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Best Practises of PEDs and its Replication Potential

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1 ABSTRACT

An important sector that contributes significantly towards climate change and global warming is the building sector. Buildings account for 30–40% of global final energy consumption [1] and nearly 40% of the global CO_2 emissions. In the last decade, policies such as the Directive on Energy Performance of Buildings (EPBD) have been introduced to address this issue, aiming to decarbonize the building stock by 2050 and to reach nearly zero energy buildings (NZEBs) [2].

The 2015 Paris Agreement has put more emphasis on international efforts to reduce CO_2 emissions, where urban areas with a 70% share of global emissions have a key role. Accordingly, the United Nations (UN) Sustainable Development Goals include as goal 11 "sustainable cities and communities" with the aim of supporting the transition towards low-carbon cities, in a general framework which also points towards, e.g., climate action, affordability, and clean energy. In 2015, when the Paris agreement was signed, the EU planned to move further ahead and reduce greenhouse gas emissions by 40% by 2030.

In order to tackle this challenge and to lead the global energy transition, the EU Commission proposed in 2016 a set of new and ambitious rules known as the Clean Energy Package for all Europeans [1]. Therefore, to reach the emission reduction goals it is important to focus both at the energy systems level and at the buildings or district level. At a global level, the need for energy efficiency and an increased share of renewable energy sources is evident, as is the crucial role of cities due to the rapid urbanization rate. As a consequence of this, the research work related to Positive Energy Districts (PED) has accelerated in recent years.

This paper is based on work in a 4 years research on positive energy districts (PED), the planning and implementation of them in various markets. It summarizes the findings on replication potential of the concept. First, the concept is explained and the key performance factors are discussed. Then, it analyses almost 100 PED projects that were collected during the research duration. The PED examples were classified into 3 categories and spread in different climatic, social, and political systems. Finally, the key success factors were derived from this analysis and the findings are highlighted in best practices. By addressing these aspects comprehensively, PEDs can create more sustainable, resilient, and equitable communities that are well-prepared for the challenges of the 21st century. They move beyond simply generating clean energy to fostering a holistic transformation of how we live and interact with our environment.

Keywords: Planning, districts, energy, positive, PED

2 INTRODUCTION

The systematic use of data, the collection of information about enabling factors, barriers and frameworks (regulatory and governmental) are fundamental to supporting the planning of urban interventions towards climate-neutral transition of our cities. Tackling the challenges of climate neutrality at an urban level, the European Commission set out the SET Plan 3.2. which contained several ambitions – i.e. 100 pioneer zero-emissions cities by 2030 [1] and 100 pilot PEDs by 2025 [2] by focusing on implementation and testing of solutions on district-scale and in an efficient, resilient and climate-neutral manner.

In this perspective, there are several international research activities ongoing that try to collect these ambitions, e.g. COST Action (CA) 'PED-EU-NET' [3] in connection with further international initiatives working on PEDs concept; PED initiative, coordinated by JPI UE [4], aims to develop 'Positive Energy Districts and Neighborhoods for Sustainable Urban Development'; 'IEA EBC Annex 83 – Positive Energy Districts' coordinated by IEA EBC [5] – with the aim of mapping PED relevant experiences and collecting key parameters to characterize these districts and support their uptake around Europe and beyond; the European Energy Research Alliance Joint Program on Smart Cities (EERA JPSC) [https://www.eera-sc.eu/], whose mission is to contribute to research and innovation in smart cities by promoting actions, at building, district and city level, that facilitate the transformation of the European built environment towards climate neutrality. In this process, a PED Database (PED DB) (https://pedeu.net/map/) is the outcome of this collaborative research.

2.1 PED database

Studies highlight the need for integrated approaches to planning green, healthy, efficient, livable, and resilient districts, aligning with local plans and addressing stakeholder needs [6-10]. Existing tools for characterizing Positive Energy Districts (PEDs) are limited. JPI Urbana Europe's PED Booklet [11] categorizes PEDs as “Projects” (achieving positive energy balance) or “Towards Projects” (adopting innovative solutions). Zhang et al. [12] analyzed these cases, developing a matrix for comparing PED models and defining archetypes. Soutullo et al. [13] mapped PED Labs, identifying strengths, weaknesses, opportunities, and threats through SWOT analysis, emphasizing real-world testing for replicability.

