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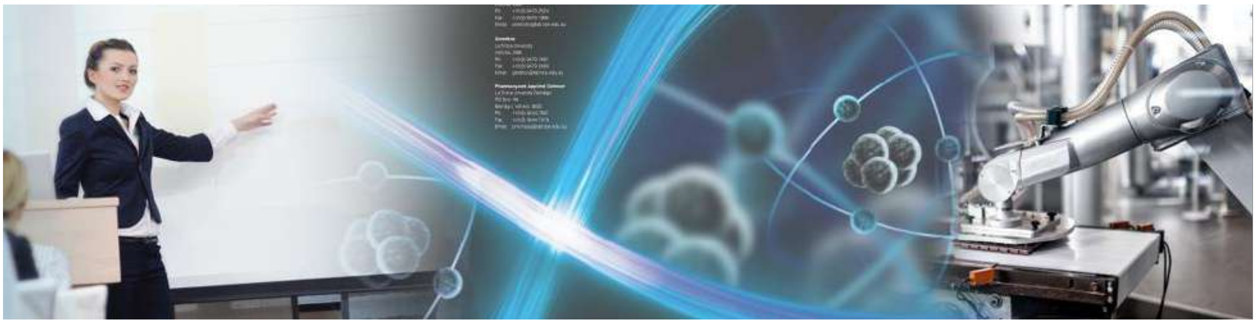

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МЕХАТРОННІ СИСТЕМИ 2024

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System Approach to the Positive Energy District Analysis

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***Abstract*:** Positive Energy Districts (PEDs) are a crucial solution for achieving urban sustainability by ensuring that districts generate more energy than they consume. This paper presents a system approach to analyzing PEDs, focusing on the integration of digitalization, data modeling, and stakeholder collaboration. The study explores whether PEDs should be considered as objects or systems, and how this distinction impacts energy management and stakeholder engagement. A system approach considers the dynamic interactions between buildings, energy systems, and users, enabling optimized energy balance at the district level. The methodology emphasizes the integration of data, simulation, and real-time energy management, supported by collaboration between municipal authorities, energy experts, and residents. The approach was implemented in the "SIMPLY Positive" project, analyzing PEDs across Europe and offering strategies for overcoming technical, economic, and regulatory challenges.

***Keywords*:** Positive Energy District, system, object, attribute, digitalization.

I. Introduction

Positive Energy Districts (PEDs) represent a forward-looking solution to achieving urban sustainability goals by ensuring that districts generate more energy than they consume. This shift is not only crucial for reducing greenhouse gas emissions but also for ensuring energy security in rapidly urbanizing regions. A system approach to the analysis of PEDs is vital to account for the complex interrelations between buildings, energy systems, and environmental factors. This paper explores a structured system methodology for analyzing PEDs, focusing on the integration of digitalization, data modeling, and collaborative frameworks between stakeholders to optimize the energy balance.

PEDs aim to not only balance energy supply and demand at a district level but to create energy-positive environments where surplus energy can be fed into the grid or used for other purposes. The complexity of achieving this requires the integration of advanced technological solutions and a detailed understanding of the energy flows within urban environments. Thus, the need for a system approach to analyzing PEDs is evident as it combines different methods, data sets, and stakeholder roles to ensure successful implementation and optimization.

The relevance of Positive Energy Districts (PEDs) has grown substantially in light of global climate goals and the urgent need to decarbonize urban environments. Recent studies have emphasized PEDs as crucial in urban sustainability, targeting energy balance and local renewable energy generation [1], [2]. However, critical gaps persist in how PEDs are approached in research. Existing models often focus on PEDs as static objects or isolated technological solutions [3], [4], overlooking the systemic interrelations between energy infrastructure, governance structures, and user behavior. This fragmented perspective limits the scalability and efficiency of PEDs in dynamic urban environments. Moreover, while advancements in digitalization and real-time data monitoring have been recognized as key to optimizing energy systems [5], many frameworks still fail to incorporate a truly integrated approach that unites stakeholders and accounts for both temporal and spatial variables [6]. Addressing these research gaps is vital for overcoming the technical, economic, and regulatory barriers that hinder PED implementation and for ensuring their scalability in diverse urban contexts. The lack of such integrated approaches restricts the adaptability of PEDs to the changing demands of urban energy systems.

