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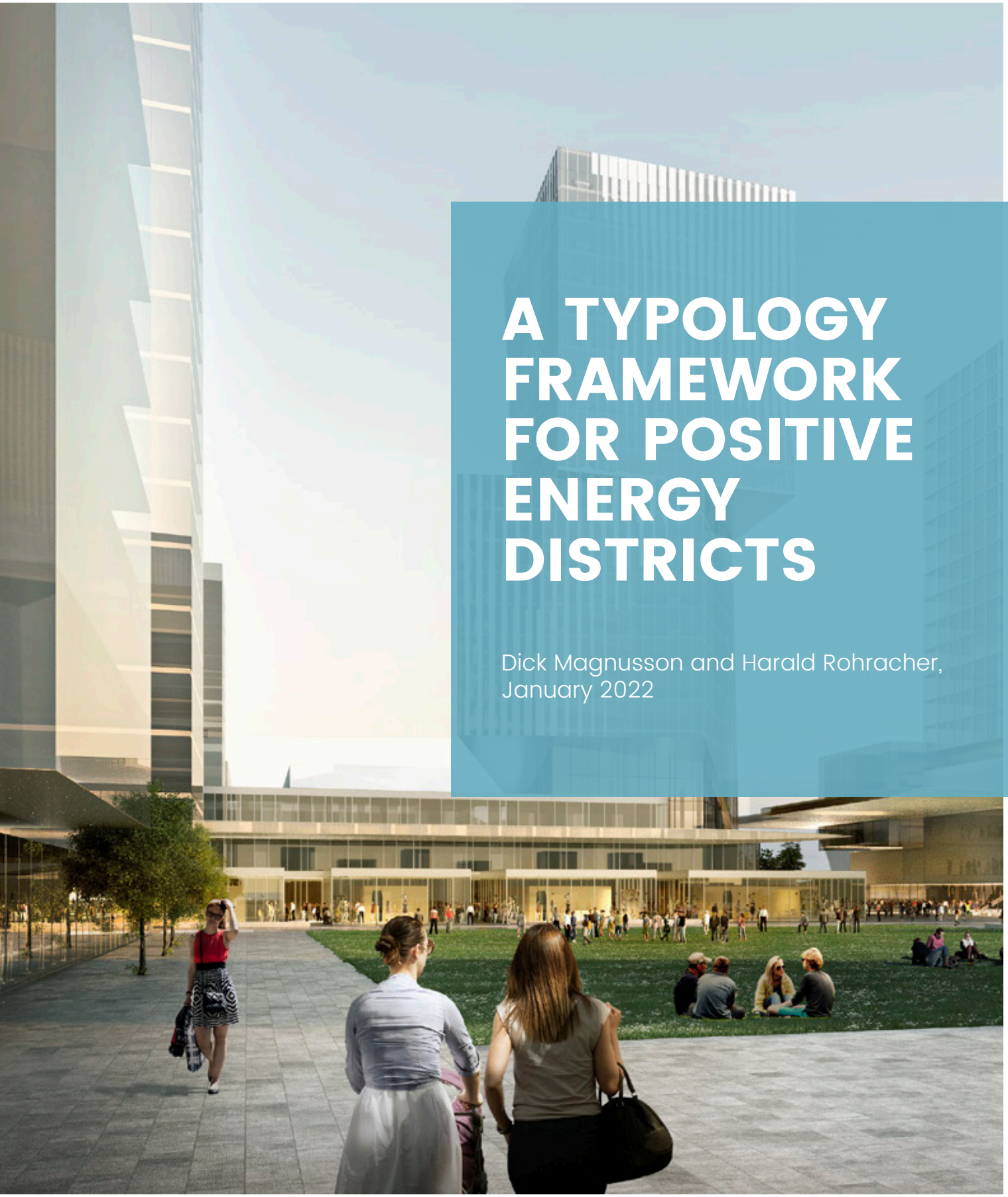
TRANSFORMING CITIES
THROUGH POSITIVE
ENERGY DISTRICTS



A TYPOLOGY FRAMEWORK FOR POSITIVE ENERGY DISTRICTS

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INTRODUCTION

The aim of this document is to develop a framework of positive energy district (PED) characteristics to provide a foundation for the analysis of PED characteristics, functions, and innovations and to facilitate transversal comparison across PEDs. The framework draws upon relevant literatures from sustainable transformations and urban energy innovation as well as previous empirical findings on PEDs and related urban energy interventions.

In addition to reviewing different bodies of literature, the report builds upon interviews with the TRANS-PED partners about their use of and reflections on the PED concept. Interviews were conducted via Zoom in the autumn of 2021 with the following individuals:

- Stockholm / Hammarby-Sjöstad (Jörgen Lööf)
- Lund / Brunnshög (Markus Paulsson)
- Graz / Reininghaus (Barbara Hammerl)
- Tyrol / Sonnendorf (Andreas Kleboth)
- Brussels / Abattoir (Kelly Mermuys)

While the literature on PEDs emphasises questions of relevant boundaries for PEDs and ways to account for energy and emissions (which forms of energy/emissions to include, how to account for transport, and so on), the practice of aspiring PEDs rather focuses on processes of PED implementation, such as energy spatial planning processes, a whole system perspective, inclusion and coordination of actors, experimenting with new solutions, and collaborative learning processes. This report is thus structured along these lines and starts with general definitions of PEDs in different policy and research programmes before summarizing results from literature on evaluations of PED performance and PED-related concepts, and finally introducing a more process-oriented definition of PEDs drawing on concepts of co-creation, living labs and energy planning.

