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

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**Abstract.** This study explored how sustainable urban development can be supported through emerging technologies, process improvement, and citizen commitment employed in the adoption of Positive Energy Districts (PEDs). The PED concept is a complex undertaking that requires a systemic, holistic, and integrated approach for its design, implementation, and operation as it addresses multiple interconnected aspects. This aim of the study has been to clarify different PED aspects by carrying out a factor analysis exploring sociocultural, technological, economic, environmental, political, legal, ethical, and demographic (STEEPLED) dimensions. Additionally, the study highlights the main PED opportunities and challenges. The outcomes of this study aid in the understanding of critical factors in the creation, implementation, and operation of PEDs.

**Keywords:** Positive Energy Districts, sustainable urban development, sustainability, 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 [5]. These technological advances aim to increase energy awareness in society, meet increased energy demand, 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 they enhance energy efficiency at both building and district levels [41]. 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 [44]. In general, PEDs create a sense of community. Economic sustainability is attained through improved socioeconomic conditions, such as decreased energy bills and operational costs, creation of new business models through for example 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 [3]. It can apply to various critical contexts, such as electricity, internet service, or water supply.

The main target of PEDs is “the optimization of energy production, energy efficiency and energy flexibility” [41]. Energy production denotes distributed renewable energy production [45]. Energy efficiency is attained by minimizing energy demand through utilization of energy saving technologies, energy distribution and supply systems, as well as 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 [36]. Energy flexibility indicates 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 establishment and operation of PEDs for enhanced sustainability, energy efficiency, and citizen engagement, have the potential for social influence [39, 41]. 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 [41].

### 1.3 Sustainable Urban Development through PEDs

Sustainable Urban Development (SUD) refers to the process of planning and managing cities and urban areas in a manner that satisfies the needs of the current population without risking the ability of future generations to meet their own needs [32]. A key enabler of this vision is the adoption of PEDs which constitute urban areas designed to generate more energy than they consume on a yearly basis [41]. PEDs are increasingly recognized as enablers of urban sustainability, supporting energy transition, climate goals, and social equity [4].

Totally, “66% of the existing PED projects consist of newly built neighborhoods” [31]. 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 is worth noting, however, that around 75% of the EU building stock is energy inefficient [12], highlighting the need to integrate PEDs into the existing urban infrastructure [38].

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 [41].

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 [6]. This supports climate neutrality and decarbonization targets for cities, which are responsible for the majority of global energy use and emissions [23]. Energy efficiency in PEDs is mainly achieved through:

- Exploitation of emerging digital technologies (smart grids, IoT, AI etc.) for managing demand and supply;
- Utilization of renewable energy resources, such as solar, wind, geothermal, and bioenergy;
- 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 attention needs to be placed on SUD (Nations, n.d.). The SDGs of the UN “aim to address environmental, economic, and social issues” [46]. “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 dedicated 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” [10]. The enhancement of urban services and infrastructure, along with

improvements in social and economic conditions, seeks to increase the competitiveness and attractiveness of urban regions. Moreover, PED initiative also promotes and aids the “Green Deal Goals” [8], the “Renovation Wave” [9], and the “Mission on Carbon-Neutral and Smart Cities” [13].

SUD through PEDs aims to foster urban resilience, namely the capacity of an urban system to cope with, adapt, and advance regardless of future uncertainties [28]. Moreover, it includes the measurable ability of an urban system to sustain continuity in the face of various stresses, while effectively adapting and evolving toward sustainability [41]. Nowadays, there is an amplified preference for solutions based on nature and natural resources, mainly attributed to their economic and ecological advantages [34].

A factor analysis concentrating on sociocultural, technological, economic, environmental, political, legal, ethical, and demographic (STEEPLED) PED features is used to identify 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 STEEPLED factor analysis for opportunities and challenges followed by a discussion in section 4. Section 5 emphasizes the way in which the SPI Manifesto could address PED challenges and section 6 is the conclusion.

## 2 PED Processes

The design and improvement of business processes is significant for attaining business benefits [30]. Business Process Management (BPM) entails a systematic approach for enhancing organizational performance through the business processes optimization and effective management [7]. 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 in order 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 [43].

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 [7].

The steps in utilizing the BPM approach in PEDs entail process mapping, visualization of processes and existing workflows. The following step includes identification of bottlenecks, redundancies, and inefficiencies. The third step includes root cause and

gap analysis, benchmarking, identification of errors, unnecessary steps, or poor resource allocation. The final step is the 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. These processes are being monitored on an ongoing basis and measured through the use of key performance indicators (KPIs).

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.

Some key processes in PEDs based on the related literature are briefly described below [2, 24, 35, 37, 39, 41]:

- *Governance and stakeholder engagement*: Involve 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 Gollner et al. [16]. Moreover, previous studies have focused on PEDs and their influence, including Ntafalias et al. [36], Bossi et al. [1], Bruckner et al. [2], Healey Trulstrup and van der Leer [19], and Zhang et al. [49]. 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. According to the literature, we have identified diverse PED opportunities, but also challenges, both of which we investigate by using the STEEPLED factor analysis presented in Sections 3.1 and 3.2.

