Lessons learned from analysing PED case studies

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Abstract

The development of Positive Energy Districts (PEDs) is a complex process that involves the integration of various technologies, stakeholders, and policies. To facilitate this process, a database for PEDs has been developed as a joint effort of COST Action 'PED-EU-NET', IEA EBC Annex 83, and JPI Urban Europe. This paper reports analyzes international strategies for PED planning and its implementation. To learn from best practice examples, there is an increasing demand for PED cases descriptions that offer a variety of implementation strategies and conceptualizations for the PED concept. The collection of case studies from various settings so far has shown that there is no one-fits-all solution for PED implementation, and the overall PED framework definitions require further detailing in the local context. In this paper the challenges and key success factors for planning and implementation of PEDs is described with a focused analysis of three PED cases. One PED case each from Europe, from Canada and from Japan highlights the challenges of PEDs. Similarities and differences of the PED cases are compared and key success factors distilled. Thus, the DNA of PEDs can be further revealed. These are technological solutions, depending on the local circumstances (natural and imposed constraints), planning and implementation processes, and overall local settings (municipality or private sector as a driver) that define the successful implementation of a PED. Overall, the PED-Database provides a valuable tool for the development of sustainable and energy-efficient urban areas.

Introduction

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

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

In this process, a PED Database (PED DB) (https://pedeu.net/map/) is the outcome of this collaborative research.

1.1 State of the art in PED databases

Studies and researches focusing on PEDs [6-10] underline the emerging need to pass from isolated best practices - *i.e.,* pilot districts - to innovative, systematic, holistic and integrated approaches supporting the planning of green, healthy, efficient, livable and resilient districts, working in strict connection with the local planning instruments - such as SECAPs, SUMPs, City or District Plans, *etc*. - and relying on stakeholders expectations and citizens' needs.

Not many tools exist that allow to deepen the knowledge and characterization of PED models. JPI Urban Europe published the PED Booklet with a collection of PEDs case studies [11], structured in two main sections: 'PED Projects' - *i.e.,* cases that have the proper ambition to achieve a positive energy balance and 'Towards PED Projects' - *i.e.,* cases that, even without aiming at an energy surplus, adopt innovative approaches and solutions for efficient and high quality districts. Zhang *et al.,* 2021 [12], analyzed the cases mapped in the PED Booklet, based on a matrix for an interoperable and updatable platform able to compare the characteristics and peculiarities of the PED models according to some relevant and specific parameters and to ensure a transversal overview of the analyzed cases towards the definition of a series of PED archetypes or models.

The study conducted by Soutullo *et al.,* 2020 [13] focused on mapping of PED Labs - intended as pilot experiences acting as context-specific laboratories to catalyze the grounding of PEDs at local level. Through a SWOT analysis, the research identifies the main strengths, weaknesses, opportunities and threats linked to the 16 investigated laboratories and highlights the need to test solutions in the real environment, in order to evaluate the replicability potential for these experiences in different geographical, social and economic contexts.

As part of the European Cities4PEDs project (https://energy-cities.eu/project/cities4peds/), a catalogue, called 'PED Atlas' [14], was defined. Starting from the identification of 25 PEDs cases. 7 pilots were selected - 3 new construction and 4 regeneration interventions - and for each of them an interviews-based storytelling was drawn highlighting the perspectives of key involved actors, underlying the main lessons learned, barriers and success factors, and extrapolating some recurring PEDs approaches and dynamics.

Still investigating the PED topic, some studies and publications work on the systematic collection and cataloguing of the following key aspects: (1) technologies and solutions for PED effective implementation [15-17], (2) financing tools and business models to support PED technical feasibility and economic affordability [18, 19] and (3) social tools to facilitate stakeholders mapping, to foster citizens' awareness on environmental issues and to support community engagement [20,21] (4) criteria and performance indicators (KPIs) to monitor and evaluate PEDs impacts on the built environment [22-25].

