

Sustainable Urban Development through Emerging Technologies, Process Improvement, and Citizen Commitment

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Abstract

In order to fight imminent global warming and to diminish anthropogenic greenhouse gas (GHG) emissions, positive energy districts (PED) have gradually been acknowledged and grown in significance regarding the European (EU) energy transition policy agenda, as an achievable solution towards a zero-emissions future. PEDs have brought about a shift from focus on individual buildings to neighborhoods. Thus, a relatively new focus area at EU level, regarding the energy transition process and sustainable urban development, has developed. The aim of the EU is to become climate-neutral by 2050. The intention of creating 100 PEDs by 2025 and their alignment with the United Nations (UN) sustainable development goals (SDG) are encouraging means to accomplishing the goal. Nevertheless, the intention raises questions regarding the way of realizing fast, coherent and comparable PED adoption across diverging environmental and sociocultural contexts. The emphasis of this study lies on how to attain Sustainable Urban Development through emerging technologies, process improvement, and citizen commitment employed in the PED adoption. The PED concept is a complex undertaking that requires a systemic, holistic, and integrated approach for its design, implementation, and operation, addressing multiple interconnected aspects. This study aims to clarify different PED aspects by carrying out a factor analysis incorporating sociocultural, technological, economic, environmental, political, legal, ethical, and demographic (STEEPLED) PED features. In this study the focus is on PED opportunities and PED challenges. Ultimately the findings of this study will enhance understanding and knowledge about critical factors in the creation, implementation and operation of PEDs, and to further progress research and development in this important contemporary field.

Keywords: Positive Energy Districts, sustainable urban development, emerging technologies, processes, opportunities, challenges.

1 Introduction

1.1 Background

Due to global warming and the requirement for replacing fossil fuels with renewable energy sources a significant transformation in the energy sector is currently taking place. Recent energy transformation systems consist of decentralized small residential units, with a reshaped structure, for generating renewable energy (de São José et al., 2021). These technological advances aim to increase energy awareness in society, meet increased energy demand and meet regional self-sufficiency goals, satisfy sustainability, and offer electricity in remote areas. In this new approach with the use of smart grids, consumers become prosumers generating and consuming energy. Potential surplus energy can be shared with others.

1.2 PED characteristics

PEDs are considered environmentally sustainable because they reduce GHG emissions and fossil fuel dependence, and enhance energy efficiency at both building and district levels (D. Siakas, Rahanu, et al., 2025). They promote biodiversity through green infrastructures, such as green roofs and urban farming. They also reduce negative health impacts, by the reduction of air pollution and noise pollution. In general, PEDs create a sense of community. Economic sustainability is attained through improved social-economic conditions, such as decreased energy bills and operational costs, creation of new business models through e.g. energy cooperatives, green investments and innovation, access to local energy communities, increased public participation and co-creation of energy solutions. Enhanced quality of life is attained through improved air quality, comfort, and accessibility to green public spaces and services, such as public transportations. Decentralized energy production reduces vulnerability to outages (temporary disruption / prolonged disruption / termination) of a service, system, or tool, usually due to technical issues, maintenance requirements, or natural disasters (Casey et al., 2020). It can apply to various critical contexts, such as electricity, internet service, or water supply.

The PED main target is “the optimization of energy production, energy efficiency and energy flexibility” (D. Siakas, Rahanu, et al., 2025). Energy production denotes distributed renewable energy production. Energy efficiency is attained by “minimizing energy demand through utilization of energy saving technologies, energy distribution and supply systems, and energy storage systems”. Energy flexibility is the ability to adjust energy generation and energy demand according to electricity prices, electricity market changes, transmission and distribution system conditions and regulation (Ntafalias et al., 2024). Energy flexibility indicate self-consumption maximization, and peak power demand minimization through smart micro grids, energy storage and energy management.

