

A review of positive energy districts' goals and services: insights for business model design

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Abstract—Positive Energy Districts (PEDs) are urban areas that achieve net-zero emissions and energy imports while striving for a surplus in local renewable energy production. This paper contributes to the understanding of PEDs through a literature review that identifies their advantages and successful practices, offering insights for developing business models that promote sustainable urban growth in the EU. PEDs engage various stakeholders to create value and deliver numerous environmental, economic, and social co-benefits, including enhanced energy efficiency, integrated renewable energy solutions, improved flexibility, and advancements in e-mobility. However, many PED initiatives remain in the development phase, requiring further efforts for effective implementation. Promoting collaboration among stakeholders and establishing supportive policies and regulatory frameworks at various levels are essential steps to ensure the successful deployment of PEDs.

Index Terms—Business Model, Energy Community, Just Transition, Positive Energy District, Smart Cities

I. INTRODUCTION

Energy communities of various sizes have a strong potential to enable just energy transition by promoting the integration of distributed energy resources, such as solar photovoltaic (PV), energy storage, and electric vehicles (EVs) to larger groups of residents that might not have the means to invest in them by themselves [1]. The concept of a positive energy district (PED) has gained attraction lately on the EU level [2], and to support the Green Deal, the EU has been aiming for 100 working PEDs in more than 19 countries by 2025 [3]. In a PED, the goal is to form an energy community of a larger area in a city, for instance in a neighborhood, to promote sustainable urban development [4] and aim for annual net zero energy import and net zero CO₂ emissions [5]. PEDs could offer many benefits, such as improving the city's energy efficiency, encouraging sustainable mobility, further promoting digitalization, supporting the integration of renewable energy sources (RES), reducing energy poverty, and improving overall sustainability [2], [4], [6], [7], [8]. Moreover, PEDs could join electricity and flexibility markets to support the local grids and the energy system at large and gain additional monetary benefits from it [9], [10], [11].

Through a literature review, this paper compares the

targets of different PED initiatives, reviews the services and benefits provided to the customers, identifies business opportunities for different stakeholders, and potential services offered by the PEDs to the energy system. Identifying all these potential services and business cases of PEDs, and analyzing their feasibility, could be beneficial for further driving PED deployment in the EU. Also, mapping the stakeholders of PEDs is vital to maximize the social benefits they could provide. These stakeholders include, for instance, city management, urban developers, energy companies, and finally but not least, the citizens themselves. Subsequently, this paper provides further inputs on planning, deploying, and replicating PEDs around the EU.

This paper seeks to contribute to the development of PEDs in the EU by identifying advantages and successful PED practices to provide insights for developing PED-related business models and promote PED deployment by exploiting the results in already existing and upcoming PEDs. Together, this could help promote just energy transition in cities by enabling novel urban development and supporting district-wide integration of distributed energy resources.

II. DEFINITION OF POSITIVE ENERGY DISTRICTS

Despite the growing interest in PEDs to promote climate targets in cities around Europe, there is a lack of uniform definition for the concept [6], [12]. Also, terms like zero-emission neighborhoods or climate-friendly neighborhoods have been used to describe similar urban development concepts [6]. In the Strategic Energy Technology (SET) Plan of the EU [5], PEDs are defined as “a district with annual net zero energy import and net zero CO₂ emissions, working towards an annual local surplus production of renewable energy”. Furthermore, the PED framework proposed by Joint Programming Initiative Urban Europe (JPI-Urban Europe) adds a note of “integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility, and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability” [13]. Whereas The International Energy Agency Energy in Buildings and Communities Programme (IEA EBC) defines PEDs as “an area within the city boundaries, capable of

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generating more energy than consumed and agile/flexible enough to respond to the variation of the energy market.” and “PED should also support minimizing the impact on the connected centralized energy networks by offering options for increasing onsite load-matching and self-consumption, technologies for short- and long-term storages, and providing energy flexibility with smart control.”[14].