Case studies of energy communities

By shifting the focus of cataloguing tools on Energy Communities (EC) - a transition model in many respects considered similar to PED concept [26, 27], the Joint Research Center (JRC) of the European Commission, following the two Directives that define the EC model at international level [28, 29], has published a preliminary report tracing an overview of 24 Communities distributed in 9 EU countries [30]. The Commission is currently developing an interactive platform, called 'Energy Communities Repository' [31], with the aim of incrementally mapping community ongoing experiences in the European context [32]. Currently the first available online version of the platform consists of a map connected to a detailed sheet for each case study that allows to display the information collected divided in thematic sections - *i.e.,* overall information, activities, governance, energy, economy, social impact and useful links. The above-mentioned studies represent key resources and inspirations to support the PED DB conceptualization, the definition of its relevant contents (*e.g.,* sections, parameters, answer options, *etc*.) and the selection of the most relevant cases and projects to be mapped and analyzed.

This paper focuses on the urgently needed internationalization of the PED model by comparing it with other community or district scale transformation projects. In fact, in continuity with the above mentioned researches, the PED DB has the objective to work towards the dissemination of PEDs practices and it is structured as a comprehensive tool that brings together case studies, projects, solutions, KPIs, policies and strategies to support the large-scale development of innovative pilot districts, working both on the implementation of new interventions and on the large-scale renovation of existing urban areas. It is this international focus (or opposite of focus: widening view) which is urgently needed in order to be able identify the challenges and key success factors for planning and implementation of PEDs. For this purpose, it was chosen to focus on three PED cases from Europe, Canada and Japan to highlight the similarities and differences of PED models and to distill key success factors. Technological solutions, depending on the local circumstances (natural and imposed constraints), planning and implementation processes, and overall local settings (municipality as a driver) that define the successful implementation of a PED are collected and compared. This information will enrich the PED-Database and helps to develop this valuable tool for the development of sustainable and energy-efficient urban areas.

Methodology

Case studies from different parts of the world. Three specific examples of PEDs from around the world were collected:

· 1 example from Europe: A total of six declared PED programmes (Sparcs, RESPONSE, Atelier, MAKING-CITYMAKING-CITY, +CityxChange and POCITYF) were identified within which each contains two case studies selected to be lighthouse cities [33, 34]. The distribution of lighthouse cities per country is as follows: three lighthouse cities are located in Finland, one in Norway, one in Ireland, three in The Netherlands, one in Germany, one in France, one in Spain and one in Portugal. General data on climatic, spatial, urban, infrastructural and renewable energy characteristics were collected and compared with the information obtained from the individual districts through bibliographic sources and by submitting specially created questionnaires to representatives of the individual projects, and the results were grouped under the Lighthouse Cities to which they belonged. The information obtained was then organized according to the climate category of the Köppen Climate Classification to which they pertained. Each city has made different technological, social and spatial planning choices according to its characteristics, needs and implemented policies. As an example, the Finnish case study in Espoo city is selected from the SPARCS project. Espoo (the only case study without a defined historical centre) chose one in an existing area, and one in a new built-up area, such as lighthouse districts, with the aim of turning them into mobility, social and economic nerve centres of the city in SPARCS project) [35]. SPARCS is working to create a network of Sustainable energy Positive & zero cARbon CommunitieS in two lighthouse and five fellow cities. The project supports these cities as they deal with the multifaceted challenges they face on their path to sustainability. By setting up inclusive management and planning models and processes, SPARCS aims to demonstrate and validate innovative solutions for smart and integrated energy systems that will transform these cities into sustainable, zero carbon ecosystems with improved quality of life for their citizens. It will do this by engaging with all the relevant stakeholders from industry and innovative SMEs and research organizations, to urban planning and technical departments. A key criterion for success is citizen involvement, and SPARCS has a clear focus on engaging with citizens and putting urban dwellers at the heart of its efforts.