Technologies that underpin PEDs, such as “cyber-physical systems (CPS), digital twins (DT), artificial intelligence (AI), Internet of Things (IoT), Edge Computing, and Blockchain Technology”, which all are essential to the creation and operation of PEDs for enhancing sustainability, energy efficiency, and user engagement, have the potential for social influence (D. Siakas, Rahanu, et al., 2025), (D. Siakas, Lampropoulos, et al., 2025). However, the design and utilization of these technologies bring about ethical questions. The integration of an ethical framework, a significant dimension often overlooked in technical PED literature, was created and enriched with a dedicated analysis mapping of key challenges and enablers identified in the literature to six ethical principles (“Quality of Life, Use of Power, Risks and Reliability, Property Rights, Privacy, Equity & Access”) (D. Siakas, Rahanu, et al., 2025). This “analysis mapping demonstrates concretely how ethical considerations manifest in real PED projects and how the framework can guide resolutions”.

1.3 Sustainable Urban Development through PEDs

Sustainable Urban Development (SUD) is “the process of designing and managing cities and urban areas in a way that meets the needs of the present without compromising future generations” (Mieg, 2022). A key enabler of this vision is the implementation of PEDs, spatial urban areas that “produce more energy than they consume on an annual basis” (D. Siakas, Rahanu, et al., 2025). PEDs are increasingly recognized as enablers of urban sustainability, supporting energy transition, climate goals, and social equity (Cellura et al., 2025).

In total 66% of the existing PED projects consist of newly built neighborhoods (Bossi et al., 2020). Existing urban structures display complex ownership structures, technological limitations, diverse building protections and preservation of protected buildings, which may present challenges in implementing a PED. It must, however, be considered, that “approximately 75% of the EU building stock is energy inefficient” (*In Focus*, n.d.), which makes “the integration of PED approaches to the existing urban structure an urgent priority” (D. Siakas, 2025).

A significant political decision to accelerate the reduction of energy consumption in the building sector would be to increase renovation rates at the district level by upgrading multiple buildings within the same area. Synergies between different approaches, including greening strategies, circular economy, building renovation and energy retrofits are particularly suitable for creating PEDs of existing urban areas (D. Siakas, Rahanu, et al., 2025).

PEDs can be adapted to various urban contexts by combining building renovations, advanced energy systems such as photovoltaic-thermal, and flexible grid usage. PEDs reduce urban carbon emissions by integrating renewable energy sources, improving energy efficiency, and enabling energy flexibility at the district level (Derkenbaeva et al., 2022). This supports climate neutrality and decarbonization targets for cities, which are responsible for the majority of global energy use and emissions (Kozłowska et al., 2024).

Energy efficiency in PEDs is mainly achieved through:

- i) Exploitation of emerging digital technologies (smart grids, IoT, AI etc.) for managing demand and supply;
- ii) Utilization of renewable energy resources, such as solar, wind, geothermal, and bioenergy;

iii) Energy sharing and synergy between buildings, users and other PEDs.

Taking into account that cities and urban areas “produce more than 60% of GHG emissions and consume 78% of the world’s energy”, more focus need to be placed on SUD (Nations, n.d.). The SDGs of the UN “aim to address environmental, economic, and social issues” (*THE 17 GOALS | Sustainable Development*, n.d.). UNs SDG11 “*Sustainable Cities and Communities*” has gained increased attention through diverse initiatives targeted at improving SUD. Other SDGs, such as SDG7 “*Affordable and Clean Energy*”, SDG9 “*Industry, Innovation and Infrastructure*”, SDG12 “*Responsible Consumption and Production*”, and SDG13 “*Climate Action*” also directly or indirectly address sustainability and energy transition.

“The EU is devoted to achieving the SDGs through diverse actions in research and innovation (R&I) activities, aiming to achieve a sustainable future through modernizing the European economy and society. The goal of making Europe climate-neutral by 2050 is promoted by the EU Framework Program for R&I advancing the transition to a sustainable future” (2050 Long-Term Strategy - European Commission, n.d.). “The improvement of urban services and infrastructures, as well as improvement of social and economic conditions, aim at enhancing competitiveness and appeal of cities and urban districts”. Moreover, PED initiative also supports the Green Deal goals (The European Green Deal - European Commission, 2021), the Renovation Wave (Climate-Neutral and Smart Cities - European Commission, 2025), and the Mission on Carbon-Neutral and Smart Cities (Renovation Wave, n.d.).