However, some common themes are observable [2], [4], [5], [15], [16]: Customer-centric approach by involvement and engagement of stakeholders (co-creation); Net positive annual (primary) energy (buildings and end-user); High energy efficiency; Local integration of RES; Energy flexibility and energy storage; Sustainable mobility; Digitalization.

Still, the nonuniform definition of a PED can cause challenges, such as regarding the energy and carbon balance calculations, with for instance the mobility sector having a huge impact on the balances [15]. Indeed, more work is needed to define the methods to calculate the environmental footprint of urban areas, such as PEDs [15].

III. GOALS AND SERVICES OF PEDS

There are many goals for PEDs, and they can offer a variety of added value for both residents and customers, but also to the energy system. This section focuses on analyzing different PED projects and initiatives, and their added value.

A. Targets of PED initiatives and projects

To support the target of 100 PEDs by 2025, the EU laid the foundational objective of creating city-driven PED labs, guides and tools for stakeholders, monitoring and evaluation tools for performance assessment, and support to replicate and mainstream PEDs [17]. Indeed, policy development has been active in the EU, and EU framework programs have been launched to promote climate actions in Europe, including PED projects. Three major initiatives can be identified: 1) Horizon 2020 Framework Programme, which aims to promote secure, clean, and efficient energy through smart cities and communities; 2) Horizon Europe Framework Programme, which aims to develop clean energy transition partnerships in urban transition and in climate neutral cities; 3) COST Action, which is focusing on European energy poverty and PEDs [12].

Following the objectives of the EU and the framework programs of past years, multiple research projects have been created to study and implement PEDs, like SPARCS [18], POCITYF [19], ATELIER [20], +CityxChange [21], Making City [22], Cities4PEDs [23], PED-ID [24], TIPS4PED [25], SUSHI [26], PEDRERA [27], and Trans-PED [28]. Indeed, there are many PED projects around the EU, and their aims and objectives are listed in Table 1. Furthermore, the location of some of the PED labs and case studies related to these projects are shown in Fig. A1 (Appendix).

Aligning the goals and interests of the PED project early on is important for the development process of the project [4]. Thus, this subsection focuses on identifying different targets and goals that PED projects have. Bossi et al. [16] analyzed 61 concurrent PED projects in 19 countries, finding the most common target of the projects to be combining new and existing neighborhoods into PEDs, to promote the integration of multiple energy sources (≥ 5), and engage citizens and

stakeholders. At the time of their study, 93% of the projects were still either in implementation or planning stage. Projects in Table 1 align with these goals, with energy efficiency and co-creation being some of the most common targets. Also, topics like energy poverty are rising as important themes to consider in many projects.

TABLE I. PED PROJECTS IN THE EU AND THEIR AIMS AND OBJECTIVES.

Project	Aims and objectives	References
SPARCS	Aims to develop urban energy solutions for mobility, land use, infrastructure, governance, circular economy, education, and climate initiatives by utilizing stakeholder engagement and workshops in multiple cities across the EU.	[2], [18]
POCITYF	Aims to integrate peer-to-peer (P2P) energy storage and e-mobility-enabled smart grids to PEDs through citizen-driven co-creation.	[19]
ATELIER	Aims to create PEDs by integrating smart urban solutions, leading to emission reductions, sustainable and affordable energy systems for citizens, and collaboration with stakeholders and fellow cities.	[20]
+CityxChange	Focuses on co-creation and community engagement in creating decision-making tools and new approaches, like P2P energy trading, to enable PEDs.	[21]
MAKING-CITY	Aims to reduce energy poverty by emphasizing citizen participation, economic viability, technical feasibility, political support, regulatory compliance, and spatial considerations. Aims to develop a framework for planning and designing PEDs, based on stakeholder involvement to define the needs of cities and technical analyses of technologies and energy balances.	[2], [22]
Cities4PED	Aims to actively involve cities and communities in developing PED co-ownership strategies and to understand how different communal aspects are affecting PEDs and the needs related to them.	[2], [23]
PED-ID	Aims to develop strategic tools for decision-makers to aid in all early phases of PED development, from identifying potential sites to planning, consulting, and final decision of approving PED projects.	[2], [24]
TIPS4PED	Aims to utilize co-creation to develop a tool, an integrated assessment platform, to help in designing and managing PEDs, by providing technical, social, financial, regulatory, and administrative aspects to decision-makers.	[25]
SUSHI	Aims to improve energy efficiency and lower energy prices, in turn reducing energy poverty in older historic districts by renovating buildings and installing PV production.	[7], [26]
PEDRERA	Aims to develop supporting tools, e.g., to detect viable business cases and co-benefits of renovating old districts.	[2], [27]
Trans-PED	Brunnshög district in Lund, Sweden, aims to become energy-positive to promote energy-efficient and sustainable urban development. The city plans to achieve this for instance by utilizing waste heat in a low-temperature district heating network, investing in public transportation and solar power, while also building parks and green spaces.	[4], [28]