Focusing on Energy Communities (ECs), similar to PEDs [26, 27], the European Commission's JRC [28, 29] reported on 24 communities [30] and is developing an "Energy Communities Repository" [31, 32] with detailed case studies. These resources inform the conceptualization of a PED database. Further PED research includes cataloguing: (1) technologies and solutions [15-17], (2) financing and business models [18, 19], (3) social and community engagement tools [20, 21], and (4) Key Performance Indicators (KPIs) for impact monitoring [22-25].

Several international initiatives promote efficient urbanization and sustainable urban development, including the EU's Strategic Energy Technology (SET) Plan [4], which inspired the goal of deploying 100 Positive Energy Districts (PEDs) in Europe by 2025. A recent publication (Haase et al. 2025) lists initiatives collaborating on a 'PED Database'. Key promoters include COST Action "PED-EU-NET", JPI Urban Europe, IEA EBC Annex 83, and EERA JP Smart Cities. The PED database aims to map, filter, sort, and compare PED experiences, providing an overview of technological and non-technological solutions in various PED projects and case studies. This collaborative effort led to the PED Database, with international PED projects listed in Haase et al.’s recent publication (Clima paper).

The International Energy Agency (IEA) Annexes are collaborative Research and Development (R&D) projects under the IEA's Technology Collaboration Programmes (TCPs). These structured frameworks address specific energy challenges or opportunities, such as renewable energy, energy efficiency, or urban energy systems.

This paper focuses on the crucial internationalization of the PED model by comparing it with other community or district-scale transformation projects. Building on previous research, the PED DB disseminates PED practices via a comprehensive tool which aggregates case studies, projects, solutions, KPIs, policies, and strategies. This supports large-scale development of innovative pilot districts, both new and renovated. This international perspective is essential to identify challenges and key success factors for PED planning and implementation.

3 METHODOLOGY

For this desktop research 98 PEDs from 33 projects were analysed. Fig.1 illustrates the life cycle stages of the PEDs. Among the 98 PEDs recorded in the PED database [7], 40 are in the planning phase, 22 are under implementation, 18 have been completed, and 18 are in operation. Of these, 42 are classified as PED case studies, 18 as PED Labs, and 38 as PED-relevant case studies (see Fig.2).

The database evaluates the effectiveness of strategies and solutions in mapped Positive Energy District (PED) case studies. It is dynamically updatable with new sources and ontologies, maintaining relevance and utility as projects evolve, and enabling the generation of archetypes or "library concepts" for scenario evaluations.

The methodology used to structure the PED database fostered data field harmonization and standardization, resulting in a glossary that ensures PED data interoperability across systems. Detailed case analysis, based on project experiences and insights from PED publications and the EU Energy Community, facilitated the identification of core components, facilitating elements, challenges, and barriers.

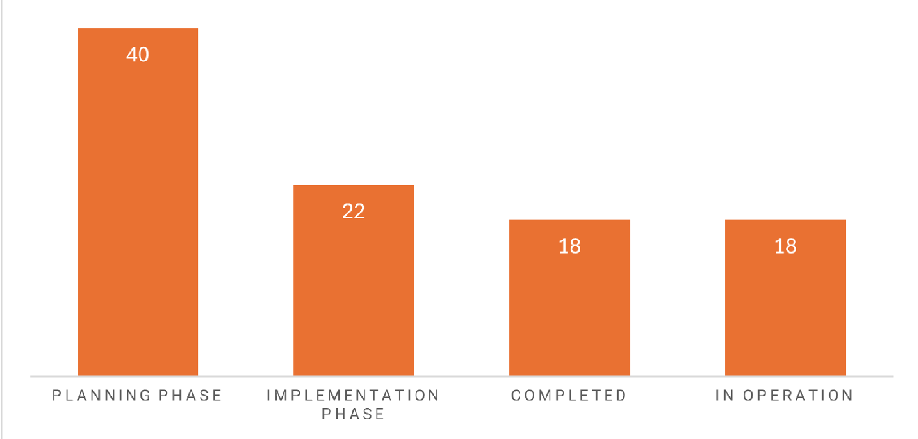

Fig. 1: PEDs from PED database [7].