SUD through PEDs aim at urban resilience, the capacity of an urban system, “to survive, adapt, and thrive, regardless of future outcomes”. Urban resilience is “the ability of an urban system to absorb, recover and prepare for future impacts”. Resilience is “the measurable ability of any urban system, to maintain continuity through diverse stresses, while positively adapting and transforming toward sustainability” (Lehmann & Szopinska-Mularz, 2024). Nowadays, there is an amplified preference for solutions based on nature and natural resources, mainly attributed to their economic and ecological advantages (Mosisa et al., 2025).

A factor analysis concentrating on “sociocultural, technological, economic, environmental, political, legal, ethical, and demographic (STEEPLED)” PED features is used to investigate opportunities and challenges related to PEDs. The aim is to enhance understanding and knowledge about decisive factors in the creation, implementation and operation of PEDs and to further progress research and development in this important contemporary field.

The remaining part of this paper consists of the PED processes which suggest the use of a business process management approach to continuously monitor and improve the processes. Section 3 unfolds PED experiences by using a STEELED factor analysis for opportunities and challenges followed by a discussion in section 4. Section 5 emphasizes how the SPI Manifesto could address PED challenges and section 6 is the conclusion.

2 The PED Processes

The design and improvement of business processes is significant for attaining business benefits (Malinova et al., 2022). Business Process Management (BPM) entails a systematic approach for improving organizational performance by managing and optimizing business processes (Dumas et al., 2018). It comprises the following steps, namely analysis, design, implementation, monitoring, and optimization of workflows for achieving specific business goals. Different disciplines, such as business management, computer science, and industrial engineering are utilized in BPM to achieve operational efficiency and effectiveness. Process Improvement is a strategic approach used by organizations to analyze, redesign, and enhance their existing processes in order to achieve greater efficiency, effectiveness, and adaptability. The goal is to streamline operations, reduce waste, improve quality, and deliver better value to customers. In software development software process improvement (SPI) is considered particularly important and revealed in the SPI manifesto (*SPI Manifesto*, 2010).

Since a PED has many similarities with a business the BPM approach could be applied, at least to some degree. Benefits of BPI are increased productivity and efficiency, cost savings, increased customer satisfaction, improved quality and compliance, and faster time to market (Dumas et al., 2018).

The steps in utilizing the BPM approach in PEDS could broadly include process mapping, visualization of processes and existing workflows, identification of bottlenecks, redundancies, and inefficiencies, root cause and gap analysis, benchmarking, reviewing of current processes for errors, unnecessary steps, or poor resource allocation, and redesign and re-engineering of processes for eliminating inefficiencies or non-value-adding activities.

The focus should be on automation, simplification, and alignment with PED goals. Redesigned processes, often include new tools, technologies, or new roles. Training, change management, and phased rollout are important steps for avoiding resistance and increasing stakeholder acceptance and commitment.

The following steps are ongoing monitoring by using measurable key performance indicators (KPIs) and continuous improvement.

Frameworks like the Deming wheel / PDCA cycle (Plan-Do-Check-Act), Lean (eliminating waste and improving flow), Six Sigma (reducing variation and defects), Total Quality Management (TQM - Focus on long-term success through customer satisfaction) and Business Process Reengineering (BPR - Radical redesign of processes for improvement) are popular BPI tools.

Below some of the key processes in PEDs identified in (D. Siakas, Rahanu, et al., 2025), (D. Siakas, Lampropoulos, et al., 2025), (Natanian et al., 2024), (Krangsaas et al., 2021), (Bruckner et al., 2025), (Sareen et al., 2022) are briefly described:

- *Governance & Stakeholder Engagement*: Involves coordination among city authorities, businesses, citizens, and investors to align goals, manage incentives, and ensure social acceptance.
- *Energy system design and integration*: Planning and implementing renewable energy generation, storage, and distribution systems at the district level, including building retrofits and smart grids.
- *Data-driven planning and optimization*: Use of advanced modeling, simulation, and AI to optimize energy flows, forecast demand, and support decision-making.
- *Performance assessment KPIs*: Continuous monitoring using KPIs such as energy balance, GHG reduction, and well-being to guide improvements.
- *Policy and regulatory support*: Development and adaptation of supportive policies, regulations, and funding mechanisms to enable PED implementation, scaling and replication.
- *Social innovation and community involvement*: Engaging residents in energy-saving behaviors, mobility choices, and co-creation of solutions to ensure long-term success.