DEFINING AND DESIGNING PEDS

PED DEFINITIONS AND CHARACTERISTICS

One of the first initiatives that went beyond the earlier focus on zero-emission or energy-positive buildings and towards PED projects was the launch of the "Positive Energy Districts and Neighbourhoods for Sustainable Urban Development" programme by the EU as part of the framework of the Strategic Energy Technology (SET) Plan Action 3.2 "Smart Cities and Communities" in 2018 (Brozovsky et al. 2021). The programme aims to support the planning, deployment and replication of 100 Positive Energy Districts (PED) for sustainable urbanisation in Europe by 2025. This programme is implemented by JPI Urban Europe (JPI Urban Europe / SET Plan Action 3.2 2020). Moreover, the International Energy Agency (IEA) has established a programme "Energy in Buildings and Communities Programme (EBC), ANNEX 83" (IEA 2022) which provides a platform to discuss and create a framework of PEDs considering different urban contexts (Hedman et al. 2021). In addition, there is a variety of programmes with similar ambitions to PEDs, but with slight variations and different names, such as zero-energy districts (ZED), low carbon energy districts, nearly zero energy neighbourhoods, positive energy blocks and zero emission neighbourhoods (for a comparative review, see Brozovsky et al. 2021). A common characteristic of these concepts is that they generally have a broader ambition than merely achieving a positive energy or emission balance.

In the JPI programme (JPI Urban Europe / SET Plan Action 3.2 2020), PEDs are defined as follows:

> Positive Energy Districts are energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require 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.

Moreover, the same document provides further information on delineating PEDs and positive energy neighbourhoods (PENs):

> In honouring the economic, cultural and climate-related diversity of European countries and cities, a definition for such PED/PENs should not be just an algorithm for calculating the input and output of energy, but rather a framework, which outlines the three most important functions of urban areas in the context of their urban and regional energy system. The first obvious requirement is that PEDs should ultimately rely on renewable energy only (energy production function), which is one of the main contributions towards climate neutrality. Secondly, they should make energy efficiency as one of their priorities in order to best utilise the renewable energies available (energy efficiency function). Thirdly, as urban areas are bound to be among the largest consumers of energy, PED/PENs need to make sure that they act in a way which is optimally beneficial for the energy system (energy flexibility function).

As the White Paper points out, such integrated approaches also have consequences for planning procedures and governance structures, thus influencing policies on different levels. Moreover, they imply a need for behavioural changes and new forms of energy consumption as well as energy flexibility through sharing or trading, and thus impact the organization of daily life and society more broadly. Not least, such locally integrated energy systems create opportunities for new business models and green business in general. Figure 1 sums up these ambitions connected with the development of PEDs.

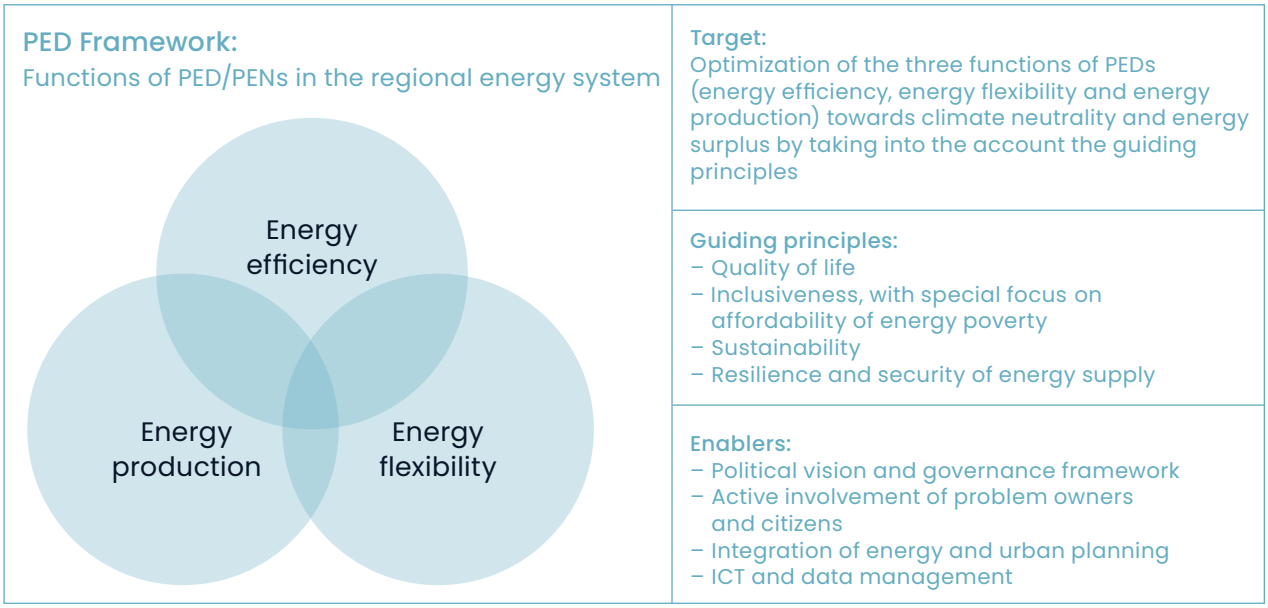

Figure 1: PED Framework (source: JPI Urban Europe / SET Plan Action 3.2 2020, p. 7)

In contrast to the JPI White Paper which takes a broad approach to characterise PEDs by including questions of governance and behaviour, other documents focus on the technical characteristics and energy balancing boundaries. The characterization of PEDs in documents of the International Energy Agency, Energy in Buildings and Communities Programme (EBC), ANNEX 83 (IEA 2022) are as follows:

> The basic principle of a PED is to create an area within the city boundaries, capable of generating more energy than is used, and agile/flexible enough to respond to energy market variations….Rather than simply achieving an annual net energy surplus, it should also support minimizing impacts on the connected centralized energy networks by offering options for increasing onsite load-matching and self-use of energy, technologies for short- and long-term energy storage, and providing energy flexibility with smart control….The PEDs can utilize the benefits of the building thermal mass, different typologies of energy storages, RES [Renewable Energy Systems], electric mobility, demand side management, and flexibility options.