By capturing detailed parameters and in-depth information, the database provides PED stakeholders with a comprehensive view of prior projects. This comprehensive approach supports the replication of effective practices in future initiatives, as it offers significant insights for deeper PED analysis.

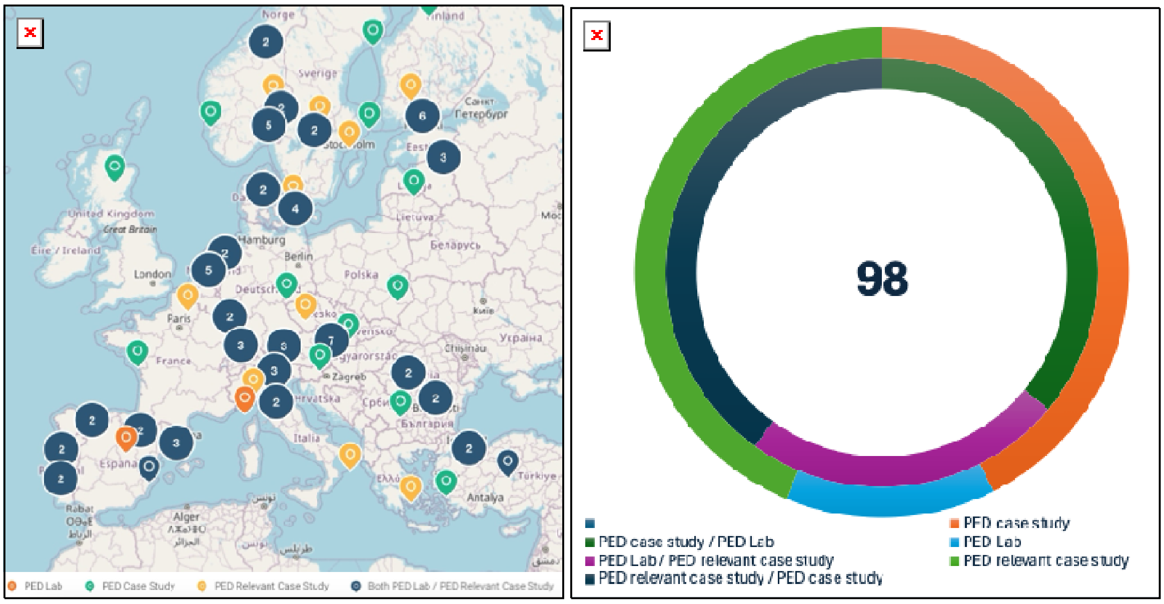

Fig. 2: PED case studies, PED relevant case studies and PED Labs in the PED database (status: Dec 2024).

4 RESULTS

Building on existing frameworks like the Annexes on energy-efficient communities, computational tools, and low-carbon heating, this initiative aims to standardize definitions and develop planning solutions. It collaborates with projects such as the EU Smart Cities Information System, Horizon 2020, and JPI Urban Europe. Annex 83 provides guidance on urban planning, impact assessments, and the economic and social implications of Positive Energy Districts (PEDs). As Annex 83 is ongoing, an evaluation framework is still in development. This framework supports cities, policymakers, and researchers in transitioning to carbon-neutral urban environments, contributing to global energy transition and sustainability goals. Annex 83 partnered with PED EU NET and Urban Europe for the PED DATABASE [26].

The PED database offers comprehensive information on new and refurbished urban environments designed to produce more energy than they consume. Its modular design and online platform enable data, in the form of PED Key Performance Indicators (KPIs), to be sourced from reliable and verified information. Developed through a database development life cycle (DDLC), it began with a scoping phase defining requirements for data collection from demo cases. Following a testing phase, the main conclusions are:

(1) There is no one-fits-all solution for PED implementation. Overall PED framework definitions require further detailing in the local context [27]. The PED Database provides an overview of not only different implementation strategies but also existing different conceptualizations and approaches for the PED concept.

(2) PEDs are still a relatively new concept, but they are gaining traction around the world. As PEDs become more popular, they are likely to play an increasingly important role in the global transition to a clean and sustainable energy future. Overall, PEDs offer a number of advantages over building-level and city-level approaches to sustainable development [28].

(3) PEDs take a holistic approach that considers the needs of the entire community [29].

