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HOLISTIC ASSESSMENT METHODOLOGY FOR POSITIVE ENERGY DISTRICTS

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Abstract. Globally, cities are responsible for most of the world's energy consumption and most of the carbon dioxide emissions. Therefore, the efficient transformation of urban energy systems is becoming a crucial step towards carbon neutrality and more effective climate protection. The Positive Energy District (PED) concept has been pointed out as one of the key principles of this path. The Positive Energy District concept leads towards an integrated and sustainable urban development with an emphasis on the use of renewable energy sources and attention shifting from energy performance at the level of individual buildings to the level of the entire district. However, PEDs represent a relatively new and still not sufficiently explored area in the field of sustainable development.

The aim of this paper is to describe the technical part of the new holistic assessment and innovative process of stakeholder engagement to identify Positive Energy Districts in the early development phase that arises within the PED-ID project. The early development phase is crucial since the structure of the urban area is being decided along with its sustainability and climate protection levels.

The assessment methodology is based on the creation and optimization of energy balance scenarios.

Case studies of existing urban areas have been developed in order to verify the methodology.

It is concluded that this innovative methodology devised for PED evaluation, together with strengthening of knowledge-based and decision-making framework, will help to accelerate the process of transforming the current urban energy systems into more efficient and renewable systems.

Keywords: Positive energy districts, sustainable urban development, assessment methods.

1. Introduction

Globally, cities are responsible for 60 to 80 percent of the world's energy consumption and for nearly 75 percent of the carbon dioxide emissions [1], whereas buildings are responsible for 40 percent of the energy consumption and 36 percent of the carbon dioxide emissions [2]. Urban agglomerations consist of a large number of non-renovated buildings, three quarters of which are not energy-efficient and therefore waste energy [2]. Only 1 % of non-renovated buildings are renovated annually [3].

The concept of Positive Energy Districts implements the objectives of the European Union by connecting sustainable urban development with renewable energy production and energy efficiency. The European Union aims to increase the renovation rate of buildings [3], increase energy efficiency in the EU to 32.5 % and the use of renewables to at least 32 % by 2030, along with the long-term goal of decarbonisation by 2050 [4, 5].

Therefore, the efficient transformation of urban energy systems is becoming a crucial step towards carbon neutrality and more effective climate protection. The Positive Energy District (PED) concept has been identified as one of the key principles of this path.

In 2021, the topic of positive energy districts was already being addressed by a number of projects [6–8]. The objective is to accelerate the pace of the transformation of the energy system in Europe to a more efficient and renewable system by achieving the Positive Energy District status and to accomplish the goal of 100 PED sites in Europe by 2025 [9].

1.1. Introduction of PED-ID project

The approach to PED assessment presented in this paper was developed under the project "Holistic assessment and innovative stakeholder involvement process for identification of Positive-Energy-Districts (PED-ID)" funded by the Technology Agency of the Czech Republic and JPI Urban Europe.

The goal of the PED-ID project was to develop an innovative knowledge-based stakeholder process for PED areas and holistic assessment methods to use information for the stakeholder process and to provide decision-makers at an early stage with better information about how to achieve PED status in the best way, but also about possible options and impacts. This process is then tested in Living Labs, all potential PEDs, with focus on the participation process and the identification of the data needed.

The principle is to create a handbook that will serve as a guide to PEDs. There are currently many guides and methods to assess the energy performance of buildings, however, in the case of PEDs, the assessment is also extended to the simultaneous assessment of a larger number of buildings and other sectors such as transport, technical infrastructure and greenery that need to be included and balanced.

1.2. PED definitions and characteristics

The PED definition is not yet clear and comprehensive. It has been addressed within a number of studies [10, 11] and documents [12–14]. Based on the definitions and descriptions of Positive Energy Districts or similar designs [15], the following elements and parameters of PEDs have been identified:

- PEDs are composed of groups of buildings or an urban area.
- PEDs require interconnection and interaction of several sectors along with a high degree of system and communication integration.
- PEDs use comprehensive (advanced) energy management.
- PEDs focus on the energy efficiency of buildings and systems and energy balance of all sectors involved.
- PEDs reach at least net-zero energy import and greenhouse gas emissions balances per year with the goal of producing surplus energy.
- PEDs rely exclusively on (local) renewable energy sources and energy storage systems.
- PEDs are not limited by social, material, technical or technological solutions.