· 1 example from America: The City of London is the fifth largest municipality in Ontario with an estimated population of 422,000 The municipality’s 2016 Official Plan established a strategic direction for London to become one of the greenest cities in Canada. Specific policies within the new official plan supported the creation of a Green Strategy as well as a Community Energy Action Plan to support more environmentally friendly and affordable energy usage. West Five is a 28-hectare greenfield property located in the northwest of the City of London. Community planning commenced in the late 1990s with a conventional suburban development form reflecting the market realities of the day. With time, demand for mid-rise and high-rise developments increased. Land use plans for the area began to intensify but around a traditional arterial road pattern. In the mid-2000s, the company Sifton Properties began development of a new vision for the West Five lands as a walkable, mixed-use community. These plans were put on hold after the market crash of 2008 but were renewed again a few years later. In 2015, an application for approval of a draft plan of subdivision and official plan and zoning by-law amendments was submitted by Sifton Properties to the City of London. All planning approvals for West Five, including site plan, were received in 2016. The special policy for the area supported and promoted sustainable and renewable energy initiatives, including solar electricity generation, district heating, ecologically efficient transportation systems, and green infrastructure technology. Consideration of the need for alternative development standards for streets, utilities and infrastructure was also included. Today, West Five has been planned as a complete community including a mixture of office, retail, residential and public open spaces. The community is to be a model of “smart” community design incorporating significant energy saving and renewable energy initiatives to achieve net zero energy. The design is pedestrian-oriented and has numerous green spaces, including a central park. The first net zero energy office building and ~90 townhouses were completed in 2017. The net zero energy vision for the West Five project has been led by Sifton Properties and S2E Technologies; it proceeded any energy policies in the official plan. The financing model was based on the development of a micro-utility through a partnership between Sifton, S2E and London Hydro. The micro-utility provides efficient energy services to the community while externalizing the incremental capital cost of achieving net zero energy from the developer’s perspective. The EVE (Electric Vehicle Enclave) PARK project, situated within the West5 sustainable community in London, Ontario, represents a pioneering endeavor to establish a pilot-scale of an all-electric community fueled by solar photovoltaic energy. The private sector project developer S2E has constructed 84 residential units in four separate buildings with eco-friendly materials and surrounding green spaces with a total of 18,823 sqm. As the regulatory framework for electricity distribution and generation differs from that of Europe, establishing such projects is crucial to demonstrate the potential of renewable energy resources such as Solar PV (with a capacity of 499kW in Eve Park and 2.7 MW in West5). The original concept for the microgrid design was a behind-the-meter (BTM) battery, tied to multiple buildings with a DC bus and multiple inverters (one for each building). However, several barriers were identified as the design developed, for example the buildings are separated by a public road and only local distribution companies are allowed to cross public roads with conductors and these companies do not do DC distribution. Regulatory issues with the Ontario Energy Board would have required obtaining an exemption for allowing energy to be moved from BTM of one property to BTM of another property. The idea of using the battery to distribute energy from one building with excess PV generation to one with inadequate PV generation was eclipsed by the community net metering pilot that West Five has entered into with the IESO. These, and other issues led to the redesign of the microgrid as an asset for the 27.6kV medium voltage feeder that supports West Five. This allows a large battery to be located within the microgrid boundary and support buildings on both sides of the public road. The battery is a 2MWh lithium iron phosphate modular system from CATL, tied to a 1.3MW EPC Power Conditioning System (PCS) inverter. A 1.5MVA transformer ties the battery PCS to the feeder. Beyond the imperative of sustainability, EVE PARK's encompasses enhancing resident well-being and quality of life through initiatives such as expansive green spaces and optimal air quality standards. Embracing emissions-free transportation through electric vehicle-sharing programs further underscores the commitment to GHG reduction goals. Crucially, the initiative seeks to foster community engagement and elevate public awareness regarding the numerous benefits of sustainable energy communities. As a pioneer of its kind in Canada, EVE PARK can provide decision-makers with economic and environmental results to pave the way for future development and more flexible regulations in favor of net-zero energy communities.

· 1 example from Asia: There are many district-scale energy community practices in Japan. However, these are not called PED yet. Compared with the European super grid, the electricity network in Japan is not large. Therefore, the interaction between the districts and the grid are not active enough. Toward achieving the carbon neutral goal in 2050, the Japanese government launched political action to support local municipalities promoting district scale energy management. The government called the proposals from the municipalities and 74 sites are selected as a pilot model until 2023 [36]. These case studies were analyzed with regard to PED criteria and compared. This allows users to understand and compare different PED scenarios by customizing their solution, accessing the information provided by real PED cases that best meets their expectations and goals. In this paper the challenges and key success factors for planning and implementation of PEDs is described with a focused analysis of three PED cases. One PED case each from Europe, from Canada and from Japan highlights the challenges of PEDs. Similarities and differences of the PED cases are compared and key success factors distilled. Thus, the DNA of PEDs can be further revealed. These are technological solutions, depending on the local circumstances (natural and imposed constraints), planning and implementation processes, and overall local settings (municipality as a driver) that define the successful implementation of a PED. Overall, the PED-Database provides a valuable tool for the development of sustainable and energy-efficient urban areas.