4.1 PED implementation

Creating a PED is not simply a technical exercise but a complex socio-technical undertaking that requires a holistic and context-specific approach. The PED Database recognizes this diversity and aims to provide a platform for sharing knowledge and experiences across different projects and contexts, enabling stakeholders to learn from each other and adapt best practices to their own unique circumstances. With regard to diverse local contexts these aresummarized in Table 1, while Table 2 provides on averview of varied conceptualizations and approaches and Table 3 summarises the dynamic and evolving nature of PEDs.

Climate	A PED in a hot, sunny climate will have vastly different strategies for achieving positive energy balance compared to one in a cold, cloudy climate. Solar potential, heating/cooling needs, and building design will vary significantly.
Urban Form and Density	Densely populated urban areas may rely on district-level energy solutions and innovative building integration, while suburban or rural PEDs might focus on individual building generation and microgrids.
Existing Infrastructure	The availability and condition of existing energy infrastructure (grids, heating/cooling networks) will influence the feasibility and cost-effectiveness of different PED solutions.
Resources and Industry	Local availability of renewable energy resources (solar, wind, geothermal, biomass) and industrial capabilities will shape the choice of technologies and strategies.
Socioeconomic Factors	Community demographics, energy affordability, and local priorities will influence the acceptance and implementation of PED projects.

Table 1: PED implemantion results with regard to diverse local contexts

Definition of “Positive Energy”	The precise definition of "positive energy" can vary. Some PEDs might aim for net-zero energy annually, while others might focus on specific energy carriers or consider embodied energy.
Scope of the District	The scale of a PED can range from a single building to a neighborhood or even a larger district, each with its own set of challenges and opportunities.
Technology Choices	The mix of renewable energy technologies, energy storage solutions, and energy efficiency measures will depend on the local context and the specific goals of the PED.
Governance and Ownership	PED projects can involve a range of stakeholders, including public authorities, private developers, energy utilities, and community members, each with their own interests and priorities.

Table 2: PED implemantion results with regard to varied conceptualizations and approaches

Technological Advancements	Rapid innovation in renewable energy, energy storage, and smart grid technologies means that PED solutions need to be adaptable and future-proof.
Policy and Regulatory Landscape	Changes in energy policies, regulations, and incentives can significantly impact the feasibility and economic viability of PED projects.
Data and Monitoring	Effective PED implementation requires robust data collection and monitoring to track performance, identify areas for improvement, and adapt strategies over time.

Table 3: PED implemantion results with regard to dynamic and evolving nature of PEDs

4.2 PED concept

Positive Energy Districts (PEDs), while still a relatively new concept, are gaining global momentum and are poised to play a crucial role in the transition to a clean and sustainable energy future. PEDs also offer advantages over building-level and city-level approaches to sustainable development. Table 4 summarises the PED concept results with regard to gaining traction and importantance, Table 5 focuses on advantages of PEDs over Building-Level approaches and Table 6 focuses on advantages of PEDs over City-Level approaches.

Addressing Climate Change	PEDs directly contribute to reducing greenhouse gas emissions by promoting renewable energy generation and energy efficiency at a district level. This aligns with global efforts to combat climate change.
Energy Security and Independence	By generating energy locally, PEDs can reduce reliance on fossil fuels and centralized energy systems, enhancing energy security and independence for communities and nations.
Sustainable Urban Development	PEDs offer a framework for sustainable urban development by integrating energy considerations into planning and design at the district level, leading to more livable and resource-efficient communities.
Economic Benefits	PEDs can stimulate local economies by creating jobs in renewable energy, energy efficiency, and related sectors. They can also reduce energy costs for residents and businesses.
Social Benefits	PEDs can foster community engagement and ownership in the energy transition, promoting social equity and inclusivity.

Table 4: PED concept results with regard to gaining traction and importantance

Economies of Scale	PEDs can achieve economies of scale by implementing energy solutions at a district level, such as shared renewable energy systems, district heating and cooling networks, and smart grids. This can lead to lower costs and greater efficiency compared to individual buildings trying to achieve positive energy balance on their own.
Integrated Planning and Design	PEDs allow for integrated planning and design of energy systems and infrastructure across multiple buildings and land uses, optimizing energy performance and resource utilization.
Flexibility and Resilience	PEDs can create more flexible and resilient energy systems by diversifying energy sources, incorporating energy storage, and enabling peer-to-peer energy trading within the district.