The seven points represent the main elements in the implementation of PEDs but also the risks and challenges as Positive Energy Districts form a very comprehensive system. PEDs aim to create an emission-neutral, energy self-sufficient and sustainable local economy. However, due to the diversity of urban areas, a holistic approach is needed in the development and implementation of PEDs, which needs to be adjusted to specific local conditions.

2. Methods applied

The information presented in this paper is based on the data from the PED-ID project, primarily on the holistic assessment method and stakeholder involvement process in early development phase of potential PED areas [16].

The method is based on an extensive analysis of documents and studies in the field of energy efficiency. First, research on PEDs was conducted followed by an analysis of technical and technological solutions, methods and tools for energy performance assessment in the sectors relevant to PEDs. Based on the analysis and synthesis of the data, their adaptation to the PED characteristics and identification of challenges and barriers, a proposal for a holistic assessment method for PEDs was developed. The proposal is a first step, which was further consulted with stakeholders for its further optimization. In 2022, the method was applied to pilot projects. The results of the implementation process together with the final adjustment of the method are expected by the end of the project.

3. Results and discussion

This chapter introduces selected outcomes of the PED-ID project. At first, the position of PED holistic assessment within the early stage of the project is defined. Subsequently, the individual assessment phases are presented.

3.1. Early stage of the project

The earlier the stage of a project is, the more it is possible to influence the outcomes. With a comprehensive and multi-layered project such as PED, involving many different stakeholders [17], cutting edge technologies and with a lifespan of decades, the importance of early stage preparation cannot be underestimated.

The PED assessment method basically represents a feasibility study, which is elaborated in a greater detail. Two directions meet here – the feasibility study should not be too complicated as its aim is to say whether to implement the project or not. On the other hand, the assessment of PEDs requires a large amount of information and quite a lot of details, increasing the complexity of the processing and assessment. However, it is possible to perform certain simplifications and aggregations or to use guide values which are then specified in the detailed design, thus reducing the amount of data needed.

PEDs differ in detail. The specific solution depends on local conditions. They nonetheless share some common features – excellent local availability of renewable energy sources, high awareness and engagement of local citizens and wider community, financial support and the method of initiation.

3.2. PED Inception

When it comes to the implementation of Positive Energy districts, it is necessary to consider 4 main topics – Motivation, Barriers & challenges, Costs and Risks. The last two topics consist in a holistic assessment dealing with economical, technical, environmental, social and political/legal aspects of PED implementation, as described in Figure 1. These must be considered and assessed together as they are interconnected and intertwined in many cases, and they affect one another.

3.3. Holistic assessment

Holistic assessment of the Positive Energy Districts implementation consists of several key steps, as shown in Figure 2. First, there is a preselection of the area, where the PED in question could possibly be implemented. For this area, the data have to be collected on the basis of which the technical and technological solutions can be selected. The assessment of potential solutions leads to the development of possible implementation scenarios. The scenarios are assessed on

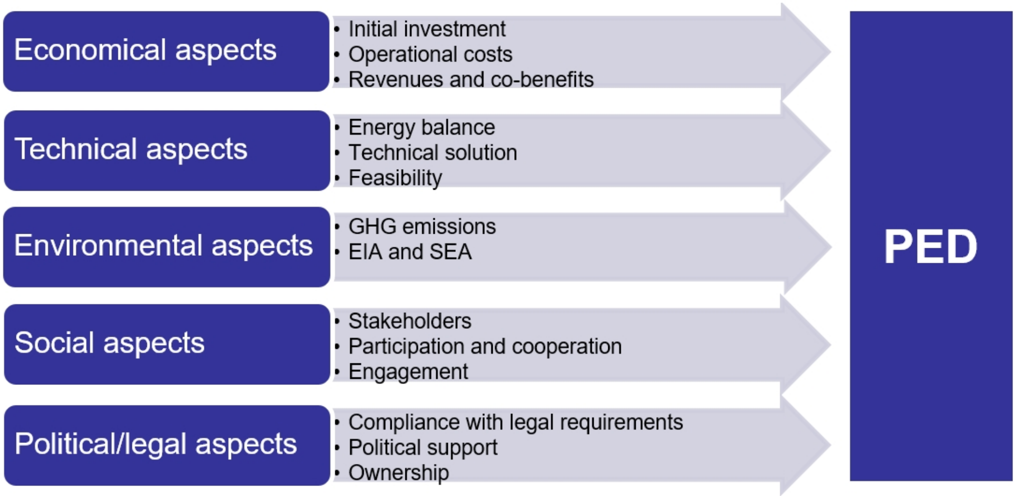

FIGURE 1. Five main aspects of PED holistic assessment.