Results

The PED platform is set up and running, a first round of data collection is being performed both at case study and project level. Figure 1 gives an overview As first result from the collection of the PED cases in the PED DB, located in 13 different European countries. 10 of them are PED Cases studies, 6 of them were classified as PED relevant, while 6 are PED Labs and 2 of them can be classified as both PED relevant and PED lab. Finland and Spain are currently presented with 4 PED case studies each, while Sweden, Austria, Portugal, and the Netherlands each have 2 case studies. Norway, the Czech Republic, Turkey, Estonia, Italy, Germany, and Greece each have a single PED case study.

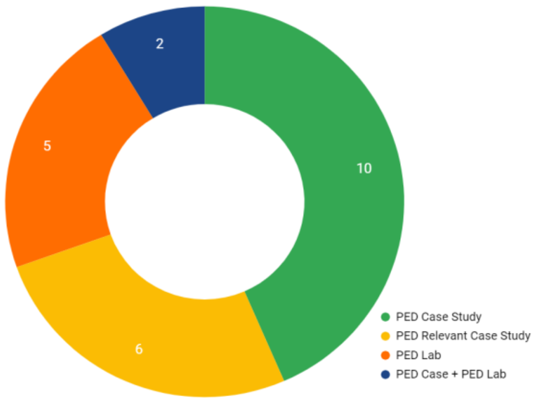

Figure 1: Case studies currently included in the database 23 from 13 countries (only including Europe)

The selection of the entries that should be collected by the database was made. This selection was expanded and agreed upon by the different working groups of the initiatives involved, resulting in a list of variables required in different sections of a survey to characterize each case study. These are organized in different sections.

It is structured in the following six sections: 'Section A' which consists of A1. Global Characteristics, A2. Technological Aspects and A3. Non-technological Aspects), 'Section B' which consists of B1. PED Case studies in detail and B2. PED Labs in detail and 'Section C' with C1. Drivers and barriers, 'Section D' on General Projects/Initiatives, 'Section E' on National Policies and Strategies and 'Section F' on Technological and Non-technological related Solutions/Innovations. 'Section D' has been fully developed and integrated into the online platform. Currently, a total of 125 parameters and 462 options are collected in this block and implemented in the online platform.

The designed PED-Database introduces definitions and insights that will guide cities' stakeholders in the creation of capacity at different levels as well as by defining core capabilities. The developed framework provides an understanding of PED concepts, planning values, and functionality criteria to create a learning environment for capacity building and, at the same time, to establish a vision for future districts. The structure developed by this database has generated an interface that shows the results stored in a differentiated way in map or table view. Each of the stored PED developments can be assessed in detail or even compared with other cases, facilitating the identification of common or differentiating elements. Another aspect to highlight is that this web platform facilitates quick access to general project information, as well as identifying the PED cases associated with each project.

Example from Finland

Project choices were influenced by geographical, political and economic reasons. An example of this is the city of Espoo, which (in addition to the Smart Otaniemi programme) joined the Sparcs programme following the city's adhesion to the Covenant of Mayors and chose to buy renewable certified electricity [37]. It means that the city buys electricity from renewable sources (in this case mainly wind), as they are not implemented or implementable in inhabited areas. This is why Espoo is referred to as a virtual PED [37]. From a geographical analysis of the lighthouse cities, these are mainly located in northern and central Europe. This distribution may be due to the fact that northern cities are better prepared (in optimization, optimized planning process, design process, digitization of city infrastructure and co-creation project) for the realization of such projects. In addition, many municipalities in these areas already have sustainable energy planning offices, which are able to implement this type of project by connecting the various actors (technology producers, energy utilities and building developers) in the area. Another factor that would influence this distribution could be the greater number of start-ups and companies that already exist in the area and can guarantee a rapid design and realization of the installations and companies that are able to guarantee the maintenance of the infrastructure over time.