Table 5: PED concept results with regard to advantages of PEDs over Building-Level approaches

Granularity and Focus	PEDs provide a more granular and focused approach to sustainable development compared to city-level initiatives. They allow for tailored solutions that address the specific needs and characteristics of different districts within a city.
Measurable Impact	PEDs make it easier to measure and track progress towards sustainability goals at a district level, providing valuable data and feedback for adaptive management.
Scalability and Replicability	Successful PED projects can serve as models for replication and scaling up to other districts and cities, accelerating the transition to a sustainable energy future.

Table 6: PED concept results with regard to advantages of PEDs over City-Level approaches

4.3 PED approach

Social Equity and Inclusion	PEDs aim to benefit everyone in the community, not just a select few. This means considering factors like affordability of energy, access to clean energy solutions, and potential impacts on vulnerable populations.
Environmental Justice	A holistic approach addresses potential environmental injustices by ensuring that PEDs do not disproportionately burden certain communities with pollution or negative environmental impacts.
Community Ownership and Engagement	Successful PEDs often involve active participation and ownership from community members. This ensures that the projects align with local needs, values, and priorities, fostering long-term support and sustainability.

Table 7: PED approach results with regard to beyond technology

Energy Systems and Infrastructure	PEDs require integrated planning and design of energy systems, including renewable energy generation, energy storage, distribution networks, and smart grids. A holistic approach optimizes these systems for efficiency, reliability, and resilience.
Built Environment and Urban Planning	PEDs consider the built environment as a whole, including building design, energy efficiency measures, land use planning, transportation, and green spaces. This integrated perspective maximizes energy performance and creates more sustainable and livable communities.
Economic Development and Job Creation	PEDs can stimulate local economies by creating jobs in renewable energy, energy efficiency, and related sectors. A holistic approach considers these economic opportunities and ensures that they benefit the entire community.

Table 8: PED approach results with regard to integrate multiple dimensions

PEDs represent a strategic middle ground between individual building efforts and broader city-level plans. They offer a tangible and manageable scale for implementing integrated energy solutions, maximizing benefits while minimizing complexity. It emphasizes a key characteristic of Positive Energy Districts (PEDs) why they are designed in a holistic way. Table 7 summarises the PED approach results with regard to beyond technology, Table 8 focuses on integrate multiple dimensions and Table 9 focuses on long-term sustainability.

Resource Efficiency	PEDs strive to minimize resource consumption and waste generation through strategies like circular economy principles, efficient use of water and materials, and sustainable waste management practices.
Resilience to Climate Change	A holistic approach considers the potential impacts of climate change, such as extreme weather events, and designs PEDs to be resilient and adaptable.
Behavioral Change and Awareness	PEDs often incorporate initiatives to raise awareness about energy consumption and promote sustainable behaviors among community members.

Table 9: PED approach results with regard to long-term sustainability

5 DISCUSSION

The holistic approach to PEDs (Positive Energy Districts) mentioned in the resutls (Table 1 – 9) focus on resource efficiency, resilience to climate change, and behavioral change and awareness:

PED and Resource Efficiency:

- Minimizing Consumption: PEDs prioritize reducing the overall consumption of resources, including energy, water, and materials. This involves strategies like energy efficiency in buildings, promoting sustainable transportation, and reducing waste generation.
- Circular Economy Principles: PEDs can incorporate circular economy principles by designing buildings for disassembly and reuse, using recycled and sustainable materials, and minimizing waste through composting and recycling programs.
- Efficient Resource Management: Smart technologies and data analytics can optimize resource management in PEDs. For example, smart grids can improve energy distribution and reduce losses, while smart water meters can help conserve water.
- Life Cycle Assessment: PEDs can benefit from life cycle assessments that evaluate the environmental impacts of materials and processes throughout their entire life cycle, from extraction to disposal. This helps identify opportunities for resource efficiency improvements.