DESIGNING A PED

A recent report by the Joint Research Centres of the European Commission draws upon literature reviews, case studies and interviews, to emphasise energy balance questions. The main factors discussed in the report to design a PED (and also a ZED – Zero Emission District) are as follows (Shnapp et al. 2020):

- The district's boundaries
- The location of the district
- The geographical and urban morphology of the district (the form of the settlements)
- The building characteristics in the district
- The characteristics of the district / building occupants
- The energy demand before and after energy efficiency measures
- The natural resources available for maximising the use of onsite and nearby renewable energy
- The balance between energy production and energy consumption (including buildings, production of on-site renewable energy)

EIGHT STEPS TO OPTIMIZE SOLUTIONS FOR A PED

1. Conduct a district baseline study
2. Map the existing buildings in the district
3. Define energy performance related measures (individual building energy efficiency and renewable energy systems)
4. Calculate energy performance
5. Determine district level energy demand
6. Define district level energy system alternatives
7. Conduct cost-benefit calculations of the district's energy system alternatives
8. Combine the building solutions, renewable energy system solutions (building and district level) and the external energy system

Beyond such performance related questions, the practice of PED implementation is also concerned with questions of economics and the need to develop business models for PEDs. Relevant issues include:

- How can legislation support community-led business models?
- How will a district level measure be financed? Who will provide the grant/loan and guarantee? Who owns the measure?
- How does the investment pay back?
- Is district heating or local district heating a precondition?

CASE STUDY

ZERO ENERGY NEIGHBOURHOODS (NORWAY)

One of the leading research centres currently focusing on PEDs is the "Research Centre on Zero Emission Neighbourhoods (ZEN) in Smart Cities"[1], funded by the Norwegian Research Council. Researchers from the ZEN Centre are also leading an ongoing Horizon 2020 project on Sustainable Plus Energy Neighbourhoods (syn.ikia).[2] The ZEN Centre researchers define a neighbourhood as a group of interconnected buildings with associated infrastructures located within a confined geographical area. A ZEN aims to reduce its direct and indirect greenhouse gas (GHG) emissions towards zero over the analysis period, in line with a chosen ambition level with respect to specific life cycle modules, buildings, and infrastructure elements.

According to ZEN Centre documents, a ZEN should focus on the following issues:

a) **Plan, design, and operate buildings and their associated infrastructure components to minimise life cycle GHG emissions**
b) **Become a highly energy efficient neighbourhood powered by a high share of new renewable energy in the local energy supply system**
c) **Manage energy flows (within and between buildings) and exchanges with the surrounding energy system in a flexible way**
d) **Promote sustainable transport patterns and smart mobility systems**
e) **Plan, design, and operate with respect to economic sustainability, by minimising total life cycle costs and life cycle system costs**
f) **Plan and locate amenities in the neighbourhood to provide good spatial qualities and stimulate sustainable behaviour**
g) **Promote the development of the area through innovative processes based on new forms of cooperation between the involved partners leading to realise innovative solutions**

An interesting point is also made regarding the system boundaries of a ZEN (and by extension, a PED). As pointed out above, a ZEN/PED is characterised by a confined geographical area. This area also has a defined physical boundary with respect to external service networks (electricity and heat, and if included, water, sewage, waste, mobility, and ICT). However, the system boundary to analyse the energy facilities that serve the neighbourhood is not necessarily the same as the geographical area. The system boundary for each ZEN pilot area is also dependent on the case and varies accordingly. One of the key areas of the ZEN Centre's work is the development of methods and criteria to assess ZEN performance. Using detailed KPIs (key performance indicators) (Wiik et al. 2018b). Table 1 provides a summary of the main assessment criteria and KPIs applied in this context.

1 https://fmezen.no

2 https://www.synikia.eu

Category	Assessment Criteria	Key Performance Indicators (KPIs)
GHG emission	– Total GHG emissions – GHG emissions reduction	– Total GHG emissions in tCO_{2eq}; tCO_{2eq}/m^2 heated floor area (BRA)/yr; $kgCO_{2eq}/m^2$ outdoor space (BAU)/yr; tCO_{2eq}/capita – % reduction compared to a base case
Energy	– Energy efficiency in buildings – Energy carriers	– Net energy need in kWh/m² BRA/yr; Gross energy need in kWh/m² BRA/yr; Total energy needed in kWh/m² BRA/yr – Energy use in kWh/yr; Energy generation in kWh/yr; Delivered energy in kWh/yr; Exported energy in kWh/yr; Self-consumption in %; Self-generation in %; Colour coded carpet plot in kWh/yr
Power/Load	– Power/load performance – Power/load flexibility	– Net load yearly profile in kWh; Net load duration in kWh; Peak load in kWh; Peak export in kWh; Utilisation factor in % – Daily net load profile in kWh
Mobility	– Mode of transport – Access to public transport	– % share – Meters; Frequency
Economy	– Life cycle cost (LCC)	– NOK; NOK/m² heated floor area (BRA)/yr; NOK/m² outdoor space (BAU)/yr; NOK/capita
Spatial qualities	– Demographic needs and consultation plan – Delivery and proximity to amenities – Public space	– Qualitative – Number of amenities and distance from building – Qualitative

Table 1: ZEN assessment criteria and KPIs (source: Wiik et al. 2018a, p. 25)

However, the ZEN Centre goes far beyond the theoretical development of definitions and assessment criteria and emphasises the development of a systematic process to establish such neighbourhoods and to test different social and technical arrangements for ZEN pilot areas and living labs. In this respect, the ZEN process is closely aligned with the principles of the TRANS-PED project.

ZEN living labs are defined as an open, inclusive space that supports user engagement through ZEN pilot projects, bridging the gap between the social and technical context (Woods et al. 2019). The researchers note that:

A ZEN living lab should function as a creative arena for knowledge exchange, between people, places and technology. It is an arena that should ideally highlight learning processes. The concept includes four main elements:

1. Representatives from the different user groups affected by the sustainable neighbourhood transition proposed by ZEN
2. A clearly defined geographical place
3. A set of clearly defined activities that can be applied iteratively
4. An experimental format based on the challenges and needs of the neighbourhood (ibid., p. 35)

Based on an analysis of drivers and barriers for ZEN development, Backe and Kvellheim (2020, p. 7) provide the following recommendations:

Owners and developers:
- Set ambitious objectives and develop innovative and sustainable business models
- Create a demand (and supply) for ZEN solutions through ambitious goals and long-term value creation
- Engage users in co-creating attractive neighbourhoods
- Support innovative approaches and acquire competence on smart technology

Supply and infrastructure:
- Challenge the current market with innovative business models and efficient solutions
- Grasp opportunities provided by technology development and digitalization
- Create new business partnerships across disciplines and traditional markets (energy and building industry)

Society and policy:
- Engage, and be engaged as citizens in the development of sustainable solutions
- Frequently evaluate regulation limiting a ZEN based on updated research and development
- Support research to develop more knowledge on the impact of a ZEN
- Best practice projects are essential for learning and further development

Also in these recommendations it becomes clear how the ZEN project moves beyond performance assessments and the development of criteria for defining a ZEN, but very much focuses on the social and economic processes that are required to establish a successful ZEN.

