Challenges for a Positive Energy District Framework

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Abstract. This paper presents the key technical and non-technical challenges for the development of a Positive Energy District (PED) framework. It draws on literature, expert reviews and surveys. Initial findings reveal that there are seven primary interacting factors that cascade from the strategic to the specific, or from international ambitions to contextual opportunities (and vice versa). Each is a necessary and integral factor that underpins successful development of PEDs.

Keywords: Positive energy district · Analytical framework · Interdisciplinarity.

1 Introduction

1.1 The Global Climate Context and PEDs

Three conditions make Positive Energy Districts (PEDs) compelling [1, 2]:

1. Global emissions reduction targets (such as those of the Paris Agreement) include reaching net-zero greenhouse gas (GHG) emissions by 2050.
2. Cities account for 65-70% of global energy use and 70-75% of global emissions, and urban development will grow by two thirds by 2050.
3. Two thirds of today's building stock will still exist in 2050.

It is evident that energy efficiency alone is insufficient to reach the GHG goals, given the current low rate of building refurbishment (ca. 1% per annum). To make significant emissions reductions, interventions should focus on urban districts – increasing energy renovations and integrating renewables – to offset the energy demand inertia of the existing building stock. PEDs are the strategy that precisely target these challenges. For the purpose of this paper, a PED can be defined most simply as a connected group of energy efficient buildings that produces a surplus of renewable energy. More sophisticated definitions and discussions exist but they are not the focus here [3, 4].

1.2 The EU Context

In 2018 the European Commission launched its PED Programme with the ambition to initiate and support the development of 100 PEDs across Europe by 2025. In 2020 it had defined a 'Reference Framework' for PEDs based on consultations with EU stakeholders [3]. This resulted in a working definition of a PED and the collation and analysis of 61 European case studies [4, 5]. A notable fact from these studies is that only 3% of the PEDs identified were in operation, with the majority (69%) in the implementation phase. This reveals that PEDs are still in their infancy and on a steep learning curve.

1.3 Perceived Challenges for PEDs

There are technical and non-technical challenges to creating a vision and framework for PEDs. On the one hand, the aim is to define generalizable tools, guidelines and targets. On the other hand, it is necessary to respond to local stakeholders, approaches and conditions. Based on Europe-wide consultation with city representative, urban stakeholders and national experts, the PED Reference Framework categorised the challenges in terms of "technological, spatial, regulatory, financial, legal, ecological, social and economic perspectives" [3]. Although no ranking was implied, it was understandable that the technical challenges were mentioned first given the energy and emissions targets outlined previously. The survey of case study PEDs provides a ranking of the success factors and challenges according to those involved in implementing the projects [5]. Based on this information, and research discussed below, the broad themes that were considered most important, across both success factors and challenges, can be ranked as follows:

1) *Governance* (politics, policy, regulations and city administration),
2) *Social* (stakeholder and citizen engagement),
3) *Market* (funding, markets and business models), and
4) *Technical* (energy and urban integration).

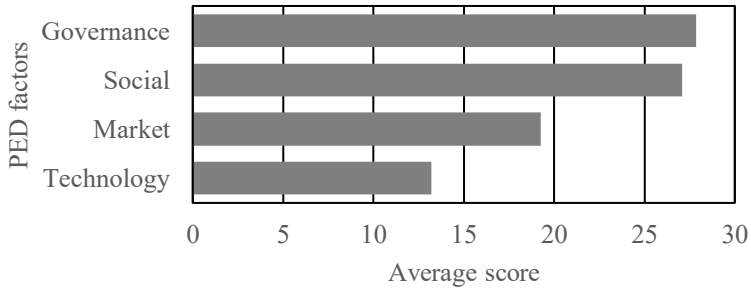

Fig. 1. Votes for perceived success factors and challenges of PEDs, equally weighted and combined into the top four principal categories, reveal their ranking of importance (after [5]).

As shown in Figure 1, the *Governance* and *Social* factors ranked highest and scored very close to each other, with a noticeable gap before the *Market* and finally *Technology* factors. The purpose of this paper is to define these and other challenges systematically, with more descriptive detail and to identify interdependencies between them.

2 Method

2.1 A Three-Stage Approach

The methods used in this paper build on the COST Action's PED European Network (PED-EU-NET) representing key professions, a range of cultures and climates, and experiences from stakeholder perspectives (160 members from 38 countries).