As most PEDs are still in early development phases, i.e. in transition towards becoming PEDs, Turci et al. [2] identified different transition approaches based on their review of

multiple publications and project descriptions. They identified three distinct approach scopes, orienting, engaging, and activating. The majority of the analyzed cases were either in the activating category, where the goal is to establish pilot projects, or in the orienting category, where the goal is to develop strategic tools for local decision-making [2]. The approach strategy with the least cases was engaging, where the aim was to prioritize stakeholder involvement in all PED development stages [2]. These applied development approaches seem to partly contradict the identified co-creation target of many of the projects. On the other hand, the tool creation approach fits the target of many projects. It could be argued that the applied approaches of reaching the final PED stage, and the targets of the functioning PED can be different from each other, and they are not exclusive.

B. Services and benefits provided by PEDs

Different services and benefits that PEDs can offer to customers are partially visible from the definition of PEDs as well as the aims and objectives of PED projects in Table 1. This subsection gives an overview of some of these services and benefits that PEDs could provide to their residents and other various stakeholders while contributing to creating sustainable and energy-efficient urban areas.

Overall energy efficiency improvements are a concern in nearly all PED projects. These energy efficiency improvements, for instance through retrofitting old buildings, would directly lead to significant improvements in living standards and to reduction in energy costs, positively impacting the ecological sustainability [7], [29]. Many PED-related studies have identified these upgrades to energy efficiency to be key in alleviating energy poverty, which is observable even in some cities in the EU [6], [7], [15].

The integration of local RES could reduce energy-related costs even further, and in turn, generate revenue by selling the excess production [7], [30], [31]. Cellura et al. [8] studied how PEDs fulfill different sustainable development goal indicators, finding PEDs to promote affordable and clean energy, sustainable cities and communities, and climate action targets, driven e.g., by the surplus of energy in PEDs. Additionally, many PEDs are aiming to integrate a variety of energy storage technologies (e.g., batteries and thermal energy storage) to support the local RES and offer flexibility, for both customers and the grid [9], [31]. Furthermore, energy storage could offer improvements in the security of supply and energy-related reliability in areas where this could be of concern [31].

Many PEDs aim to improve ecological mobility by developing sustainable public transport [28] or by integrating EVs into the PEDs. For instance, the +CityxChange project is developing mobility-as-a-service schemes, including bidirectional charging of EVs in PEDs [32]. Likewise, effective urban planning should also pay attention to supporting walking and cycling [32], further contributing to sustainable mobility.

PEDs generate extensive data by monitoring various aspects, enabling new data platforms for tracking energy flows within them [33], but also to optimize the use of energy, powered by machine learning and digital twins [34]. Indeed, data is in a key position in PEDs, and many projects are for

instance utilizing digital twins of the districts [25], [32], enabling them to simulate and track how different solutions impact the district. Furthermore, digitalization and data platforms could create new forms of energy trading. P2P trading could enable the residents to trade energy between themselves and avoid external electricity markets [35].