KEY QUESTIONS FOR PEDS

The White Paper on Positive Energy Districts concludes with a number of key questions which need to be addressed at the conceptual level (JPI Urban Europe / SET Plan Action 3.2 2020, p. 22). These questions show the entanglement of technical questions for characterizing a PED with institutional contexts which need to be adapted and processes of stakeholder engagement which are needed to create support for a PED. The following issues should be clarified in order to provide a coherent framework for PED development:

- What is the ultimate goal of a PED? Minimizing CO_2 emissions or achieving a positive energy balance? Are there conflicting interests regarding this? What is the importance of cost-efficiency, i.e. dependency on the bias between fossil and renewable energies?
- Who are the key actors and problem owners (e. g. city administrations, real estate developers, energy suppliers) in your country for the development of PEDs? How can they be activated? What are the main drivers and barriers for them to get involved?
- Is there a need for changes in legislation and regulation? In which areas? What is needed for appropriate business models? Is there a lack of finance? For which stakeholder group?
- How can mobility issues be taken into account in PED implementation? Are the approaches of front-running countries (e. g. Switzerland, Austria) suitable for your country? Which adaptions need to be made?
- How can green and blue infrastructures be considered in the PED concept? What are the barriers for their realisation? How can their benefits be evaluated? (including the increase of energy efficiency, avoidance of the urban heat island effect and increased demand for cooling, reduction of air pollution and noise, increase of quality of life)
- Can PEDs increase the resilience of urban areas? What is necessary in this context? How can this be tested? What should be avoided?
- What are the different (national) methodologies to calculate CO_2 emissions of a PED? (e.g. using annual averages or hourly resolution and/or considering the emissions of the marginal power plant)
- How can a life cycle analysis be carried out in the PED context? Which countries have developed methodologies? What are the advantages and disadvantages of the different methodologies?
- How can questions of sustainability (e.g. the UN Sustainable Development Goals) and of liveability be embedded into the PED concept?

In summary, there is a thriving literature on how to define, assess and plan for PEDs. While methods to calculate PED performance figure prominently in some of the projects and reviews, much emphasis is also put on processes of implementing PEDs and the required policy, organizational and behavioural changes accompanying and supporting such processes. This is very much in line with the interests of the practice partners in the TRANS-PED project whose ambition lies not so much in nominally achieving different performance criteria, but rather in the practices and policies of working towards PEDs as sustainable energy districts.

RELATING PEDS TO SIMILAR CONCEPTS

In this section, academic concepts with a specific focus on urban sustainability and relevance for PED development are summarised. This should not be seen as an exhaustive overview or review, but a presentation of frequently used concepts in the academic debate over the last decade. The concepts include urban living labs, urban experimentation, and urban transformative capacity. All academic debates and theoretical concepts in these sections relate to answering more or less the same question: how can we transform cities and city districts to become more sustainable?

URBAN LIVING LABS

The concepts of urban living labs (ULL) and living labs focus on forms of experimental governance with urban stakeholders developing and testing new technologies and ways of living to produce innovative solutions to the challenges of climate change and urban sustainability (Bulkeley and Castán Broto 2013; Voytenko et al. 2016).

JPI Urban Europe (2013) announced a funding call in 2013 and defined ULLs as:

> A forum for innovation, applied to the development of new products, systems, services, and processes, employing working methods to integrate people into the entire development process as users and co-creators, to explore, examine, experiment, test and evaluate new ideas, scenarios, processes, systems, concepts and creative solutions in complex and real contexts.

Voytenko et al. (2016) argue that an important aspect of ULLs is not only technologies that are central, but also consumption, behaviour, and lifestyles. When summarizing the different definitions of ULLs, they further conclude that there is no uniform definition. While some see ULLs as partnerships between sectors, including public and private actors as well as citizens, other see them in relation to demonstration projects and how they may serve as supportive tools for private actors to commercialise services, products, and technology. Schliwa (2013) argues that ULLs can be seen both as an arena (geographically or institutionally bounded spaces) and as an approach for deliberate collaborative experimentation between researchers, companies, citizens and local governments.

Steen and van Bueren (2017) argue that ULLs have four defining characteristics. First of all, the aim is to learn and experiment, and is often integrated with research and innovation processes. In terms of learning, the exchange of knowledge between involved actors is key, and usually the aim is to replicate the experiments and innovations elsewhere. Another key aspect is to focus on urban sustainability as an overarching goal. A third key characteristic relates to the activities taking place. This usually involves the development of a product such as an artefact or process innovation, and to co-create within the lab, often together with the user. The fourth characteristic relates to the participants, and how all stakeholders contribute to the process. The stakeholders can be users, private actors (companies, firms), public actors (governments and public institutions), and knowledge institutions. The last key characteristic is the context, and how they take place in real-life environments.

Voytenko et al. (2016) further argue that there are five main components in ULLs: geographical embeddedness, experimental approaches, participation and user involvement, leadership and ownership, and evaluation processes. ULLs are predominantly not virtual platforms, they are rather situated in a real urban context, although scale may vary from a city or region to a district or even building. In the experimental approaches, learning is undertaken between the involved actors with a particular focus on user-centered experimentation. A clear sense of ownership is important to coordinate and manage the ULL and ensure further development of the process. Evaluation of the actions and impacts is important, as part of feedback loops, in order to refine goals and visions over time.

Marvin et al. (2018) proposed a typology for ULLs that makes a distinction between strategic, civic, and organic variations (Table 2). Strategic ULLs are characterised by various degrees of steering from national or regional authorities and with involvement from private actors. Civic ULLs are more often aligned with municipal governments and civic universities and local companies and emphasise the needs on a local and urban level. Organic ULLs are created by communities and/or neighbourhood groups and address the specific needs in these areas.