The first stage of the approach was to carry out a literature review of PEDs. This is summed up in the introduction and results sections, and was also used to define the broad themes introduced in 1.3. The second stage was to adopt the Delphi method, which is a structured communication technique that relies on a core panel of experts [6]. This method was used to brainstorm and identify the key challenges to implementing PEDs. Debates with the expert panel and detailed individual discussions led to a consolidation of the definition of these challenges and the interdependencies between them. A third stage consisted of a survey of the wider PED-EU-NET membership to determine the ranking of the key challenges and whether additional factors should be included.

2.2 The Delphi Method

The ten authors of this paper – experts drawn from the research and development community of PED-EU-NET – formed the core panel. The aim of the panel was to identify the key challenges that confront the implementation of PEDs, including those identified above. The Delphi method provided a structured communication and decision-making technique by which the panel of experts can address the questions, led by a facilitator (in this instance this was Dr Gohari Krangsås). The principle of the method is that findings from a structured group of experts will be more accurate that those from an unstructured, random, unrepresentative, or undefined group. By working with R&D experts with a breadth of 'disinterested' knowledge of PEDs, informed by literature reviews, we avoided the potentially distorting effects or the gaps in knowledge of different special interest groups, such as political, business or citizen representatives. We were then able to compare and contrast our findings with those of others available in the literature, and where there may be vested interests, or where a more unstructured approach has been adopted. Furthermore, "the Delphi method is well suited as a research instrument when there is incomplete knowledge about a problem or phenomenon" [7]. Given the early stage of development of PEDs, and the very few case studies identified as being in operation and realized to date – only 2 in Europe [5] – this method was particularly appropriate and timely.

In this research, the Delphi method involved six months of iterations with the expert panel, where initial decisions were recorded, revisited, and reviewed before finally being agreed. The first of these communications consisted of a brainstorming session using 'Padlet', a collaborative web platform hosted by the facilitator and via which panel members could share and organize content to a virtual bulletin board. In total, four communications were held between November 2020 and June 2021. The first meetings identified seven key factors and the final one resulted in a more detailed definition of each.

2.3 Survey

Once the Delphi method had revealed the seven themes for a PEDs framework, a survey was prepared using 'Mentimeter', an online interactive polling tool. This survey consisted of three sections: 1) to rank the seven factors in order of importance from a drop-down menu; 2) to score each of the challenges in terms of the strength of agreement; 3) to use free text to identify other factors to note. This simple survey was sent to the members of the PED-EU-NET project during May 2021 with a response rate of 15%.

3 Results

3.1 Seven Challenges

From the iterative Delphi method, the panel identified the following seven factors using the same vocabulary as previous, in provisional order of importance::

1. *Governance*: Identifying an appropriate and inclusive governance model
2. *Incentives*: Social and environmental drivers and motivators
3. *Social*: Local community and stakeholder engagement
4. *Process*: Need for alternative planning and decision-making approaches
5. *Market*: Conducive market design and business models
6. *Technology*: Balancing energy demand and supply systems
7. *Context*: Regional and local differences

The four categories identified and defined previously – *Governance*, *Social*, *Market* and *Technology* (see section 1.3) – also emerged in this list and in the same rank order. This provided a degree of confirmation and reassurance that the two methods were compatible. However, our review highlights the importance of three other considerations – *Incentives*, *Process* and *Context* – which rank amongst the other four (Figure 2).

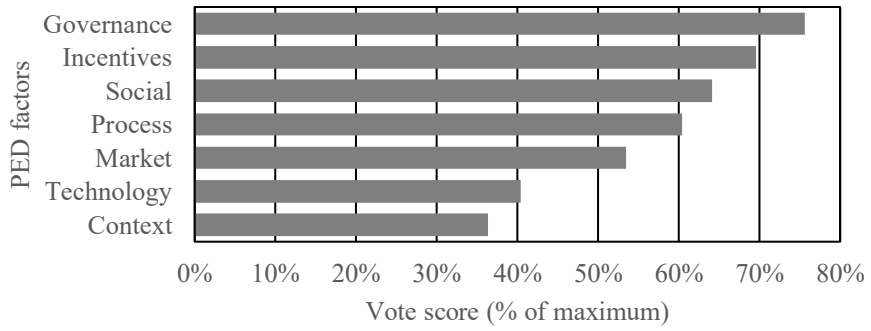

Fig. 2. Survey results of ranking PED factors showing the percentage of scores based on voting scores of 7 for first ranking to 1 for last ranking out of the maximum score.