This paper aims to develop a structured system approach for analyzing PEDs, emphasizing the integration of digitalization, energy modeling, and collaborative stakeholder frameworks. By treating PEDs as dynamic systems rather than static objects, this study seeks to provide a framework methodology to optimize energy performance and resilience, ensuring adaptability to varying urban conditions.

II. Is PED an "Object" or a "System"?

When analyzing a PED, an essential question arises: should we consider it an object or a system? The classification of PEDs as either an object or a system has significant implications for the analysis and stakeholder involvement. While there are numerous approaches to identifying stakeholders, most models highlight the involvement of buildings, energy generation units, residents, and governance structures. The distinction between considering PEDs as objects or systems impacts how these stakeholders are engaged.

If PED is treated as an object, the involvement of governance structures is minimized, and while residents remain external to the analysis, their actions indirectly influence energy flows within the district. On the other hand, when PED is viewed as a system, there is a dynamic interaction between components, including energy users, buildings, and governance structures, which leads to a more holistic understanding of energy management and sustainability.

According to system theory, an object is a distinct entity with clearly defined boundaries, unique identity, state, and behavior [7]. In contrast, a system is a collection of interconnected components working together to achieve a shared goal or perform a specific function [8]. This conceptual difference is critical for how PEDs are modeled and analyzed. Table 1 provides a comparative analysis of the key characteristics of objects and systems [9].

TABLE 1. CHARACTERISTIC FEATURES OF "OBJECT" AND "SYSTEM"

Attribute	Object	System
Definition	A separate entity with a unique identity, state, and behavior	A set of interconnected components working together toward a common goal
Identity	Unique in itself	Determined by the interaction of components (objects)
Purpose	It may have its own goals	Always aimed at achieving a collective goal or function
State	Defined by properties	Described by the state of all components and their interactions
Behavior	Described by actions or methods	Defined by functions and processes performed by components

In the context of PED analysis, this distinction influences the overall approach to energy management. Table 2 presents examples of the attributes of PED as both an object and a system.

TABLE 2. COMPARISON OF ATTRIBUTE CONCEPTS FOR OBJECT AND SYSTEM

Attribute	Object	System
Identity	Defined by physical characteristics and components	Characterized by the interaction among buildings, energy units, residents, and governance
Purpose	To function as a physical space that generates more energy than it consumes	Dynamic, multifaceted, aimed at sustainability, energy efficiency, and resilience
State	Refers to its current physical and energy characteristics	A dynamic measure of its overall performance and operational status
Behavior	Changes in its physical state over time	Encompasses dynamic processes and interactions within the district

Understanding whether PED is an object, or a system has practical implications. For example, treating PED as an object might focus on optimizing individual energy generation units or buildings. Conversely, treating PED as a system encourages an integrated approach, where the interaction between various components (e.g., smart grids, energy storage, and residents' behavior) is key to achieving positive energy goals.

III. SYSTEM APPROACH OVERVIEW

A system approach to PED analysis involves considering all key components within a district, including buildings, energy infrastructure, climate conditions, and user behavior. The analysis should be conducted across various scales, from individual buildings to entire neighborhoods, taking into account both temporal and spatial variables. One of the critical steps in this system approach is identifying the necessary data inputs for modeling energy balances and integrating various data sources.

Data sources required for PED analysis typically include building characteristics, renewable energy generation potential, weather data, and occupancy patterns. The methodology should allow for the collection and integration of real-time and historical data to capture dynamic changes in energy demand and supply. A combination of Geographic Information Systems (GIS), Building Information Modeling (BIM), and energy management platforms can be used to ensure accurate simulation of energy flows within the district.