Characteristic	Strategic	Civic	Organic
Lead actors	Innovation agencies, national government, corporate business	Municipal/local authorities, higher education and research institutes, local companies, SMEs	Civil society, communities, NGOs, residents
Urban imaginary	Urban as test-bed that can be replicated or generalised	Urban as a contingent and historically produced context	Urban understood in particular ways by local communities
Primary purpose	National innovation and technological priorities	Urban economic and employment priorities	Community social, economic and environmental
Organisation form	Competitive – urban selected as a site for experimentation	Developmental – partnerships formed by local actors	Micro/single – multiple forms of community organization
Funding type	One-off/competitive	Co-funding/partnership	Improvised
Analogue	National innovation	Urban technology policy	Grassroots innovation

Table 2: Types of ULLs (source: Marvin et al 2018, p. 8)

URBAN EXPERIMENTATION

A related conceptual framework relates to urban experimentation and is often motivated by urban responses to climate change, and how local actors (predominantly municipalities) govern activities focusing on combating climate change. One could argue that projects focusing on climate change might lie outside the direct core competences and tasks of municipal authorities, leading to failed or fragmented, case-by-case approaches instead of a comprehensive plan. In other cases, windows of opportunity, such as sporting events or infrastructure renewal programmes, might catalyse action while remaining as one-of-a-kind projects. Furthermore, private actors might take charge of projects directly or indirectly and focus on climate change measures in partnership with the municipality. These examples suggest a fragmented landscape where municipalities have insufficient capacity to coordinate and thus fail to develop an integrated, planned approach for urban climate governance (Bulkeley and Castán Broto 2013). All in all, the argument is that:

> Central to the urban response to climate change is a mode of experimentation where municipalities, private and civil society actors seek to demonstrate, experience, learn and challenge what it might mean to respond to climate change through a multiplicity of interventions, projects and schemes. Such experiments, we argue, are not simply ad hoc ventures, but need to be understood as situated and purposive interventions that demonstrate the ways in which new forms of authority are emerging in the context of climate change and the critical socio-technical dimension to realising any governance response. (Bulkeley et al. 2015, pp. 4-5)

Furthermore, governments use experimentation as a highly visible way to demonstrate their will to improve. Bulkeley et al. (2015) propose a three-step analytical framework to explore and explain the ways experimentation becomes a central part of urban climate change governance. The steps include making, maintaining, and living experiments.

Making experimentation entails first a problematization process. The framing of the problem is a political process, meaning that power relations play a crucial role in terms of whose problem formulation might be put forward, as the solution to the problem might be shaped by the solutions at hand. If the problematization is based mainly on technical aspects, the solution might be proposed as purely technical, when there are several important factors and actors that should have input. Assembling the involved actors creates spaces where interventions can be devised and implemented. They argue that:

> The making of experiments relies both on opportunities to ensure that experimentation is visible and the ability of intervening agencies to enrol actors, materials and resources through the production of suitable narratives that legitimate the experiment as a form of intervention (Bulkeley et al. 2015, p. 44).

In the next step, there is an emphasis on how experiments unfold in the urban context, how they are maintained, and how actors are engaged and how the ideas are circulated. In this aspect, various forms of upkeep are necessary to maintain the physical and technical features of innovation, to deliver smooth operation and to ensure that the experimental aspects are upheld, made visible and circulated. A second key aspect is to make "metabolic adjustments" to align experimentation to existing structures while also sustaining the novelty of the experiment. It is a challenge to innovate within existing structures and to balance feasibility and novelty. It is also important to authorise knowledge and to demonstrate experimental successes and failures to ensure that the experiments are visible and can be extended and mobilised in other places.

Finally, experiments are "lived" and taken up in daily practices of individuals and institutions that are implicated in the experiment. Then new subjectivities are produced and contested around the experiment, pushing the boundaries around the experiment. It puts emphasis on the boundaries between the ordinary and original, as well as the political and technical, as the experiment requires compromises among the involved partners. The limitations of politics and governmentality may be exposed and contested, and by focusing on experiments and everyday practices, attention can be directed towards the contingent nature of socio-technical intervention.

All in all, by focusing on the fine-grained processes of climate experiments, politics are scrutinised. The increased urban focus on climate change action highlights decentralised power that is shared among several actors and levels, as well as the negotiations between them. The experiments shift existing social and spatial relations and create new relations, meaning that actions can include new actors and emphasise actions previously considered to be peripheral.

URBAN TRANSFORMATIVE CAPACITY

A concept that has gained more attention in recent years relates to urban transformative capacity (UTC) and how transformations and transitions of urban practices, sociotechnical systems, and processes toward higher levels of sustainability can be achieved. The point of departure is to question which factors enable "cities and urban stakeholders to purposefully initiate and perform such transitions?" (Wolfram 2016, p. 121). These factors relate to how systemic change towards sustainability can be realised and driven. Capacity refers to how characteristics of agency and structure affect the possibilities to make societal transformations. Wolfram (2016, p. 126) defines UTC as:

> The collective ability of the stakeholders involved in urban development to conceive of, prepare for, initiate and perform path-deviant change towards sustainability within and across multiple complex systems that constitute the cities they relate to. It is a qualitative measure for an emergent property that reflects attributes of urban stakeholders, their interactions, and the context they are embedded in.

Wolfram (2016) then identified a conceptual framework, which has been further developed in later studies (cf. Wolfram et al. 2019). The framework excludes corporate innovations, and focuses instead on areas that are urban, placed within urban contexts, or have obvious implications for cities. Specific emphasis is put on understanding how resources, power relations, and the obduracy that physical structures (e.g. technical infrastructure and buildings) may contribute to, not only from the physical limitations they impose but also "cognitive and social processes that enable stakeholders to recognize and understand systemic path dependencies" (Wolfram 2016, p. 126). Table 3 summarises the key components of the UTC framework.