The improved energy efficiency, integration of local RES, and added flexibility give cities a significant chance to reduce both local and global emissions [29] and to decrease the environmental impact of the building sector [15]. In turn, the reduced local emissions improve air quality in the city and further improve the quality of life of the residents [7], [36]. Gouveia et al. [7] argue, that these significant social benefits should be given more weight in investment decision-making, but also that new quantitative methods are needed to measure these benefits.

The co-creation aspect of many PED projects allows the creation of such services that are truly impactful for specific communities by considering local needs and creating inclusive services [32], [37], [38]. Cities and districts are typically unique, with varying customer bases, benefitting from bespoke solutions to enable fulfilling the requirements of a PED. However, this should not lead to excessively limited systems that restrict integration, scale-up, and replication [37]. Still, co-creation enables bringing valuable insight to the development process, while increasing residents' awareness through engagement [37]. Indeed, end-users actions are also in a key role in enabling for instance energy efficiency measures, and lack of active participation can be a barrier to PED implementation [30].

In conclusion, PEDs can provide a variety of technical energy-related services and benefits, along with significant environmental and social co-benefits that should not be overlooked [29] for many beneficiary stakeholders, such as residents and property managers. PEDs have the potential to offer a wide range of services that contribute to sustainable urban development and provide environmental, economic, and social benefits. However, efforts are needed to realize their development and provide access to these services and benefits to the customers.

C. Business opportunities of PEDs

Like there is no uniform definition for a PED, there are yet no business models that would fit all needs. On the one hand, this can create lots of flexibility to identify relevant business cases and form PED-specific business models, such as through tools like business model canvas [39]. On the other hand, this creates added complexity and inefficiency for PED implementation [30]. For this reason, this subsection focuses on identifying different business opportunities that PEDs can create for several stakeholders. This can also aid in defining stakeholders' role in PED-related value creation [30].

Following the services that PEDs could provide, new sustainable investment and business opportunities arise for many stakeholders. The innovative nature of the energy sector holds a great opportunity for bringing new solutions to many needs related to PEDs, resulting from understanding the needs of the customers and the built environment [29]. At least four key business areas are observable for PED-related

stakeholders: actions in energy efficiency, renewable energy, flexibility, and mobility [37].

Given that PEDs aim for very high energy efficiency, efforts are needed either in building new buildings or renovating the old. This creates business opportunities for many building and renovation companies to offer expertise. Likewise, sustainability contracts with developers and collaboration contracts with energy companies are needed to reach needed energy efficiency targets [4]. Similarly, collaboration with municipalities, property owners, and property managers is needed [4]. Furthermore, Sareen et al. [29] identified a lack of technical advisory services to be a key barrier on a local level, underscoring the need for new service providers on multiple levels.

Considering PEDs require local RES, this creates the potential for many related stakeholders throughout the development, building, and operating phases of a PED. In addition to directly investing in the RES equipment, different leasing schemes have also been proposed for implementing RES into PEDs [37]. Especially colder climates create unique challenges, with higher heat demand and limited PV potential, but also opportunities, as these PEDs require innovative solutions e.g., energy supply and distribution [40]. Marrasso et al. [41] called these systems multi-vectoral, highlighting the fact that PEDs require not only RES-based electricity but also climate-neutral cooling and heating sources, to reach decarbonization.

As discussed in the previous subsection, PEDs have great potential for offering energy balancing and flexibility services, but in turn, they need services such as aggregation [4], [29], creating a variety of business opportunities for such service providers, e.g., energy companies. One such aggregation model would be forming virtual power plants, allowing to harnessing the potential for demand side management and offering this flexibility toward grid [11], further creating business opportunities. Ahlers et al. [32] proposed a battery-centric value proposition model, where battery storage in PEDs would participate in the flexibility market, providing grid balancing services and optimization of electricity prices through optimized charging-discharging. In general, PEDs have strong potential for joining the electricity market through RES and flexibility, creating value for both the customers and the energy system as a whole [42]. Also, changes in tariff structures towards capacity-based pricing could further improve the feasibility of offering flexibility, such as in the form of cutting peak demand [37].

