer-learning networks specifically for community-led initiatives. These measures will help to de-risk participation and ensure that all stakeholders possess the requisite tools for meaningful contribution.

5.1.1. For Project Developers

Success hinges on initiating engagement during the conceptualization phase. Comprehensive stakeholder mapping is crucial. Partnerships with trusted local organizations are essential for addressing community gaps. Dedicated resources for participatory processes can be allocated, and flexibility should be maintained to adapt to stakeholder input.

5.1.2. For Communities

Investment in collaborative visioning is imperative to establish a unified direction. An honest self-assessment of available capacity and resources appears to be necessary. Strategic partnerships to access technical and financial expertise need to be developed while transparent and democratic governance structures should be established from the outset. Proactive planning for long-term operational and financial sustainability is important.

5.1.3. For Policymakers

The role involves codifying participation by directly involving communities in the policy development process. Concrete implementation support, such as technical assistance and funding, needs to be provided. Regulatory barriers that hinder community energy models should be actively removed. Continuous capacity-building programs need to be

invested in. Metrics for engagement effectiveness should be integrated into formal project evaluation criteria to ensure accountability.

This comprehensive study serves as a foundational framework for the inclusive, effective, and sustainable development of PEDs. By aligning PED development with community needs and advancing climate objectives, this study contributes to broader energy transition through meaningful citizen participation and provides systematic approaches to community engagement that can be adapted to diverse European contexts, ensuring the success of PED development initiatives.

5.2. Guide for Key Stakeholders

5.2.1. Advocacy of Citizens and Civil Society

The study delineates three primary contribution pathways in which actors can engage in energy transition. These pathways operate at varying scales of agency and formality. Individual actions can encompass energy efficiency retrofits, renewable technology adoption, and shifts in mobility behavior. Organizing the energy transition involves the formation of energy communities, grassroots political advocacy, and local educational initiatives. While formal participation includes structured engagement in municipal planning processes, official consultation requires experts that serve on advisory committees to influence governance.

The development process for civil-led initiatives is formalized into three critical phases called formation, implementation, and operation. In the formation phase, the focus is on building a motivated core group, establishing a shared vision, assessing resources, and engaging necessary expertise. The implementation phase entails securing financing, detailed infrastructure planning, selecting and matching technical solutions, ensuring regulatory compliance, and executing broad stakeholder engagement. The operational phase makes it a priority to require the establishment of democratic governance structures, technical system management, ensuring long-term financial sustainability, and engaging in ongoing community building. Underpinning this civil mobilization is a set of clear citizen demands, which often include a mandate for 100% renewable energy, effective carbon pricing, equitable public good spending, climate justice, energy independence, and a broader transformation of industrial practices.

5.2.2. Private Sector Engagement

The private sector is a critical engine for energy transition. It provides innovation, technology development and adaptation, and the implementation expertise necessary to deploy complex PED systems at scale, while ensuring that the technological state of the art is continued and its availability for replicators is guaranteed. Its primary role is characterized by the mobilization of specialized knowledge and providing significant capital resources toward the investment in and financing of viable projects. To ensure commercial sustainability, this engagement necessitates robust business model development, which includes conducting thorough market analysis to identify opportunities, articulating a clear value proposition that defines tangible community benefits such as cost savings and increased reliability, formulating strategic partnerships with public and academic entities, and designing revenue models that effectively balance profitability with equitable community benefits.

Beyond a purely transactional role, achieving project success also requires a deep community integration of the innovation pathway. This demands a proactive approach to stakeholder engagement, incorporating community input directly into the project design phase to enhance social acceptance and adoption. Furthermore, it necessitates concrete benefit-sharing mechanisms, such as prioritizing local employment and procurement,

to ensure that economic value is retained within the community. Ultimately, securing a long-term social license to operate depends on maintaining transparency regarding corporate objectives and project outcomes while demonstrating a verifiable commitment to the community's well-being that extends far beyond the initial implementation phase.

5.2.3. Public Sector Leadership

Public sector leadership is indispensable for orchestrating the multi-stakeholder ecosystem required for PED development. This role encompasses three primary domains of responsibility: establishing a supportive policy framework through clear climate targets, regulatory incentives, zoning adaptations, and performance standards; directing strategic infrastructure investment in enabling systems like smart grids, public transit, and district energy networks; and acting as a neutral facilitation body to coordinate disparate stakeholders, provide public education, and offer technical and financial support to de-risk private and civil investment.

A successful development strategy executed by the public sector must be methodical and evidence-based. It begins with a comprehensive baseline assessment and stakeholder mapping to understand the local context. This informs the setting of specific, measurable goals that are directly aligned with overarching climate targets. The strategy requires the deliberate integration of these goals into policies across all relevant domains (e.g., energy, transport, housing) and is executed through a phased implementation plan that prioritizes the systematic development of partnerships to share risk, leverage resources, and ensure long-term operational success.

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