Component	Key ideas
Inclusive and multiform urban governance	Wide participation and active inclusion of stakeholders from all sectors, diversity of governance modes and actor networks (de-/centralised, formal/informal, multi-level, etc.), and sustained and effective intermediary organizations and individuals between sectors and domains (hybridization)
Transformative leadership	Leadership needs to be polycentric and socially embedded and supporting exchange between sectors and scales
Empowered and autonomous communities of practice	Social learning networks formed through the shared experience of urban place and/or wider joint concerns are decisive for identifying and articulating unmet social needs, and to formulate responses
System(s) awareness and memory	Awareness and understanding among stakeholders of the system dynamics, path dependencies and obduracies that undermine urban sustainability
Urban sustainability foresight	Collection of diverse and transdisciplinary knowledge, followed by development of a shared collective vision for radical sustainability changes, and finally development of alternative scenarios and future pathways
Diverse community-based experimentation with disruptive solutions	Experimentation can take place by place-based or issue-driven communities of practice, focusing on experiments that suggest disruptive urban sustainability solutions
Innovation embedding and coupling	A presumption that stakeholders share and/or enable access to basic resources for developing capacity, and later financial and material resources. By enabling resources, barriers for innovative practices are removed, and then embedding the practices into routines, organisations, plans and legal frameworks
Reflexivity and social learning	Reflexive monitoring should take place on all levels and across all dimensions in urban innovation processes. Feedback loops are connected to all actions for change. Skills for applying assessment methods are necessary.
Working across agency levels	All agency levels (individuals, households, groups, organisations, networks, society at large) need to be addressed in the process.
Working across political-administrative levels and geographical scales	Particular emphasis is placed on local level, but implications of interactions between scales needs to be addressed. Administrative boundaries (local, regional, national) must be considered

Table 3: Key components in urban transformative capacity (source: Wolfram 2016, pp. 127-8)

The conceptual framework is supposed to help in considering critical preconditions while supporting radical urban change towards sustainability. The embeddedness in local contexts, with everything that this entails, including existing buildings and infrastructure systems as well as stakeholder compositions, sets the boundaries for future development. By understanding the preconditions, taking advantage of stakeholder knowledge, and supporting change, the potential for radical systemic changes can be increased.

In a later study, Wolfram et al. (2019) argue more specifically for understanding and emphasizing the role of urban planning, intermediaries, and local academia, in shaping inclusive and multi-form governance arrangements, and the development of novel self-assessment techniques to foster reflexivity in the processes.

DISCUSSION

All in all, the concepts of ULLs, urban experimentation and UTC have several aspects in common. All have an urban focus, and centre on the development of geographically delimited areas such as a district, a block, or even a building. The transformative components point towards orienting new and existing sociotechnical systems towards higher levels of sustainability. Governance structures are designed with the aim of involving a variety of actors in carrying out and evaluating experiments. That means that structures and aspects of system obduracy are acknowledged to create realistic transformations that do not start from a blank slate. Involvement of citizens and citizen groups is an important part of all concepts, taking into consideration situated knowledge.

The concepts also focus on establishing structures for development that go beyond technological considerations (especially in the UTC framework) and account for the whole process, including existing structures, user knowledge, social aspects, political dynamics and learning processes. Feedback and learning are emphasised less in urban experimentation in favour of a focus on political governance structures.

The concepts have the potential to enrich the understanding on how to support PED development processes. There is an emphasis on understanding governance structures and engaging with large groups of actors, as well as suggesting steps along the way. The UTC framework provides insights on how to assess the landscape and existing sociotechnical system configuration, how to engage and enrol actors and create networks for learning, and to test new products, participatory practices and system configuration, as well as integrating feedback loops.

At the same time, ULLs and experimentation can also take place within a PED. The concepts are not, and should not be seen as, mutually exclusive and may rather enrich one another. In order to become a PED, experimentation might for example be an important goal of engaging actors in becoming climate neutral and moving towards energy efficiency.

TOWARDS A PROCESS-BASED DEFINITION OF PEDS

Based on the literature review of PEDs and related concepts as well as the interviews with TRANS-PED partners, we suggest an emphasis on a process-based definition of PEDs. Much focus in the current literature is on how to define and operationalise criteria and key performance indicators to qualify as a PED including how to draw boundaries, how to calculate emissions, which sources of emissions and energy use to include (transport, grey energy, consumption-based emissions), which time-period to achieve a positive balance (a year, full life cycle), how to define and assess the interaction of a PED with the broader energy system or city, and so on. These definitions are without a doubt important for a better understanding of PEDs. However, as the interviews with the TRANS-PED partners confirm, they might have more relevance to academics than to practitioners. In the practice of implementing a PED, emphasis is placed on concrete achievements and working with stakeholders rather than sophisticated calculations and questions about fulfilling PED criteria. This also has to do with the fact that PEDs are just one of several concepts and 'labels' that attract political and public attention, alongside smart cities and neighbourhoods, eco-districts, sustainable cities, and so on.

However, when it comes to achieving a positive energy balance as an ambition or an aim, several questions guiding urban development activities which contribute to sustainable urban change are foregrounded, even if the PED criteria are not immediately fulfilled. One such issue is for example that an integrated energy systems perspective needs to be taken also at the local/district level which includes questions of efficient energy use, possibilities of local energy supply with renewable sources, the interconnection of different energy consumers (buildings, businesses, transport, etc.) and the management of this local energy system (e.g., through smart grid technologies or including local energy storage possibilities). A further issue which is raised through PED ambitions is how to facilitate the cooperation and involvement of local stakeholders, as control and decisions about local energy use and generation usually is distributed across many actors, be it local residents and businesses, energy supply actors, and other types of organisations (civil society initiatives, network and intermediary organisations, etc.). A PED can only be achieved as a joint effort between these actors, which means that they need to be involved in the process, and need to be convinced about the benefits of such activities to their everyday life or business. Strategies of communication, participation, empowerment and facilitation are thus core to the process of achieving a PED. At the same time, this relates to the geographical and organizational delimitations of PEDs, as most definitions focus on delimiting a specific area. Depending on the focus and responsibilities of the involved actors, this might not be aligned with overarching aims of learning on a wider city level. A municipal stakeholder would probably want the PED to contribute to learning on a city and municipal level, but if the PED is treated too much as an enclave, opportunities for wider learning might be missed.