PEDs are complex constructs and there is an intertwined relationship between the different processes. For example, governance, the process of governing by which all actors involved in policymaking and implementation are answerable and transparent, aligns all processes toward a shared PED vision. Diverse technical systems and their related processes, enable energy self-sufficiency and data-driven optimization, which are foundational for decision-making in governance and business models. Moreover, the feasibility of technical systems depends on viable economic models that are created in the governance and stakeholder engagement process. Also, economic incentives usually drive social engagement influencing social acceptance and involvement, both critical factors for the success of technical implementations and policy legitimacy. Social input may drive policy reforms. Integrated synergetic planning of processes and process improvement based on KPIs created according to feedback, user needs, and new technologies or policies, are of utmost importance for PED success. Each process needs to consider and support the other processes.

3 PED Experiences

PEDs positively influence sustainability accomplishment in urban areas. As a result, PED-related developments are continuously increasing.

Collected PED cases by “JPI Urban Europe are summarized and presented in a PED booklet” (Gollner et al., 2019). Moreover, extensive scientific literature has been published on diverse PED experience reports (see e.g. (Ntafalias et al., 2024), (Bossi et al., 2020), (Bruckner et al., 2025), (Healey Trulsrud & van der Leer, 2024), (Turci et al., 2024), (Zhang et al., 2021)). Since the PED concept is comparatively new, highly innovative, fairly complex and rather context specific, experience from existing PEDs, is likely to provide the incentives for SUD.

Based on the literature review of existing PEDs we have identified diverse PED opportunities, but also challenges, which we investigate by using the STEELED factor analysis presented in sections 3.1 and 3.2.

3.1 PED Opportunities

In general, there is a lack of knowledge and awareness regarding PED opportunities connected to the creation of PEDs.

- *Sociocultural opportunities*, include enhanced social equity, reciprocity and added collaborative efforts. Effective PEDs require active involvement from citizens, local organizations, and diverse stakeholders. This engagement fosters social innovation, strengthens community identity, and encourages shared responsibility for sustainability goals (Kozłowska et al., 2024). PEDs suggest innovative models of energy ownership and energy generation that aim to reduce energy poverty (which impacts a substantial portion of the population). PEDs can help reduce energy poverty and promote social equity by redistributing surplus energy to low-income households, supporting economic savings, and improving access to clean energy (Hearn et al., 2021). However, guaranteeing fair participation and sharing of benefits is crucial to avoid enduring inequalities. Households can “improve their energy behavior and with increased awareness and the application of smart solutions reduce their energy cost” (Hearn & Castaño-Rosa, 2021).
- *Technological opportunities* are related to the rapid advancements of emerging technologies which can positively affect the realization of PEDs and render them more adaptive and responsive to urban sustainability goals. Among the various technologies, CPSs, AI, machine learning, big data analytics, IoT, blockchain, edge computing, and DTs show great promise to further enhance the efficiency and effectiveness of PEDs and, in turn, improve sustainable development and have positive social impact (D. Siakas, Lampropoulos, et al., 2025). Specifically, CPSs enable real-time simulation and control of energy flows, resource production, distribution, and consumption optimization across interconnected urban infrastructures. AI and machine learning can enhance system autonomy and support intelligent decision-making, improving the effectiveness of automated operations, predictive maintenance, and resource optimization. DTs offer dynamic, virtual representations of physical assets, allowing for advanced monitoring, realistic simulations, and proactive planning. Big data analytics empowers informed decision-making by identifying patterns and forecasting energy demand, while IoT devices enhance data collection and real-time monitoring across buildings and energy systems. Edge computing further supports low-latency, localized processing of sensor data, enabling faster and more efficient energy management. Finally, blockchain can provide decentralized energy transactions, improve transparency and security, and aid in building trust in energy exchanges. These technologies improve energy self-sufficiency and resilience and contribute to broader sustainability goals by enabling data-driven and participatory urban governance (Lampropoulos et al., 2024).
- *Environmental opportunities* present “great potential for reducing GHG emissions, through urban energy system transformation, energy demand-side management, renewable energy integration, and energy storage solutions. Due to local distributed power generation in PEDs resilient, adaptable and efficient energy system are created” (D. Siakas, Lampropoulos, et al., 2025). PEDs support decarbonization both of buildings and mobility and address urban heat islands, an urban area hotter than comparable rural area due to design and human activity, and promote circular resource use (Marotta et al., 2021). Increasing photovoltaic capacity (by e.g. installing more rooftop PVs) and utilizing demand-side management and battery storage are pivotal for “reaching carbon neutrality in urban areas by 2050”. (G. Wang et al., n.d.)
- *Economic Opportunities*. “Contemporary decentralized energy systems create benefits that are shared between stakeholders, encourage new forms of energy ownership, such as cooperatives or community-owned energy systems, which can empower residents and keep economic benefits within the community” (Hearn et al., 2021). The development, retrofitting, and operation of PEDs stimulate local economies by creating new jobs in construction, renewable energy installation, maintenance, and energy management (D. Siakas, Rahanu, et al., 2025). Retrofitting existing buildings in a PED is particularly important from a circular economy point of view, job creation, and restoration of existing urban appearance. “Increasing number of distributed energy resources, such as, electric vehicles (EVs), and distributed energy storage, being integrated into the distribution systems” also create new economic opportunities and benefits for the community (Y. Wang et al., 2023).
- *Political opportunities*. Supportive policies, including strong political commitment, clear regulatory frameworks, and active policymaker engagement are essential for PED creation and scaling (Sareen et al., 2022). Policymaker engagement and support is crucial for effective PED governance and pivotal for stakeholder awareness, trust, and knowledge sharing (Hearn & Castaño-Rosa, 2021). Financial incentives, innovative financing instruments, and public-private partnerships, all dependent on political initiatives, can accelerate PED deployment and encourage community participation (Krangssås et al., 2021). An important political opportunity is closely related to the legal/legislative opportunity, since political decisions need to be taken on the EU member states level for legally supporting PEDs.