It was considered possible that the three additional considerations are cross-cutting factors – the relationships between factors will be discussed later and in future research. It also became evident in the Delphi meetings that there were multiple interactions between all seven topics. Each PED challenge is described below before exploring the potential

interdependencies. These descriptions are brief summaries based on the outcomes from the final stage of the Delphi method, and will be expanded in future research.

Governance. The successful implementation of PEDs relies on service transformation, on a balance of social cooperation and economic competition, and cuts across jurisdictions of public and private organizations. This requires more innovative forms of governance in which all stakeholders can contribute to decision-making and can manage uncertainties to build commitment and ownership. In this dynamic context, network theory and network management offer a valuable approach [8]. In contrast to traditional hierarchical government, PED governance should be based on developing such networks of interdependency, pluralism, negotiation and trust.

Incentives. PEDs require incentives that address all seven areas, or subsystems, identified previously as composing the PED factors (see section 3.1). An integrative approach has the potential to balance multiple benefits at local, city and national levels, and to limit unintended consequences in any one area. In order to coordinate the process, a management and procurement program can adopt a 'nearly decomposable system' and give incentives connected to the competencies of each subsystem [9]. Thereby incentives can relate to, for example, meeting local and national greenhouse gas emissions targets, or improving quality of life, affordability and job prospects.

Social. Citizen access to and engagement with the development of PEDs can achieve local adoption of such decentralized, bottom-up energy projects. There is inherent value in empowering local consumers to becoming energy 'prosumers', producing and selling their own energy. More strategically, social engagement can facilitate a system-wide transformation through collective action and social transformation towards 'citizen autonomous energy communities'. To benefit from these opportunities it is necessary to: 1) create an engagement culture and platform; 2) improve communications, knowledge, transparency and trust, and; 3) ensure funding, empowerment and capacity for engagement [10].

Process. The decision-making process related to the opportunities presented by urban energy systems typically demands a democratized, multicriteria approach. It is a process that should respond dynamically to different technologies, policies, stakeholders, etc. To achieve this, a shared, transparent and structured decision-making process is required that links policymaking and planning for PEDs [11]. This typically takes the form of phased steps, starting with agreeing common objectives amongst the stakeholders ('targeting') before proceeding to the 'synthesis', 'design' and 'operation' phases [12].

Market. Identifying an appropriate energy market design for PEDs needs to make the best use of resources and promote efficient investment in new resources [13]. The challenge for the energy market is that a PED implies a decentralized system in which energy can be generated, stored, distributed and consumed in response to fluctuating local demand and

supply. The financial structures, business models and procurement options will differ according to PED characteristics, with the need for the right price signals to encourage efficient production, consumption, pricing and investment.

Technology. The balance between energy supply and demand is a key technical challenge for PEDs. On the one hand, renewables typically represent a variable and intermittent source of energy, whilst on the other hand, consumers are increasingly active and engaged (i.e. the energy 'prosumer'). To mediate between renewable energy supply, prosumer demand and energy storage provision, a PED system can involve power, gas and thermal energy supply and storage technologies. Such networks or microgrids require the use of smart ICT and optimization techniques to provide efficiency, flexibility and reliability of the overall PED system [14]. This in turn presents a challenge for developing a comprehensive method of analyzing the entire energy process and management at a district level.

Context. A challenge for PEDs is that they need to relate directly to a specific, local context, although they clearly also respond to wider international targets and directives. The regional climate, a district's urban form, building conditions, ages and uses, are examples of local physical factors that will inform appropriate technological options [15]. Local socio-political and economic conditions are also key to a holistic engagement. Developing stronger narratives that respond to the regional context have been identified as of crucial importance, such as those addressing opportunities for local jobs, industry and competitiveness [16].

3.2 Survey – Strength of Agreement

The survey produced not only a ranking of which PED factor was considered most important, as shown in Figure 2, but also asked subjects to score to what extent they agreed about the importance of individual factors (i.e. not in comparison to other factors). The results are used to examine how much consistency there is amongst experts for each PED factor, but this study did not explore how different professions responded to each topic.