A third issue raised by PED ambitions is related to the uniqueness of each PED and the high bar set by the aim to become energy-positive at the district level. There are no mature, off-the-shelf solutions for PEDs to achieve this and thus, developing a PED requires inventiveness, creativity, experimentation and learning. Current PED developments have characteristics similar to living labs and it is important to develop structures for systematically learning from other PEDs and to have the flexibility to implement solutions within a PED and maintain an open and adaptive development process to allow for new insights. At the very least, the ambition of achieving a PED requires consideration of how the PED relates to other parts of the city and energy system. Questions about how a PED can contribute to an urban energy transition and how it supports the sustainable operation of the wider energy system (e.g., electricity grid) are important. In a broader sense, such considerations and experiences with PED implementation can make important contributions to the development of urban governance capacities for transformative change, within and beyond the energy system.

A further set of questions related to PEDs concerns the meaningfulness of an exclusive focus on energy and the different pre-conditions to achieve a positive energy balance. Regarding the energy focus, most of the interviewees also emphasised other sustainability questions. As some of the interviewees convincingly pointed out, this does not pose a problem for the PED concept. The advantage of the PED concept is that it is relatively coherent and measurable. However, this does not mean that a PED cannot also be part of a 'smart city' with a focus on digitalization, or a 'sharing city' or other sustainability framings. Rather than making the energy focus blurry, it might be an advantage to have a clearly defined goal which is at the same time combined with other urban development strategies. An exemption to this broadening is made regarding social sustainability dimensions. There is a lively current discussion in the literature about how to address questions of energy justice in PEDs including questions about affordability, social distribution and general wellbeing (see e.g. Hearn et al. 2021) and about how to apply the concept of the 'doughnut economy' to PEDs, i.e. having an outer boundary defined by environmental PED criteria (such as a positive energy balance and reducing emissions) but also an inner limit of social standards which should be fulfilled by a PEDs (Derkenbaeva et al. 2022). The importance of participation and empowerment in PEDs can also be seen in this context.

The question of varying conditions to achieve a PED is also raised by a number of authors (Derkenbaeva et al. 2022; Lindholm et al. 2021). A strict focus on PED performance criteria poses a problem as conditions to use renewable energy sources vary significantly between PEDs, just as the potential for energy savings varies for different PED actors. Oftentimes, the effects of these conditions are not so clear-cut. For example, a high density of buildings might limit the preconditions for e.g. use of photovoltaics while also increasing energy efficiency potential. Some researchers thus work on more sophisticated PED framework conditions which take differences in the PED context into account and introduce context factors to create a level playing field for districts wanting to become a PED. Another approach by Lindholm et al. (2021) distinguishes between three different types of PEDs. Autonomous PEDs are completely self-sufficient with respect to energy (however, export of excess energy is allowed). Dynamic PEDs allow for open interaction with other PEDs and the electricity grid (or district heating or gas networks) for energy management purposes. And virtual PEDs allow for renewable energy generation and storage outside of the geographical PED boundaries (although these facilities are required to be an asset of the PED). Different PED types can be pursued depending on local preconditions.

STEPS TO CHARACTERISE PEDS

The following sections provide specific guidance on specifying different types and preconditions of PEDs and then describe the dimensions relevant to a process-oriented definition of PED. The aim is to draw attention to "the making of a PED" in contrast to measuring the performance of a PED. Focusing on what needs to be done to achieve a PED requires on the one hand an understanding of the contextual conditions which make certain PED pathways more likely than others, and on the other hand an awareness of different concerns and action fields which need to be considered in working towards a PED.

SPECIFYING PED PRECONDITIONS

In a first step, different characteristics of PEDs can be delineated to outline the specific preconditions and context of a PED. This influences which type of PED can eventually be developed. The following dimensions are of primary importance to characterise a PED.

Geographical characteristics have a major influence on which type of PED is possible and which social and technical characteristics will shape PED development. It is very likely that a PED in an urban context will look very different from a rural PED with different infrastructure preconditions (e.g. transport), needs of PED inhabitants, availability of certain technological solutions, and so on. Also within cities, urban morphologies (e.g. density, connection to regional context) will influence possible PED designs, just as the question of whether the PED is a new-build district or an adaptation of an existing district. Geographical characteristics also determine the availability of different types of renewable energy sources, their connection to different climate conditions and so on. Which type of PED can be developed under such conditions, how easy it is to achieve a PED, and which (socio-) technical configurations will be most feasible thus is strongly influenced by these spatial characteristics.

However, PEDs may also diverge with respect to **socio-economic characteristics**. Whether a mainly residential area is turned into a PED, or whether businesses and industrial actors are part of a PED will obviously play an important role in the PED design and development process. Similarly, it is important to note if a planned PED is situated in an area with wealthy and highly educated residents (as is often seen in new-build urban eco-districts) or in an economically less resourceful area with various social problems but also socio-cultural resources. Along similar lines, conditions of dynamic economic development versus economic decline, depopulation and industrial shrinkage will influence the PED type. Strategies to develop a PED need to take into account socio-cultural diversity of the place, cultural heritage and historically emergent characteristics such as traditions of citizen engagement, which are existing in some places but not others. Again, these specific socio-economic and socio-cultural characteristics will shape which strategies for developing a PED are feasible or not and which types of solutions are applicable in these contexts.

Institutional and regulatory conditions are a further influence on PED design and development. These conditions also affect the type of lessons that can be transferred from one PED to another. Regulations, such as the possibility to operate an electricity mini-grid within a PED, or whether there can be peer-to-peer trading of energy between different PED inhabitants and buildings, differ significantly between countries. Moreover, a PED is shaped by its ownership structure such as privately owned houses versus public housing companies as well as ownership of energy grids or other infrastructures and the existence of absence of an organisation to coordinate and manage PED activities.

PEDs may **follow different models** which make certain configurations and technologies possible while creating barriers to other strategies. One of the PED typologies mentioned in the literature review section distinguished between (1) largely autonomous and self-sufficient districts, (2) neighbourhoods that are strategically integrated into the broader urban energy system, and (3) virtual PEDs that allow for renewable energy generation and storage outside of the geographic PED boundaries. Another distinction between PED concepts is the way that transport is included in energy planning assumptions. The selected models ultimately determine how the performance of a PED can be defined and measured.

DEFINING PED PROCESSES

As a next step, a process-oriented approach to becoming a PED is suggested. The following steps/dimensions are crucial to move towards becoming a PED.