- *Legal / Legislative opportunities.* New forms of shared energy ownership can be created within PEDs with supporting legislative and regulatory frameworks. Adapting regulations to local renewable energy resources, storage potential, and consumption patterns is necessary. Tailored legislation can support the unique needs of different regions and cities. “*The legislative features of energy communities might benefit the PEDs since they reduce the economic friction between renewable energy producers and consumers within the community*” (Lindholm et al., 2021). EU PEDs must address justice issues in order to guarantee a just transition (Hearn & Castaño-Rosa, 2021). EU member states are aligning national laws to implement EU PED policy, but their maturity varies significantly. Much of the legal and regulatory support for PEDs is embedded in broader frameworks for energy efficiency, renewable energy, and sustainable urban development or e.g. local government climate targets and smart grid and energy community laws. In order to implement successful PEDs there are legislative and regulatory opportunities that reinforce all other STEEPLED opportunities.
- *Ethical opportunities.* An ethical examination, as part of the STEEPLED analysis, is an important one. Although it is acknowledged that there is an intimate relationship between Law and Ethics, there are examples where the bond between the two breaks down, and the law struggles to provide moral guidance. Therefore, to solely, and exclusively, rely on legislative and regulatory frameworks for guidance, may lead to occasions where a stakeholder(s) fails to accomplish their ethical responsibility (E. Siakas et al., 2023). In such instances legislative and regulatory frameworks can be edited to ensure that they do additionally fulfil ethical obligations. “*From the ethical study of the social impact of PED technologies our understanding of the nature of the problems is increased and adequate solutions can be proposed. Through this process, justifiable policies can be created to enable ethical development and deployment of PED solutions that are socially beneficial*” (D. Siakas, Rahanu, et al., 2025).
- *Demographic opportunities.* Citizens and residents are given an important opportunity with the creation of PEDs to have a saying in design and implementation of the neighborhood they are living in. In fact, their opinion is of decisive importance for the success of a PED. By integrating social innovation and community engagement, PEDs can create new opportunities for wellbeing, particularly when demographic factors like age, income, and social needs are considered in planning (Kozłowska et al., 2024). The aims of a PED is to ensure fair access, participation, and benefits for all demographic groups, including those at risk of energy deprivation (Hearn et al., 2021). PEDs). “*Demographic diversity across regions means PEDs must be adapted to local population structures, energy behaviors, and cultural contexts for maximum impact*” (Lindholm et al., 2021). This gives new demographic opportunities for context-sensitive solutions and social acceptance, which positively will contribute to the PED success.