The graph in Figure 3 reveals that there is a range of responses for each factor. For the seven PED factors overall there was predominant agreement, with 68% of votes being positive and only 20% negative. *Governance* and *Incentives* drive this overall finding, and scored the most positive, at 75%. In contrast, *Context* elicited more polarized responses with 54% in agreement and 33% in disagreement. When comparing between factors, the scores largely matched the rankings. *Governance* scored with the greatest agreement and *Context* with the lowest agreement, coinciding with their overall ranking positions of first and seventh respectively (see Figure 2). *Social* factors were an anomaly and showed less agreement than might be expected from the overall ranking in third place. Here *Social* has ranked sixth in terms of degree of agreement. This suggests that more focus, knowledge and dissemination is required in this sector, given its overall importance in this and previous studies.

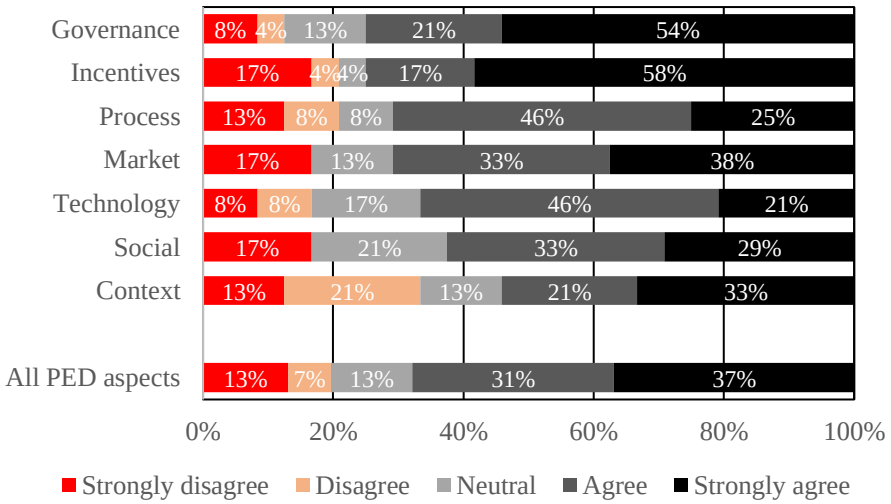

Fig. 3. Degree of agreement within each PED factor independently, ranked in order of most positive (i.e. combined 'agree' (dark grey) plus 'strongly agree' (black) percentages).

3.3 Survey – Other PED Issues

For the final part of the survey, in a free text section, respondents were encouraged to raise any other issues that they considered should be included in a PED framework.

The majority of the 18 suggestions were specific points that fall in to one of the seven categories of factors defined in this paper and thereby contributed to enriching their definitions. An example of this was the important role of 'Life Cycle Analysis' as a technical method (i.e. *Technology*) to analyze the total environmental impact of PED systems. The embodied energy of buildings can be as large as half of the life cycle energy, and this proportion gets even larger for more energy efficient buildings incorporating high tech equipment and systems. Another example was the challenges and opportunities presented by 'urban design and aesthetics' which should be incorporated in the decision-making processes (i.e. *Process*) of a PED project, particularly where this concerns a historic urban centre or heritage buildings.

A second category of suggestions can be considered as general principles for all PED factors, such as for example the importance of creating 'simple and robust' definitions and processes. There was occasionally a tendency to present the challenges for PEDs as complex, specialized and opaque to stakeholders in some of the literature, despite the importance of transparency and accessibility – crucial principles referred to previously.

Thirdly, some responses highlighted the importance of considering the interdependencies between different PED factors, such as 'integrating social and technical' considerations in the decision-making processes (i.e. linking *Social*, *Technology* and *Process*). These interactions were considered as particularly important and will be noted in the next section of this paper and forthcoming research in the PED-EU-NET project.

4 Discussion

The results of this paper have demonstrated that there are seven challenges to the implementation of PEDs that need to be taken in to account, and our contention is that all seven need to be addressed to deliver successful PEDs. Although there are different ways of defining the key factors, these definitions depend to an extent on the perspective of the originators (whether municipalities, engineers, citizens, etc.). Despite this, the literature suggests that there are common and recurring themes, although not all that have been identified here are always present in the literature.