PED and resilience to Climate Change:

- Risk Assessment and Adaptation: PEDs should conduct thorough risk assessments to identify potential climate change impacts, such as increased temperatures, extreme weather events, and sea-level rise. Based on these assessments, they can develop adaptation strategies to enhance resilience.
- Diversification of Energy Sources: PEDs can diversify their energy sources to reduce reliance on any single technology or fuel. This can include a mix of solar, wind, geothermal, biomass, and other renewable energy options.
- Decentralized Energy Systems: Decentralized energy systems in PEDs can enhance resilience by reducing vulnerability to disruptions in centralized grids. Microgrids and distributed energy resources can provide backup power during emergencies.
- Green Infrastructure: Integrating green infrastructure, such as green roofs, permeable pavements, and urban forests, can help mitigate the impacts of climate change by reducing urban heat island effect, managing stormwater runoff, and improving air quality.

PED and behavioral change and awareness:

- Education and Outreach: PEDs can implement education and outreach programs to raise awareness about energy consumption, climate change, and sustainable practices. This can involve workshops, community events, and online resources.

- Incentives and Rewards: PEDs can offer incentives and rewards for residents and businesses that adopt sustainable behaviors, such as energy conservation, waste reduction, and use of public transportation.
- Citizen Engagement and Participation: Engaging citizens in the planning and implementation of PED projects can foster a sense of ownership and encourage behavior change. Participatory processes can empower communities to take an active role in the transition to a sustainable future.
- Data Transparency and Feedback: Providing residents with transparent data on their energy consumption and environmental impact can motivate them to adopt more sustainable behaviors. Smart meters and energy management platforms can provide valuable feedback and enable real-time monitoring.

6 CONCLUSION

In conclusion, creating a PED is not simply a technical exercise but a complex socio-technical undertaking that requires a holistic and context-specific approach. The PED Database recognizes this diversity and aims to provide a platform for sharing knowledge and experiences across different projects and contexts, enabling stakeholders to learn from each other and adapt best practices to their own unique circumstances.

We found that a holistic approach to PEDs recognizes that energy is not just a technical issue but is deeply intertwined with social, economic, and environmental dimensions. By considering the needs of the entire community and integrating multiple perspectives, PEDs can achieve greater sustainability, resilience, and social equity. This comprehensive view is what distinguishes PEDs from more narrow, technology-focused approaches to sustainable development.

Further, PEDs represent a strategic middle ground between individual building efforts and broader city-level plans. They offer a tangible and manageable scale for implementing integrated energy solutions, maximizing benefits while minimizing complexity.

By addressing these aspects comprehensively, PEDs can create more sustainable, resilient, and equitable communities that are well-prepared for the challenges of the 21st century. They move beyond simply generating clean energy to fostering a holistic transformation of how we live and interact with our environment.

Regarding replication potential we can state that community-centricity can be both a challenge and an opportunity for replication. Because PEDs are designed to meet the specific needs of a community, a direct, cookie-cutter replication might be difficult. Each community has unique characteristics (climate, resources, social structures, etc.) that will influence the PED design. However, the principles of community engagement and a holistic approach are replicable. The process of understanding community needs and tailoring solutions can be replicated even if the specific technologies or designs are different.

Further, the holistic approach suggests a framework that can be adapted. While the specifics will vary, the idea of integrating various aspects (energy, social, economic, environmental) into a PED project provides a replicable framework. Other communities can adopt this integrated planning approach, even if the details of their PEDs are different.

The focus on community needs implies scalability through modularity. If PEDs are designed with a modular approach, where smaller units can be combined or adapted, this improves the potential for scaling up successful elements. This modularity could be replicated in other communities, even if the overall scale of the project is different.

Replication of PED is possible, but it will likely involve adapting the core principles and framework rather than simply copying a PED design from one location to another. The process of community-centered design is replicable; the specific solutions will likely need to be tailored. Information on the availability of resources and technologies needed for PEDs can be found in the PED database. Replication depends on access to necessary resources. To understand the true replication potential, more information is needed, such as:

- Case studies of successful PEDs and attempts at replication. These would provide concrete examples of successful implementation We gathered this information where we could, but more work is needed to better understand what worked and what didn't and why

- Analysis of the costs and benefits of PEDs in different contexts. Economic viability is a key factor in replication potential. This information is very difficult to get and to digest it so that it can become comparable.
- We need more work that focuses on policy and regulatory frameworks that support or hinder PED development. Supportive policies can encourage replication.

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