3.2 PED Challenges

“Studies have suggested that PEDs face challenges including the need for clear definitions, stakeholder engagement and lack of practical implementation experiences” (Kozłowska, 2024). “The PED concept is a complex phenomenon that for its design and its implementation requires a systemic, holistic integrated approach addressing technological complexity, environmental questions, socioeconomic issues, financial and regulatory aspects, governance and legal restrictions, difficulties in replicating successful models” (Guarino et al., 2022), (Ntafalias et al., 2024), (D. Siakas et al., 2023).

- *Social-cultural challenges comprise “social, inclusiveness, opportunities for social participation, energy poverty, energy affordability for residents, employment and business opportunities”* (Kozłowska, 2024). Opinion leaders, change agents, citizens and other local stakeholders are pivotal in creating a sociocultural fair and successful PED. Common and shared vision and values underpin stakeholder engagement (Sareen et al., 2022). Lack of awareness, trust, and knowledge among residents can hinder PED adoption (Hearn & Castaño-Rosa, 2021). Policymaker support and tailored communication are essential. Without careful design, PEDs risk reinforcing existing social inequalities (Krangsaas et al., 2021). A critical, human-centric approach is needed to ensure procedural, distributive, and recognition justice. “*For attaining successful PED creation and operation local stakeholders, including citizens and residents, need to be motivated in order to engage in governance processes*” (Fatima et al., 2021). They are expected to contribute to the achievement of societal goals, such as collective social responsibility and dynamic involvement in sustainable initiatives. “*Cultural differences and social acceptance are likely to impact the PED employment. Scaling up or replication of successful PEDs is challenging because different urban areas have different cultural, spatial and social context*” (D. Siakas, Lampropoulos, et al., 2025).
- *Technological challenges* surround the infrastructure and technology available for a PED. The PED energy system is characterized by “*various renewable energy provisions, flexibility, and high energy efficiency*” (Sareen et al., 2022). Due to the PED novelty, there is limited experience “*regarding how to manage reciprocal*

energy streams from photovoltaic (PV) generation into the energy system". (Ntafalias et al., 2024) However, it should be noted that in addition to challenges related to digital tools or technologies, there are also challenges associated with the physical infrastructure to support PEDs. Hence, there are various types of technological challenges associated with their implementation. Given the emphasis on data and real-time exchanges, there are cybersecurity and data privacy concerns that should be examined. The complexity of these systems, their resource demands, and their ability to be used in conjunction with emerging technologies necessitate the need for advanced infrastructure. The maturity of the related technologies is another factor to consider. Given the data-driven nature of PEDs, there are challenges associated with the quality, trustworthiness, reliability, and availability of data. There is also a clear lack of standardized data formats and protocols. Finally, if their adoption and integration are not carefully planned, there is a risk of increasing the digital divide and access to critical resources.