With PEDs aiming to improve sustainable mobility, opportunities open for EV charging service providers [29]. This includes both building and operating phases of the charging infrastructure. Also, previously discussed mobility-as-a-service [32] serves as an opportunity for providing different services, such as shared communal cars. Likewise, electric mobility could have a strong contribution, but also a business opportunity, in the flexibility market. EV battery capacity could be harnessed for the PED's use through bidirectional charging [37]. This could create business opportunities for the customers if they lend their EVs' batteries to the needs of the PED [32]. Furthermore, this would apply to both residential but also commercial customers

and their fleets of cars.

All the previously mentioned areas require strong information and communication backbone, building towards integrating the different aspects into the smart grid concept [29]. PEDs require vast amounts of small building blocks to be integrated into a larger system and to have fluent interaction between these smaller pieces [37], creating a significant need for new solutions, and in turn need for new service providers.

In conclusion, combining all the previous aspects, the possible reductions in primary energy use and reductions in emissions, while providing a surplus of RES and energy flexibility, create inviting investment opportunities for PED customers and investors alike to energy solutions, infrastructure, and smart grid technologies [7], [43]. PEDs also enable the creation of local jobs, further contributing to sustainable growth [44]. Indeed, the communal aspect of PEDs is also strongly reflected in the business opportunities. First, stakeholder and community involvement and engagement are valuable for identifying needed businesses [29]. Second, PED customers have a strong potential to take part in sustainable value co-creation, becoming an integral part of the PED business model [44]. However, policymakers have a large role in enabling the initial transition towards PEDs, for instance through permitting and legislative decisions, but also through different incentives [30], [45].

D. PEDs supporting the energy system

In addition to providing a variety of services to customers, PEDs can support the local power grid and district heating system, as well as the energy system at large. Ochs et al. [40] studied how different measures, including RES and energy storage, affect PED's impact on the local grid. They identified that energy efficiency improvements were the most important measures for reducing the grid impact of PEDs, as they led to the most significant peak demand reductions. However, PEDs have vast potential to offer various energy system support services beyond just reducing the peak demand towards the grid. Indeed, PEDs are a perfect match for the needs of future decarbonized energy systems, as they consist of a surplus of RES and flexibility resources, like demand response and energy storage of multiple energy vectors [7], [31], [41].

Lindholm et al. [46] and Anastasovski et al. [31] studied different energy storage solutions in PEDs, concluding that batteries and thermal energy storage are the most suitable solutions for most PED sites, providing flexibility for both power and heat sectors, with hydrogen showing some future potential. Energy storage technologies that are integrated into PEDs together with demand response, are vital parts of modern energy systems, as the share of RES increases [4], [31], [47]. Locally they provide e.g., peak demand cutting and voltage regulation, and at a larger scale they ensure the efficiency of energy supply by providing energy balancing, supporting RES integration [29], [31], [32], [48]. Furthermore, electrification of heating coupled to thermal energy storage provides opportunities for providing flexibility services to reserve markets for frequency balancing [49]. Moreover, utilizing P2P trading for both energy and flexibility trading could also contribute to optimizing the energy use of the PED, reducing the impact on the grid [32].

PEDs should be integrated into both distribution networks and district heating, if available, to maximize the offered flexibility. Furthermore, PEDs around the city could be interlinked, to further extend the flexibility potential [15], [46]. As a whole, flexibility plays a key role in enabling decarbonization, as it helps to integrate RES into the energy system [50]. Thus, the development of and provision of access to, electricity and flexibility markets is in a key position in enabling not only the PED's participation to these markets but also securing the decarbonization targets of the EU.

IV. DISCUSSION & CONCLUSION

Positive energy districts (PEDs) have become of high interest in the EU, as PEDs aim to reach net zero emissions, net zero energy imports, and production of surplus renewable energy. PEDs have strong potential to aid the EU in reaching strict climate targets, and thus research around PEDs has been active in past years, supported namely by EU framework programs like Horizon 2020 and Horizon Europe. However, a high share of PED projects is only in the planning phase and more work is needed to reach the implementation and construction phases.