Example from Canada

Using renewable energy sources in the format of an energy community (REC) is not widespread throughout Canada compared to European countries. Reasons are the cheap energy prices, but also legal barriers. But the imperative of developing these resources is undeniable, which arises from the increasing need for electricity because of cases such as, increasing electrification of the building sector, the growing prevalence of Electric Vehicles, and the burgeoning population. Addressing this heightened demand presents a formidable challenge for the centralized utilities in many provinces. The governmental policies and incentives are influential in the development of REC and the associated business model for them. In Canada, the regulations are different in each province, particularly in the energy market structure, incentives, and electricity tariffs. For example, there is a monopoly in Quebec from Hydro Quebec, while Ontario offers a free electricity market and pricing based on auction. The following table compares the differences between the four main provinces' jurisdictions regulating in Canada.

Incentives and regulations in Canada for renewable energy generation.

Title	Item	Scale	Building Type	Alberta	British Columbia	Ontario	Quebec
Tariff structure	Fixed	Provincial	Both	*	-	-	-
	Time of Use (ToU)	Provincial	Both	*	-	*	-
	Segmented	Provincial	Both	-	*	*	*
Allowed market models	Auction-based open energy market	Provincial	Both	*	-	*	-
	Government electricity provider	Provincial	Both	-	*	-	*
	Third-party retailer	Provincial	Both	*	-	*	-
incentives	Net metering	Provincial	Both	*	*	*	*
	Virtual net-metering	Regional	Both	-	-	*	-
	FIT	-	-	-	-	-	-
	Accelerated Capital Cost Allowance (ACCA) tax incentives	federal	business es	*	*	*	*
	Clean Investment Tax Credit (Clean Technology Investment Tax Credit)	federal	business es	*	*	*	*
	Canadian Renewable and Conservation Expense	federal	business es	*	*	*	*

	(CRCE) tax incentive						
	Provincial Tax Exemption	provincial	Both	-	*	-	-
	Property Assessed Clean Energy (PACE) loan	regional	Both	*	-	*	-
	Carbon Offset	provincial	Both	*	-	-	-
	Canada Greener Home Grant (rebate)	federal	residenti al	*	*	*	-
	Canada's greener home loan	federal	residenti al	*	*	*	-
	loan/rebates (per W of solar energy installation)	regional	Both	*	*	*	-

As shown, Quebec has the least number of incentives for renewable energy development among other Canadian provinces. However, the similarity among them is the existence of net metering as an incentive plan for households to use renewable energy resources. In Ontario, there is no limitation for the capacity of renewable energy sources installed by a single user, and the credits can be transferred up to 12 months to the following bills. It can include a storage system. However, the users are not allowed to use the utility-owned distribution system and wiring. Recently, Ontario started allowing community net metering (virtual net metering) for the case study described (West5) with up to 10 MW capacity limitation for ten years. The maximum renewable energy system capacity is 100 kW in British Columbia and 50 kW in Quebec. In Alberta, the unused credits at the end of the year are paid to the users by the retailer, and the credit price is equal to the electricity provided by the retailer for the system under 150 kW and the hourly wholesale market price for the system from 150 kW up to 5 MW. British Columbia also pays for the annual surplus at CAD 0.106 for 2023. The excess credit will expire in Ontario and Quebec after one and two years, respectively. The West5 and EVE PARK community is considered to be a micro-grid which the electricity is generating within its geographical boundaries. The possibility of trading electricity with the main grid is also met in the design. Considering the Canadian climate which extreme weather in winter, supplying the heating electricity with heat pumps and geothermal energy and battery storage adds resilience to the system.