#### 3.1 PED Opportunities

PEDs have shown great potential in achieving sustainable development. Below, some of the benefits are presented and categorized according to each STEEPLED dimension:

- *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 [23]. 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 [21]. However, in 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” [20].
- *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 [39]. Specifically, CPSs enable real-time simulation and control of energy flows, resource production, distribution, and consumption optimization

across interconnected urban infrastructures [26]. AI and machine learning can enhance system autonomy and support intelligent decision-making, improving the effectiveness of automated operations, predictive maintenance, and resource optimization [25]. DTs offer dynamic, virtual representations of physical assets, allowing for advanced monitoring, realistic simulations, and proactive planning [26]. 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 [25]. 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 [27].

- *Environmental opportunities* present great potential to reduce GHG emissions via the transformation of urban energy systems, including demand-side energy management, integration of renewable energy, and the implementation of energy storage solutions. The decentralized power generation PEDs foster the creation of resilient, flexible, and effective energy systems [39]. 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 to promote circular resource use [31]. Increasing photovoltaic (PV) capacity (by e.g. installing more rooftop PVs) and utilizing demand-side management and battery storage are important for achieving carbon neutrality in urban areas [47].
- *Economic opportunities* include modern decentralized energy systems which offer shared benefits among stakeholders, promoting new models of energy ownership, including collaborative or community-owned systems [20]. These approaches can empower local residents and ensure that economic advantages remain within the community. The development, retrofitting, and operation of PEDs stimulate local economies by creating new jobs in construction, renewable energy installation, maintenance, and energy management [41]. Retrofitting existing buildings in a PED is particularly important from a circular economy point of view, job creation, and restoration of existing urban appearance. The growing integration of distributed energy resources, including decentralized energy storage and electric vehicles (EVs), into distribution systems also generates new economic benefits and opportunities for local communities [48].
- *Political opportunities* involve supportive policies, including strong political commitment, clear regulatory frameworks, and active policymaker engagement are essential for PED creation and scaling [37]. Policymaker engagement and support is crucial for effective PED governance and significant for stakeholder awareness, trust, and knowledge sharing [20]. Financial incentives, innovative financing instruments, and public-private partnerships, all dependent on political initiatives, can accelerate PED deployment and encourage community participation [24]. An important political opportunity is closely related to the legal/legislative opportunity,

since political decisions need to be taken at the EU member states level for legally supporting PEDs.

- *Legal / Legislative opportunities* include 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 regulatory aspects of energy communities could benefit PEDs by minimizing economic barriers between renewable energy producers and consumers [29]. EU PEDs must address justice issues in order to guarantee a just transition [20]. 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 for example 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 STEELED opportunities.
- *Ethical opportunities* are varied in nature. An ethical examination, as part of the STEELED 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 fails to accomplish their ethical responsibility [42]. In such instances legislative and regulatory frameworks can be edited to ensure that they do additionally fulfil ethical obligations. An ethical analysis of the social impact of PEDs enhances our understanding of the underlying issues, allowing for the development of appropriate solutions. This process helps formulate justified policies that foster the ethical PED solution deployment and development, ensuring they provide solutions that are beneficial on a social scale [39]
- *Demographic opportunities* can influence all stakeholders. Citizens and residents are given an important opportunity with the creation of PEDs to have a saying in the 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 [23]. Some of the aims of PEDs are to ensure fair access, participation, and benefits for all demographic groups, including those at risk of energy deprivation [21]. The demographic differences between regions highlight that PEDs should be customized to fit local population energy cultural contexts, use behaviors, and structures to maximize their effectiveness [29]. This gives new demographic opportunities for context-sensitive solutions and social acceptance, which positively will contribute to the PED success.

### 3.2 PED Challenges

Research has highlighted several challenges faced by PEDs, including difficulties in engaging stakeholders, lack of practical experience in implementation, and the absence of clear definitions [22]. The PED concept is a multifaceted phenomenon that demands a systemic and integrated approach for both its design and implementation. This approach must address socioeconomic factors, environmental concerns, governance challenges, technological complexities, legal constraints, financial and regulatory issues, and the difficulties associated with replicating successful models [18, 36, 40]. Below, these challenges are further discussed [18, 36, 40]:

- *Social-cultural challenges* involve social equity, inclusivity, social engagement, energy poverty, energy affordability, and employment and business prospects creation [22]. Opinion leaders, change agents, citizens and other local stakeholders are significant in creating a socioculturally fair and successful PED. Common and shared vision and values underpin stakeholder engagement [37]. Lack of awareness, trust, and knowledge among residents can hinder PED adoption [20]. Policymaker support and tailored communication are essential. Without careful design, PEDs risk reinforcing existing social inequalities [24]. A critical, human-centric approach is needed to ensure procedural, distributive, and recognition justice. To ensure the successful development and functioning of PEDs, it is essential to motivate local stakeholders, including citizens and residents, to actively participate in governance processes [14]. They are expected to contribute to the achievement of societal goals, such as collective social responsibility and dynamic involvement in sustainable initiatives. The implementation of PEDs can be influenced by social acceptance and cultural differences. The successful replication or scaling of PEDs is often influenced by the distinct social, spatial, and cultural aspects present in different urban areas [39].
- *Technological challenges* surround the infrastructure and technology available for a PED. The energy system within a PED is distinguished by the integration of multiple renewable energy sources, a high degree of operational flexibility, and a strong emphasis on maximizing energy efficiency. This system leverages diverse renewable energy provisions while ensuring adaptability to fluctuating demands and environmental conditions [37]. Moreover, it prioritizes energy-saving measures and technologies to optimize consumption, contributing to both environmental sustainability and economic viability [39]. 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 supporting 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* 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. Ongoing adaptation is essential for this type of planning. Specifically, the cultural aspect, despite its critical role in shaping people behavior, acceptance, and commitment has received scant attention by researchers. Furthermore, the assessment of environmental impacts at the district level highlights the need to use standardized, reproducible, and transparent methodologies [17, 22].
- *Economic challenges* related to the realization of PEDs involve the initial capital investment needed for their setup, as well as the potential for escalating grid costs resulting from the growing number of individual and collective prosumers [41]. The sustainability and feasibility of the PED business model can be held back by high initial costs, absence of available financing, and inadequate expertise, which, in turn, is likely to avert homeowners from investing in these systems. An important barrier for full PED utilization is the low reimbursement offered for surplus energy sold back to the grid. Unsuitable governance structure and lack of stakeholder engagement also enhance the financial burden.
- *Political challenges* involve unclear definitions, inconsistent system boundaries, and fragmented regulations which hinder PED deployment. Effective governance is needed to coordinate stakeholders, align incentives, and clarify responsibilities across city, regional, and national levels [24]. 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 [37].
- *Legal, legislative, and regulatory challenges* influence different aspects of PEDs; hence, a supportive and flexible legal framework to address them is required. The low-carbon energy system, driven by advanced technologies and innovations, is viewed as people-centered because it takes into account fairness issues associated with PEDs [21]. However, the high implementation costs of energy efficient renewable energy technologies are likely to lead to the elimination of people faced with energy poverty [11]. “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” [29].
- *Ethical challenges* and risk in PEDs 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 [15]. There is concern about green gentrification, where sustainable upgrades drive up costs and displace lower-income residents [41, 42]. In addition, the reliability concerns of technologies must be considered, along with the safeguarding of the infrastructure to deliver PED.

- *Demographic challenges* highlight the influence of PEDs on all stakeholders. 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. [33] advise that in periods of transition collaborative and participatory decision-making is of paramount importance. By challenging traditional top-down decision-making approaches, society can promote more participatory and inclusive processes. Emphasizing holistic and collaborative methods allows for the active involvement of stakeholders in the development of economic policies and strategies. This approach supports and considers a broader and diversified range of values and perspectives to provide more sustainable and fairer results [33].

## 4 Discussion

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

The main functions of a PED are “energy production, energy efficiency and energy flexibility” [41]. Energy production signifies distributed energy production from renewable sources. Energy efficiency is attained mainly by “decreasing energy demand through utilization of energy saving technologies” [41]. 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 vision of smart cities and smart PEDs emphasizes sustainable urban environments utilizing smart emerging digital technologies for information and data collection through sensors from the surrounding environment. Several emerging technologies have been identified to be significant to the creation and operation of PEDs for enhancing energy efficiency, sustainable energy, and user engagement [39]. However, challenges that need to be considered include 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 involves 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 [14]. 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 another significant challenge. Local conditions and cultural differences should also be considered. All in all, to effectively manage and address the challenges and complexities of urban areas, a systematic, holistic, and cross-disciplinary comprehension is required [41].

## **5 How the SPI Manifesto could address PED Challenges**

The SPI manifesto consists of three values, namely Business, Change, and People [43]. These values can also be used in the PED approach. 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. Finally, the People value comprises active involvement and engagement of stakeholders, which is one of the most important PED success factors.

The three core values of the SPI Manifesto are elaborated into ten guiding principles, which serve as the basis for action. Under the Business value, the key principles include: aligning with the organization objectives and vision, employing adaptable and flexible models, and integrating risk management practices. The Change value emphasizes principles such as effectively managing organizational change, maintaining a sharp focus on goals, and ensuring clear communication and consensus among all stakeholders [43]. Lastly, the People value emphasizes principles such as motivating all participants, focusing on needs, grounding improvements in experience and measurable outcomes, understanding the organizational culture, and fostering a culture of continuous learning [43].

## 6 Conclusion

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 STEEPLED features was used to identify opportunities and challenges related to PEDs to enhance the understanding and knowledge about the creation, implementation, and operation of PEDs.

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