FIGURE 2. Key steps in PED holistic assessment.

the basis of indicators and benchmarks and then the final solution with the final area is selected.

3.3.1. Pre-selection of the area

The basis of the Positive Energy Districts is formed by the initial idea of their development which is followed by a core notion of the area where the Positive Energy District could be implemented. A Positive Energy District can be part of both rural and urban infrastructure. There are three options for pre-selecting the area type [11]. PEDs can be built as a new greenfield district, implemented into an extension of an existing urban area as a combination of old (renovated) and new buildings, or rebuilt from an existing urban area through deep renovation. Within the third option, the renovation level together with the renewable energy production must balance the final energy consumption of the area.

All in all, greenfield development is the easiest way to create PEDs, while utilization of existing urban areas is the most difficult one. New buildings (districts) can be built as energy efficient as possible. On the other hand, given the average age of the building stock in Europe, most of the buildings have to undergo deep renovation in order to comply with increasingly stringent climate policies [3]. PEDs in built-up areas therefore represent a significant potential to boost the renovation rate along with new renewable energy capacities.

When selecting an (preliminary) area for implementation of Positive Energy Districts, the boundaries of the area must be determined and the following points must be considered:

- system, technical, topographic and geographical boundaries;
- objects to be included in the PED area – built-up area and non-urban area – general identification of objects and infrastructure for disposal;
- the scope of PED in terms of feasibility – considering the size of the area;
- compactness of the PED area – should be as compact as possible as it is easier for the overall assessment and ongoing management, although it is possible to involve more separated or distance areas as well (especially for the renewable energy sources utilization). However, the fragmentation of the PED area can cause problems when there are changes in its surroundings;
- Site specificity – adaptation to the specific conditions of the area.

Positive Energy Districts should ideally form a coherent area within of which all relevant parameters can be evaluated. This area cannot be selected immediately without prior analysis as it may not be entirely clear where the PED will be implemented. First, it is necessary to identify the potential of the area, i.e., its possibilities, barriers and limits (data collection). Then, a decision on the selection of the final area is made based on individual elements of the area (options available) and in relation to the implementation analysis (what can be achieved after the implementation of the selected measures).

3.3.2. Current situation – data collection

Data collection is one of the crucial steps within the PED preparation as it forms the basis for a holistic PED assessment. It is also one of the most time-consuming steps because usually many data are missing or are not available at the moment. Therefore, a comprehensive survey must be carried out to obtain the data. However, it is often the case that data are not available at the early stage, and then an estimation has to be made based on the available benchmarks and other calculations.

Better quality data facilitates subsequent assessment and design of suitable solutions for PED implementation. However, with larger PED (preliminary) area, the amount of data needed (and obtained) grows significantly, which makes the data processing more demanding. Therefore, data collection efforts must be optimised. Estimates based on similar or grouped parameters can also be used to simplify the process.

It is also appropriate to apply spatial analysis, e.g. [18], which uses geographic information systems (GIS) for data processing. The spatial analysis within PEDs should address the following topics:

- **Buildings** – type of building, ownership, energy consumption and production, building use (load profiles, temperature level, flexibility potential, etc.), technical and technological condition (energy sources – primary heat sources, energy performance, other information).
- **Infrastructure** – current heating and electricity systems, other energy sources, current utilities (heat pipes, MV/LV networks, water mains, sewers), water treatment plants, incinerators.
- **Transport and mobility** – traffic intensity, traffic routes, energy consumption.
- **Other municipal objects** – energy consumption parameters and energy savings potential
- **RES potential** – current production from RES, potential production from RES – water energy (rivers, creeks, reservoirs, ponds, weirs, water canals, irrigation canals), geothermal energy (near-surface geothermal energy potential), wind power, bio power (production of unused biomass in the area or its surroundings, areas suitable for biomass production), solar power (roofs, facades, windows, other – large water bodies, free unused areas, covered parking).
- **Utilization of energy recovery** – waste power (municipal waste, bio-waste and sorted waste – focus on unused biological and "combustible" waste in the area and its surroundings), heat recovery (significant heat sources in the area – not at the level of individual buildings).
- **Greenery potential** – current state (mature free-standing trees, parks, forests, grass areas), unused or underused areas for future potential (flat roofs, parking areas, covered car parks).
- **Restrictions** – heritage protection, urban development plan, other (easements . . .).