Need for energy planning. Working towards a PED requires the assessment of energy demand and whether it can be met through local energy generation. An important step is to conduct an inventory of the potential for renewable energy production within the geographical area. What are the possibilities for solar photovoltaic installations? For heating? For transportation? For energy storage? For energy efficiency measures? Are there possibilities for renewable energy production and storage outside the geographical boundaries? Such an assessment needs to take stock of the above-mentioned geographical conditions and include these insights in an energy planning process.

Energy system integration. Moving towards a PED requires a 'whole system perspective', and an understanding of the different socio-technical dimensions and interactions of the local energy system. Achieving such an understanding is a key difference when compared to traditional district planning procedures and requires a whole set of new competences, capabilities and approaches. One step to create a systemic perspective is to map the involved actors and analyse their specific responsibilities, drivers and obstacles in the process. Is there potential for synergies? How could the energy system be managed in the most efficient way? A second step involves creating an understanding of how new energy production can be integrated into existing energy structures and identifying the drivers and barriers to this integration. A third step involves the identification of relevant institutional settings and contexts for PED development. Which legislative barriers need to be addressed? What are possible incentives to attract the main actors? Based on these insights and understandings one can then ask, how the energy system can be integrated technically and organizationally at the district level in conjunction with the key actors. It is important to delineate the organizational, behavioural and technical changes that are needed to achieve such an energy system integration within the PED boundaries.

Stakeholder involvement, participation, and empowerment. All PEDs are multi-actor systems which are not centrally organised but require voluntary cooperation and engagement. Moving towards a PED requires getting these actors and stakeholders on board – motivating, engaging and empowering them. This requires a broad mapping of relevant actor groups (NGOs, community representatives, citizen groups) to catalyse broader involvement, and include them in the PED development process. To start the process of becoming a PED, one needs to ask who could be involved and how their involvement can be best achieved. Coordinating, involving and empowering local actors is a prerequisite for PED success. Such an effort requires the creation of arenas for discussion between key stakeholders, especially citizens. Empowering actors requires agreement on common goals. Is the PED mostly aiming for a generation of surplus of renewable energy? Is the main focus to reduce CO_2 emissions? Setting delimited goals in an inclusive matter will help to reach the overarching goals. It is also important to clearly link these goals to broader aims of societal transition and transformation.

Energy justice and social sustainability. Taking inspiration from the doughnut economics model, successful PEDs not only need to achieve a balance in energy demand and generation but should do so in a way which also ensures basic social standards, affordability and wellbeing of involved citizens and other actors. Energy systems should not be seen as a separate entity, with no input from citizens. Moving away from the traditional engineering perspective that frames users as “loads” or “nodes” instead of active users is crucial. This also involves the analysis and understanding of socioeconomic prerequisites and the potential to address social sustainability goals through the PED process. Relevant questions in this context are: What are the pressing issues for citizens? How can the PED process be designed to accelerate change and empower citizens while aligning with broader sustainability aims?

Experimentation and the creation of infrastructures for learning. PEDs have diverse geographical, technical and organizational preconditions that require new solutions as well as the adaptation of successful strategies from other PEDs. There is no “off-the-shelf” solution for PEDs in the foreseeable future. The development of adapted and embedded solutions cannot be achieved without testing new socio-technical configurations and learning from such experiments as well as other PED developments. The mapping and mobilization of stakeholders in early stages can encourage the development of small and large projects to implement and trial in the PED. This addresses social sustainability, energy justice, and user engagement. However, it is also important to develop infrastructures to gather such ideas and to build on existing forums and arenas. This requires processes to create systematic procedures and infrastructures to experimentation and learning via feedback loops that focus on long-term evolution and change.

Integrating the PED into broader urban and energy system contexts. PEDs are not an aim in themselves but should rather be part of a broader transition towards a sustainable energy system and sustainable city. This requires an emphasis on the interactions with the wider energy system and the potential services the PED can provide as well as embedding PED development in broader processes of urban sustainability and climate transitions. This requires an expanded perspective that goes beyond the PED's geographical boundaries, not only in terms of replicating and upscaling, but also by inspiring other change activities and by aligning with other projects aiming at sustainable urban development. Questions in this context are: How do PED goals and activities link up with broader city, municipal, and regional goals? Are there synergies to be found? Are there conflicting goals and aims? Which actors play crucial roles in different contexts? It is important to develop structures for outreach and knowledge sharing activities to benefit the city as a whole. Questions of dissemination, upscaling and transferring of lessons learned to other parts of the city need to be established in early stages of PED design.

PED preconditions and PED processes can be established by asking to what extent certain preconditions (e.g. wealthy, educated residents; rural context) can align with certain PED processes (e.g. higher level of involvement of residents; greater difficulties of system integration in rural areas). A better understanding of how PED processes can be adapted to the specific preconditions and contexts of a PED can further increase the chances of realising a successful PED.

CONCLUSION

The TRANS-PED project has the ambition to further develop the understanding of the PED–concept through case studies and conceptual work. This typology framework addressed PED definitions and characteristics, design criteria and related concepts including urban living labs, urban experimentation, and urban transformative capacity. An outcome of studying the thriving literature around PEDs and receiving inputs from our TRANS-PED partners about the practical challenges of PED development involves a shift away from PED performance criteria towards PED-as-process. It is through a broad assessment and alignment of PED preconditions and processes that sustainable energy and urban transformations can be realised.

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ABOUT TRANS-PED

This document was produced within Trans-PED, a project funded by JPI Urban Europe. Trans-PED is a 2-year pilot project to develop a governance approach for Positive Energy District stakeholders to better realise deep changes to their cities.

Energy is one of the critical issues cities will need to address on their path to climate neutrality. Positive Energy Districts (PEDs) are one key instrument for that transformation. Trans-PED is an international project involving 11 partners from Austria, Belgium and Sweden, led by KTH Royal Institute of Technology and co-funded by JPI Urban Europe. The team is developing a governance approach through collaboration with five established and aspirational PEDs.

Positive Energy Districts are urban neighbourhoods with annual net zero energy import and net zero CO_2 emissions. A PED couples built environment, production, consumption and mobility to reduce its energy use and produce the remainder locally. The European Union aims to support the planning, deployment and replication of 100 PEDs by 2025.

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