Through a literature review, this paper identified targets of PED initiatives, services and benefits that PEDs can provide, PED-related business opportunities, and ways that PEDs can support the energy system. This paper contributes by identifying the advantages and successful practices of PEDs to provide insights for developing PED-related business models and promoting PED deployment in the EU. Together, this could encourage just energy transition and endorse sustainable urban development in the EU.

Common goals on which PEDs are formed are co-creation, energy efficiency, renewable energy, flexibility, and e-mobility. Following these goals, PEDs can offer various services and benefits to their customers like decreased energy costs from enhanced energy efficiency and RES, improved air quality and quality of life in general, effective integration of EVs, and new data-related amenities like energy monitoring and optimization of energy use. Likewise, PEDs can support the local power system and the energy system at large by incorporating RES, energy storage, and demand management systems to offer various levels of flexibility. These services and benefits that PEDs can offer could further be turned into new business opportunities for many stakeholders, rising from the energy efficiency efforts, RES, flexibility, and mobility. Even though business models can be case-sensitive, building a business model for PEDs around these common themes could act as a building block for new PEDs, and help improve the existing PEDs.

PEDs have multiple important stakeholders, such as but not limited to citizens, commercial customers, the public sector, decision-makers in municipalities and local governments, energy companies, service providers, building developers and managers, and investors. These stakeholders are in a key position when developing PEDs, and many PED projects have taken co-creation approach of varying level. Similarly, the initial motivation of stakeholders has been recognized to be fundamental for successful PED [29]. Indeed, considering the needs of local customers is important for

developing viable business models, while including aspects of sustainability, equality, and value co-creation.

Despite the growing activity in this field, there are still challenges for PED deployment. Even as most projects are aiming for co-creation, Sareen et al. [29] identified the lack of support from city-level decision-makers and compromised stakeholder involvement to be some of the most encountered barriers to PED projects. Likewise, Trulstrup and van der Leer [4] identified a lack of integration between energy and urban planning, adding that this typically leads to the inability to meet energy targets. This highlights the need for actively taking the stakeholders into the development process from early on. This could be further promoted from the country or EU level by policy changes, requiring cities or municipalities to actively support the PED development. Indeed, Bossi et al. [16] identified the legislation and regulation processes to be a big barrier to PED development. The development of PEDs requires supportive regulatory frameworks and policies to ensure successful implementation and scalability [53], [54].

Seasonality also brings challenges for PEDs, as winters have lower PV production and colder weather, and on the other hand, very high PV generation during summer might cause stress for the power grid [15]. A need arises for many energy storage solutions coupled to energy management systems. However, a high number of case studies in Northern Europe [4], [16] has shown that positive energy districts are also possible in cold climates with limited PV production during the winter. Technologies like geothermal energy and waste heat recovery are important for these cases. Likewise, Guarino et al. [15] and Ochs et al. [40] concluded that reaching the net positive energy is challenging if the project relies only on PV [15], [40], calling for the use of other additional local energy sources and energy storage.

Some other identified barriers include homeowners' limited funds for upfront investment and loan-based support schemes, which are ineffective [7]. Similarly, complex ownership structures, technological limitations, building protection, and preservation of cityscape are some of the challenges that PED projects are facing [16].

Furthermore, many aspects should be given more consideration when designing and developing PEDs. Building new PED-oriented districts has gained a lot of attraction, but refurbishing existing areas [6], [15] and historic districts [7] could provide very significant mitigation actions for energy poverty on the EU level by improving energy efficiency and climate friendliness. PEDs can serve as testbeds for innovative energy solutions and technologies, providing valuable insights for broader implementation [51], [52].

In conclusion, PEDs have the potential to offer sustainable urban development, while contributing to the climate efforts of the EU. They enable significant improvements in energy efficiency, integration of renewable energy, provision of flexibility, enhancement of e-mobility, and support just energy transition in cities. One area for further study includes analyzing the impact of regulation on PED development in different countries. How are policies in different countries enabling or limiting PED development?

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