The panel of authors of this paper, and the wider PED-EU-NET consortium, represent a breadth of perspectives and as a result this paper has highlighted and prioritized factors that have not consistently emerged as important in previous studies. The approach adopted in this paper has revealed that one area in particular, the *Social* factors of PEDs, elicit a more polarized set of responses related to their significance. This suggests that this is an area that, although widely recognized as important, warrants specific attention, development and integration in a PED framework or toolkit.

The methods used for this paper not only identity but also define and rank the seven factors in brief. We note that the ranking loosely follows a geographical hierarchy, from *Governance* issues with top-down international directives (such as the Paris Agreement or European Green Deal) to the importance of bottom-up local *Context*. A framework should acknowledge that both a top-down and a bottom-up approach are in play (Figure 4).

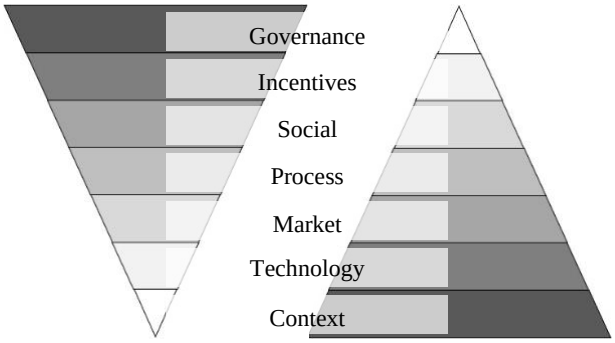

Fig. 4. A potential framework for PED factors can be considered to act hierarchically as both top-down (from large scale to local) and bottom-up (from specific to general).

The definitions and descriptions of the PED factors that were developed for this work also revealed that there are interrelationships and overlaps between them. A simplified assessment of the links between the factors, where only the first two of the most important links (based on the Delphi discussions) are included, reveals an interdependent network of interactions (Figure 5). Noteworthy is that even in this simple view *Governance* has the most connections to the other factors, reinforcing its primacy as a challenge for PEDs. The network also implies that no single parameter can be considered in isolation of the others and that no factor can be left out in order not to skew an assessment of PEDs. More research on this issue in ongoing in the PED-EU-NET project.

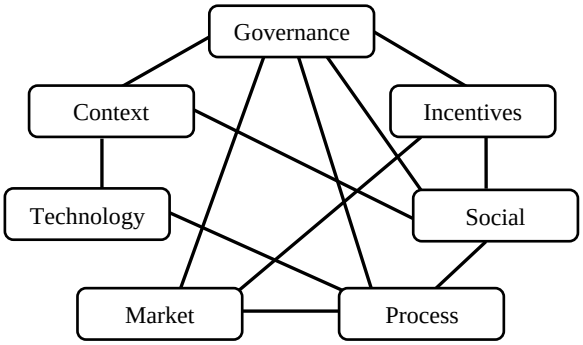

Fig. 5. Simplified interdependency network of first two most significant interactions for each PED challenge demonstrates the importance for an integrated and holistic PED framework.

5 Conclusions

This paper has identified, defined and ranked the seven key topics that need to be addressed for the successful implementation of PEDs.

A framework for PEDs can be considered as hierarchical, ranging from international ambitions to local conditions. However, it is evident that top-down diktats are not effective on their own, and that bottom-up, locally relevant narratives are necessary to enhance engagement and success.

The paper also finds that a PED framework can be described as a network of internacting factors where each is to a greater or lesser extent reliant on the success of others. We conclude that these factors are interdependent and, in order to achieve a successful outcome, they cannot be implemented in isolation.

Governance consistently ranks as the most significant factor. It provides the necessary conditions to support most if not all other PED factors, and is therefore central to a PED framework. The *Social* challenges rank high and are also directly linked with several other challenges. However, it is the factor that is least well-developed in the context of PEDs and thus requires attention. This is particularly the case because of the diversity and diffuse nature of stakeholders that are involved at different phases of a PED's development.

The next step in this research, building on the findings to date, is to define not only the framework in more detail but also the tools, guidelines and targets that are necessary to implement PEDs throughout Europe and beyond. This is the ambition of the PED-EU-NET action.

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