- *Environmental challenges.* The main environmental challenges in PEDs include integrating renewable energy, managing urban heat, ensuring resource circularity, and addressing context-specific impacts. Urban heat island effects and microclimate changes, are challenges that need to be considered. Nature-based solutions and green infrastructures are increasing, but not yet fully integrated. PEDs must be tailored to local climate, infrastructure, and socio-cultural context. This kind of adaptive planning requires ongoing adaptation. In particular the cultural factor is not considered in any PED literature as far as we know although culture is the underlying factor in people behavior, acceptance, and commitment "*Evaluation of environmental impacts at the district level requires a standardized, reproducible, and transparent method*" (Kozłowska, 2024). "*The absence of a common assessment methodology has given rise to attempts using multiple and diverse resilience indicators*" (Gondeck et al., 2024).
- *Economic challenges* associated with the creation of PEDs include the initial investment required to set up a PED and "*the potential for rising grid costs due to the increasing number of both individual and collective prosumers*" (D. Siakas, Rahanu, et al., 2025). The sustainability and viability of the business model behind PEDs can be hindered by high upfront costs, a lack of available capital financing, and insufficient expertise, which, in turn, could prevent homeowners from investing in these systems. A significant barrier for fully utilizing PEDs is the low compensation offered for surplus energy sold back to the grid from diverse forms of prosumer relationships. The governance structure and stakeholder engagement also add to the financial burden.
- *Political challenges.* Unclear definitions, inconsistent system boundaries, and fragmented regulations hinder PED deployment. Effective governance is needed to coordinate stakeholders, align incentives, and clarify responsibilities across city, regional, and national levels. (Krangsås et al., 2021). PED implementation faces interconnected challenges related to technology, market dynamics, governance, and social factors. Unclear governance structures together with inconsistent policy support may lead to lack of and accountability and transparency as well as the misuse of power, corruption, and a loss of citizen and other stakeholder trust in achievement of sustainable development goals. Lack of clear governance models and coordination among city and urban authorities, private actors, and citizens complicates decision-making and slows progress. Effective PEDs require cross-sectoral collaboration and shared leadership (Sareen et al., 2022)
- *Legal challenges - Legislative and regulatory challenges.* Legislative challenges exist and there is a clear need for a supportive legal framework. "*Low-carbon energy system utilized by smart emerging technology and innovations is considered to be people-centered*" due to the consideration of PED fairness related matters" (Hearn et al., 2021). However, the high implementation costs of energy efficient renewable energy technologies is likely to lead to the elimination of people faced with energy poverty (Energy Poverty, n.d.). "*Regulations might prohibit PEDs defined as energy communities from exporting energy to the external electricity grid and district heating network, as energy communities may not be allowed to engage in commercial energy trading*" (Lindholm et al., 2021).
- *Ethical Challenges.* PEDs risk exacerbating inequalities if benefits (like lower energy costs or improved infrastructure) are not distributed fairly, or if vulnerable groups are excluded from planning and decision-making. (Gohari et al., 2024). There is concern about green gentrification, where sustainable upgrades drive up costs and displace lower-income residents (D. Siakas, Rahanu, et al., 2025). In addition, the reliability concerns of technologies must be considered, along with the safeguarding of the infrastructure to deliver PED.
- *Demographic challenges.* Transitioning to PED involves a large demographic variation by age, socioeconomic position, geographic location, prior knowledge and experience in new technologies. Such fundamental change is likely to generate apprehension, fear, and/or resistance to change. Different stakeholders will need to be consulted and engaged. Morales et al. (Morales et al., 2024) advise that in periods of transition collaborative and participatory decision-making is of paramount importance. "*Society can foster more inclusive and participatory processes by questioning mainstream top-down decision-making methods. Holistic and participatory processes encourage the engagement of diverse stakeholders, including communities, civil*

society organizations, and marginalized groups, in shaping economic policies and strategies. This ensures that a wider range of perspectives and values are taken into account, leading to more equitable and sustainable outcomes” (Morales et al., 2024).

4 Discussion

PEDs represent solutions for SUD and climate neutrality. PEDs enable energy transition towards renewable energy sources and smart infrastructures by utilizing different emerging digital tools for analyzing data to meet efficiency, sustainability, productivity and safety objectives.

The main functions of a PED are “*energy production, energy efficiency and energy flexibility*” (D. Siakas, Rahanu, et al., 2025). Energy production signifies distributed energy production from renewable sources. Energy efficiency is attained mainly by “*decreasing energy demand through utilization of energy saving technologies*”. High energy efficiency means that less energy is used to provide output from a service, i.e. heating, or cooling. Energy flexibility is the ability to adjust energy generation and energy demand according to electricity prices, electricity market changes, transmission and distribution system conditions and regulations.