Example from Japan

The key aims of the sites are not only challenges for carbon neutral, but also creating new jobs in local, raise resiliency for emergent situations such as natural disasters. Ishikari City in Hokkaido is planning to allocate a data centre which is a huge electricity user at the port area and to supply that electricity with renewable energy. The cluster of industries in the planning zone. For Ishikari citizens, the goal is to revitalize the region through sector coupling between the region and public transportation. Another case, Higashi Matsushima City in Fukushima, which is in the moment of declining population reconstruction from the earthquake in 2011, aims to creating new jobs in the city by promoting greening of the natural environment, inviting companies to the fields of new energy industry through the Higashi Matsushima Mirai Tosh Organization (HOPE), a general incorporated association established by the city, the Chamber of Commerce and Industry, and the Social Welfare Council, and by improving transportation systems utilizing next-generation vehicles. The promoting decentralized local energy production and management is an opportunity for regenerating local society. By modifying PED concept to fit for Japanese context, PED can be acceptable. And Kitakyushu city is one of the large industrial cities located in the southern part of Japan. Through collaborating with local small and medium industries and local towns, the city plans to reboot the local industries and regrowth of local economy. The existing office buildings are redeveloped with renewable energy production. Table 1 shows the key technologies of each city. All cities have solar PV generation and CV cars as key technology. Because of the requirements in emergency situations under natural disasters, energy storage is an essential factor rather than grid interaction. From the point of configuration of stakeholders, the city coordinates the consortium including local industries and companies.

Table 1: The main technical data from the three different city districts in Japan

	Ishikari City	**Higashi Matsubara City**	**Kitakyushu City**
Solar PV	Yes	Yes	Yes
Biomass	Yes		Yes
Wind		Yes	Yes
EV	Yes	Yes	Yes
Battery	Yes	Yes	Yes
Hydrogen	Yes		Yes
Microgrid	Yes	Yes	

Comparison

A comparison of the three different case studies Espoo, Finland; Eve Park, Ontario, Kitakyushu City, Japan was made and is summarized in Tables 1 and 2. Table 2 shows the main technical data of the three case studies while Table 3 summarizes the objectives of the three different sites/districts. Table 2: The main technical data from the three different case studies (Espoo, Finland; Eve Park, Ontario, Kitakyushu City, Japan) (compare also [38]).

Technical data	**Espoo, SPARCS**	**EVE PARK**	**Kitakyushu City**
Wind	Yes (virtual)	No	Yes
Solar PV	Yes	Yes	Yes
Geothermal	Yes	No	No
Hydrogen	No	No	Yeso
Bioenergy	Yes	No	Yes
Waste energy	Yes	No	No
Electrical storage	Yes	Yes	Yes
Heat storage	No	No	???
Heat pumps	Yes	Yes	???
E-mobility	Yes	Yes	Yes
District heating network	Yes	No	???
Combined heat and power	Yes	No	No

Microgrid	???	Yes	???

Table 3. Comparison of the objectives of the three different sites/districts

Objectives	Espoo, SPARCS	EVE PARK	Kitakyushu City
Positive energy	Yes	Yes	
Zero emissions	Yes	Yes	
Energy efficient	Yes	Yes	
Carbon free	Yes	Yes	
Energy flexibility			

Discussion

The design of the PED database highlights the use of data as enabler for cities to uphold global Agenda 2030 commitments, thus to deploy technology and innovation in a way that ensure sustainability, inclusivity, prosperity and human rights in cities. The collection and use of data can be considered as a support tool for cities enhancing alignment and direction of their plans, increase awareness of their Citizens, Public and Practitioners about future scenarios and address vexing and seemingly intractable problems of urban governance.

The database for PEDs is a joint effort of COST Action 'PED-EU-NET', IEA EBC Annex 83 and JPI Urban Europe to provide a wealth of information about new and refurbished urban environments aiming to produce more energy than they consume. The realization of the PED-Database framework and its online implementation in the form of a web interoperable platform has been designed in a modular way which allows the division of the general survey into smaller and independent sections that facilitate data entry and subsequent processing.
The development process moved through a database development life cycle (DDLC) starting with the scoping phase of establishing requirements expressed as a statement of requirements with the aim to create a framework for data collection from demo cases.

- There is no one-fits-all solution for PED implementation. Overall PED framework definitions require further detailing in the local context. The PED Database provides an overview of not only different implementation strategies, but also existing different conceptualizations and approaches for the PED concept.
- Thanks to contributions, all inputs are collected in the Database, the users of the platform can visualize and compare different scenarios of PEDs by customizing their selection. Before exporting, it can be displayed in the user-friendly frontend of the PED-EU NET Database that covers each KPI resulting from the gathered information by DB editors. Then, the selected comparison can be saved as an output file and successively can be exported as a .csv format file. In this way, users of the tool can select and work on the information that best meets their expectations, goals, and then build their own further storytelling.
- On an international level, more work needs to be done. The concept of PED is not well known outside of Europe. Other concepts like microgrids, or carbon neutral communities need best practice examples to show case costs and benefits.
- The analysis of the collected international cases from Europe, America and Asia, shows on the other hand, there are common features that can be noted. All developments apply solar PV on site and generate electricity. Thus, the district becomes a "prosumer", producing and consuming electricity. Special rules and regulations occur in microgrids, where electricity trading between the buildings (and their users) is allowed.