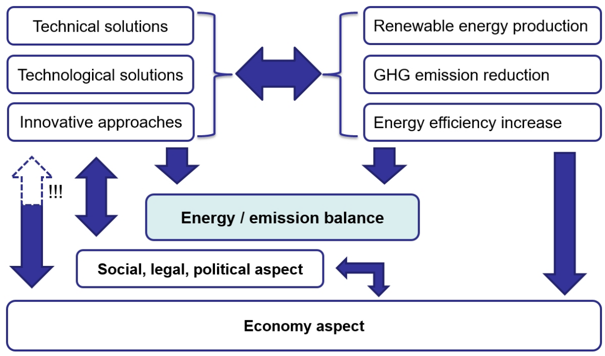

Figure 3. Assessment of key Positive Energy Districts aspects.

Within the data collection, levels of data detail have been set. The basic level is only sufficient to provide a comprehensive overview of the area and for some basic estimations, the advanced level can already be used for most calculations and evaluations. The expert level will enable an accurate assessment of all parameters, but it is also the most difficult to obtain and process all the required information.

3.3.3. Options available

Following the data collection at least at the basic and advanced level, technical and technological solutions for the implementation should be considered. A technical-technological analysis is therefore the first step, followed and accompanied by social, legal and political assessment (see Figure 3).

Within the PEDs, an effort is expected for maximum utilization of the area's potential to reduce the energy consumption, greenhouse gas emissions (GHG), and increase renewable energy production. Technical concepts are then used to develop models and scenarios for PED implementation. Figure 4 shows the technical relations within the Positive Energy Districts, which are further described below.

The issue of energy consumption and its coverage is crucial in the case of PEDs. Positive energy districts are energy self-sufficient locations that provide a secure supply of energy while responding flexibly to changing demand, balancing energy consumption peaks and optimizing energy supply. Surplus production of renewable energy is integrated and supplied to the regional or national energy distribution network [9]. The goal of positive energy districts is to minimize

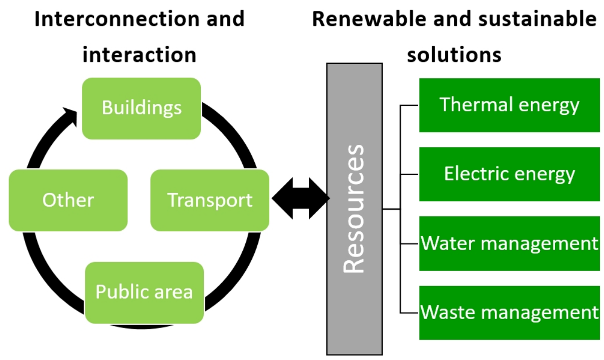

FIGURE 4. Technical relations within Positive Energy Districts.

energy consumption, use highly efficient systems and cover energy consumption with local renewables [19].

The emphasis is placed on energy recovery and exploiting the maximum potential of resources including grey water use and black water management, the issue of waste sorting and waste management. The use of different types of energy creates new links, for example between individual owners of smart grids, owners of buildings and production facilities (photovoltaic panels, cogeneration units) and consumers/users. New links are also emerging at the legislative, economic and social levels.

A key element of energy positive districts is the interconnectedness of buildings that makes the site energy-plus, even if a certain number of buildings do not and cannot meet the plus-energy standard [13]. These include, for example, historic buildings that cannot undergo a deep renovation for historic preservation reasons, or buildings with high energy demands, such as freezers and cold stores.

Within PEDs, the use of smart communication and information technologies as well as energy management itself is essential. Also, each building will need to have its own energy performance target, having its own contribution or roadmap to achieve the district's targets.

Attention should also be paid to district mobility. An optimal mobility solution is the situation when all means of transport in the PED territory use renewables. The promotion of non-motorized modes of transport as well as utilization of smart mobility solutions and vehicle sharing is a matter of course, which can help reduce GHG emission as well as improve quality of life in the PED area.