SUD aims to create cities and urban areas that are environmentally accountable, socially inclusive, and economically viable for future generations. Emerging technologies are playing a critical role in achieving this goal by enabling sustainable urban planning. The European perception of smart cities and smart PEDs highlights sustainable urban environments that use smart emerging technologies with information and data collected through sensors from the surrounding environment. Several emerging technologies have been identified to be pivotal to the creation and operation of PEDs for enhancing energy efficiency, sustainable energy, and user engagement. Such emerging technologies are for example “cyber-physical systems (CPS), digital twins (DT), artificial intelligence (AI), Internet of Things (IoT), Edge Computing, and Blockchain Technology” (D. Siakas, Lampropoulos, et al., 2025). However, challenges that need to be considered are the digital divide (unequal access to technologies can increase social disparities), data privacy and security (data collection must be balanced with ethical governance), regulatory barriers (rapid innovation often outpaces policy development), financing and investment (high initial costs can discourage PED adoption particular incase where supportive policy frameworks and incentives are lacking). Emphasis on SUD lies on how governance of cities and urban areas manage and improve the processes. By applying process improvement methodologies, cities and urban areas can reduce inefficiencies, and provide better outcomes for their citizens. The role of citizens in SUD concerns everyday matters that concern citizens, such as urban mobility, energy use, waste management, and consumption habits. Citizens are encouraged to participate in local planning, sustainability workshops, and civic initiatives, such as movements which advocate for greener policies and corporate accountability (Fatima et al., 2021). Urban mobility includes promotion of public transport, biking, walking, and electric vehicle adoption as well as carpooling / ride-sharing typically to and from work or a shared location. Waste reduction and recycling are citizen initiatives that deal with household-level waste separation. Support for composting and community clean-up drives (empowerment of communities to clean, and conserve their local environment) are incentives for citizens to apply circular economy approaches. Citizens are expected to reduce unnecessary energy consumption through the use of emerging smart applications. They are also expected to utilize solar panels and participate in greening attempts and green space creation.

Replicating of successful PED models has been identified as a significant challenge. Local conditions and cultural differences need to be considered. “*A holistic, cross-disciplinary and systematic understanding is crucial for managing complexities and urban challenges*” (D. Siakas, Rahanu, et al., 2025).

5. How the SPI Manifesto could address PED Challenges

The Software Process Improvement (SPI) Manifesto consists of three values, namely “*People, Business and Change*” (SPI Manifesto, 2010). These values can also be used in the PED approach. The *People* value comprises active involvement and engagement of stakeholders, which is one of the most important PED success factors. The *Business* value helps reaching the PED goal of generating more renewable energy than the PED consumes. The *Change* value is crucial for achieving a change from utilizing fossil fuel to generating a surplus of renewable energy in the PED. The change value also requires a change in mindsets for successful PED implementation.

The three SPI Manifesto values are further expanded into ten principles, that serve as a basis for action. The *People* value embraces the principles: “know the culture and focus on needs, motivate all people involved, base

improvement on experience and measure, create a learning organization” (SPI Manifesto, 2010). The *Business value* embraces the following principles: “support the organizations vision and objectives, use dynamic and adaptable models as needed, apply risk management”. The *Change value* embraces the principles, “manage the organizational change in your improvement effort, ensure all parties understand and agree on process, do not lose focus”(SPI Manifesto, 2010).

6. Conclusion

Positive Energy Districts (PEDs) are a key concept in sustainable urban development. They are areas within cities and urban areas that produce energy for the community but often more energy than they consume (which can be consumed by other users or communities), using renewable energy sources and smart energy management. The goal is to help cities reduce their carbon footprint, support energy independence, and enhance quality of life. PEDs utilize digital tools (e.g. smart grids and IoT sensors) to monitor and optimize energy production, energy storage, and energy use. Integration of mobility, heating/cooling, and electricity systems increases overall energy efficiency. The rapid advancements of emerging technologies which positively affect PED creation and operation have positive social impact and are responsive to urban sustainability goals. An important characteristic of PEDs is citizen engagement and local ownership of energy systems that fosters a sense of community and stewardship. In this study a factor analysis concentrating on “sociocultural, technological, economic, environmental, political, legal, ethical, and demographic (STEEPLED)” PED features were used to investigate opportunities and challenges related to PEDs. The aim of this study was to enhance understanding and knowledge about the creation, implementation and operation of PEDs and to further progress research and development in this important field.

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