Conclusions

5.1. Future developments and conclusions

The platform is set up and running, a first round of data collection is being performed both at case study and project level. The designed PED-Database introduces definitions and insights that will guide cities' stakeholders in the creation of capacity at different levels as well as by defining core capabilities. The developed framework provides an understanding of PED concepts, planning values, and functionality criteria to create a learning environment for capacity building and, at the same time, to establish a vision for future districts. The structure developed by this database has generated an interface that shows the results stored in a differentiated way in map or table view. Each of the stored PED developments can be assessed in detail or even compared with other cases, facilitating the identification of common or differentiating elements. Another aspect to highlight is that this web platform facilitates quick access to general project information, as well as identifying the PED cases associated with each project. PED DB is something updatable/interoperable and can be connected to other tools e.g., interoperable dashboard from (Zhang et al., 2021) [22]. In comparison with EU Energy Communities the PED database is not only trying to map experience, but to comprehend with a deep analysis of each case study. This underlines the different approach that was chosen for the PED database development.

5.2. Widening the perspective to global scale

Positive Energy Districts (PEDs) are still a relatively new concept, but they are gaining traction around the world. There are now 23 PED Labs and cases underway in over 13 countries. These are just a few examples of PEDs from around the world. As PEDs become more popular, they are likely to play an increasingly important role in the global transition to a clean and sustainable energy future. Overall, PEDs offer a number of advantages over building-level and city-level approaches to sustainable development. PEDs take a holistic approach that considers the needs of the entire community. This allows for a more coordinated and comprehensive approach to sustainable development, which can help to reach the SDGs more effectively. PEDs can be a more effective way to reach the Sustainable Development Goals (SDGs) than on a building or city level because they take a holistic approach to energy and sustainability. PEDs consider the needs of the entire community, including residents, businesses, and government agencies. This allows for a more coordinated and comprehensive approach to sustainable development. These are global challenges and PEDs offer a good approach to tackle these in a holistic manner. The database will help to spread the examples and identify the key success factors of planning, implementation and monitoring of PEDs.

5.3. Replication potential of cases in database

The Database supports a paradigm shift towards an integrated and comprehensive approach to innovation. Even if technology will be an important factor, a transition can only happen if there is also innovation on organisational and societal level. It is therefore important to consider aspects beyond technology. At least three levels need to be integrated that facilitate a structured approach to fostering innovation in PED projects. On the other hand, it might contribute to compatibility, intermobility, scalability, and replicability.

1. Technology – the database can help to define which technology or system solution is needed. (components, hard & software, prototypes, incremental improvement or breakthrough, interoperability, etc.)

2. Market; The database can help to show how to organise it it the most effective way. (living labs, sandboxes, business models, regulatory frame, market design, socio-economic research, etc.)

3. Transition – The database helps to find answers to the motivation for PEDs (design, retail, community & society, social sciences, education, policy, governance etc.).

These three levels can be further used related to system integration where more than one of the three levels must be covered. The methodologies and approaches, which are used in the different case studies to work on aspects on the different levels should be clearly defined. The work plan and deliverables should reflect all included levels and the potential interconnections between them.

This would give the potential to define replication schemes and highlights the need for setting up interdisciplinary teams including partners and/or experts with different backgrounds (e.g. economy, market design, management, social sciences, and technology) to bring greater value for the project. It is also important that the risk assessments for the projects fully consider all levels involved in the project, not only potential technological aspects.

The different levels can be used to clearly describe research and innovation activities that integrate technology with cross-cutting dimensions. In general, the level represents three domains where barriers to transition may be present.

It would be good to include a PED Readiness assessment in the next step that allows to assess the dynamics of PED developments by measuring the status and the potential for future development towards an "ideal" PED or a sustainable built environment.

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