The technical and technological options within PEDs offer many possibilities that include increase in energy efficiency of buildings, reduction of energy losses in infrastructure, green transport and mobility, maximization of RES potential (including small and micro energy sources), utilization of energy recovery, greenery potential, smart innovations and others. The emphasis should be put on the use of proven technologies as well as on new innovative solutions.

3.3.4. Model and scenarios

The model and scenarios are based on the available technical and technological solutions proposed in the previous phase. The development of the scenarios consists of three main parts:

- **Technical analysis** – calculation of basic technical units, e.g., for energy consumption and production. This should also include an energy balance evaluation of the proposed measures. Energy balance is in fact a comprehensive input/output model that can be conveniently depicted by Sankey diagrams or other specialized calculation tools (e.g., City Energy Analyst or District Energy Concept Adviser . . .). Detailed energy flows may be aggregated to show individual buildings within a PED or different energy uses within buildings or the whole PED.
- **Economic analysis** – use of payback period, discounted payback period, net present value and internal rate of return for both costs and revenues. Basically, the economy is considered in direct relation to investments, energy consumption and production but for larger PEDs it is appropriate to include also various non-energy benefits. The life cycle assessment method should be used as it can assess all costs over the life cycle [20]. However, it needs to be adapted for the whole PED, which can be quite difficult. Also, the preliminary funding options based on stakeholder consultations should be resolved during this phase.
- **Emission analysis** – GHG emission balance calculation, environmental impact assessment.

Within the points mentioned above, the model building scenarios, sectoral scenarios, renewable energy scenarios, and partial and overall energy balances need to be addressed. Together these parts should form the overall scenario. The use of modern evaluation methods, approaches, models and tools is an advantage for successful assessment.

3.3.5. Selecting a solution

Determining the final extent of PEDs depends on how we evaluate the number of inputs. Technical and economic constraints as well as preferences of a wide range of stakeholders must be taken into account. Therefore, the decision on the PED area needs to follow an evaluation of multiple criteria, both quantitative and qualitative (e.g., ensuring the quality of the indoor environment). Combining an energy and financial assessment relying on quantitative methods with stakeholder input proves to be challenging and calls for a holistic approach to support decision making.

Such an approach has been explored in a study [21] which encouraged stakeholders to scrutinize the quantitative modelling results in a structured manner through a Multi-Criteria Decision Analysis (MCDA). MCDA follows the technical analysis presented in the previous sections and introduces additional criteria – economic, social, urban planning-related etc. The aim is to benchmark technical scenarios vis-à-vis more subjective criteria beyond simply achieving PED energy balance or not. The evaluation based on the selected criteria can also be used to compare different PEDs.

4. Conclusions

This paper presents the basis of the holistic assessment methodology for Positive Energy Districts, which can contribute to a greater uptake of PEDs and thus accelerate the transformation of the energy system in Europe to a more efficient and renewable system. Developing PEDs is a way to achieve carbon neutrality in a given area, which is in line with the long-term goals of climate protection and decarbonization of the economy (and cities) by 2050.

However, due to the specific conditions across the municipalities and different areas, there are still barriers to overcome. The first is to clearly define the PED boundaries and the degree of solution complexity, which is crucial within the solution assessment. The interconnectedness of different sectors can be challenging for proper evaluation or application of the life cycle assessment method due to the need for a large amount of data. It is therefore necessary to further develop evaluation procedures or specialized tools for a detailed PED assessment. Although the tools for assessing specific individual areas exist, there is currently a lack of comprehensive evaluation tools.

The second obstacle lies in political and public support, as the PED implementation represents a significant transformation in the social, economic and environmental areas. Stakeholder engagement is essential in the PED development. Therefore, it is necessary to develop and apply a comprehensive (visual) framework (e.g., in the form of an overview maps and schemes [10]) to engage various stakeholders to present them the meaning and goals of the Positive Energy Districts as well as to facilitate communication within the development process and within the presentation of results and benefits to maximize the PED implementation potential.

Obtaining sufficient funds is also a challenge, as it can be expected that PED implementation will have high initial financial costs. Various innovative financing methods will need to be used. On the other hand, it can be assumed that the benefits of PEDs can sufficiently outweigh the initial investment in the long run.

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