The proposed system approach also emphasizes the importance of collaborative efforts between district representatives, energy experts, and municipal authorities. This collaboration is essential for the successful collection of data, refinement of energy models, and alignment with district energy goals. By involving multiple stakeholders from the outset, the system approach ensures that PEDs are designed with both technical and social considerations in mind.

IV. METHODOLOGY

The methodological approach to Positive Energy District analysis is based on the systematic integration of data, modeling, and active stakeholder engagement, all of which are essential to achieving sustainable energy balance goals. This study identifies four key stages: data collection and integration, energy balance modeling and simulation, establishing a collaborative stakeholder framework, and leveraging digitalization and real-time data utilization. These stages were chosen because each plays a critical role in building an accurate and effective energy management system at the district level.

1. **Data Collection and Integration**:
   The foundation of the PED analysis system is the integration of multiple datasets that cover general building characteristics (e.g., year of construction, materials, insulation), energy systems (HVAC, renewable sources), and environmental factors (weather patterns, shading, orientation). These datasets are gathered from various sources, including local databases, satellite imagery, and monitoring systems. GIS and BIM platforms play a critical role in managing spatial and structural data, ensuring that every building's energy usage and potential are accurately modeled within the district's energy framework.
2. **Energy Simulation and Modeling**:

The second step in the methodology involves energy simulation, where software tools such as EnergyPlus or TRNSYS are employed to model the energy flows and performance of the district under different scenarios [10]. These models must consider the interactions between buildings, renewable energy installations (solar panels, wind turbines), and the grid. A system approach ensures that the energy balance is calculated not just at the building level but also at the district level, optimizing the overall energy performance.

3. **Collaborative Frameworks**:
   A system approach to PED analysis requires the active involvement of district stakeholders, including municipal representatives, energy providers, and building managers. Collaboration is key in obtaining accurate data, securing buy-in for energy-saving initiatives, and aligning PED goals with broader urban sustainability objectives. In regions with low digitalization, district representatives play a larger role in manually collecting data and providing insights into local energy use patterns.
4. **Digitalization and Real-Time Data Utilization**:
   In highly digitalized districts, real-time data from smart meters, sensors, and energy management systems can be used to continuously monitor and adjust energy use in response to changing conditions. This level of digitalization allows for dynamic energy management, where systems can respond to fluctuations in demand or renewable energy supply in real-time.

V. Results

The described systematic approach was realized in the research project "SIMPLY Positive" [11], which encompasses the characterization and analyses of four focus districts: Großschönau (Austria), a district in Settimo Torinese (Italy), a district in Resita (Romania), and the central part of the Amsterdam (Netherlands).

The project emphasizes a systemic approach, combining urban planning, energy technologies, and social engagement to ensure that districts not only achieve energy positivity but also contribute to overall urban sustainability. One of the key outcomes of the project is the identification of strategies to overcome technical, economic, and regulatory barriers, fostering collaboration between municipalities, industry, and citizens. The project also provides tools and guidelines for cities to plan and implement PEDs, helping accelerate the transition towards climate-neutral cities. By applying a holistic framework, Simply Positive addresses challenges such as grid integration, local energy storage, and dynamic energy balancing, ensuring that PEDs can operate efficiently within broader urban and regional energy networks. This systemic approach highlights the importance of cooperation among stakeholders and the need for adaptable, scalable solutions that can be customized to different urban contexts.

VI. Conclusion

A system approach to Positive Energy District analysis integrates data, digital tools, stakeholder collaboration, and scenario planning to create sustainable, energy-positive urban environments. By combining advanced digitalization with structured methodologies for data collection, simulation, and stakeholder engagement, this approach ensures that PEDs can be optimized for energy efficiency while remaining adaptable to future challenges. The distinction between PED as an object or a system plays a significant role in determining the complexity and scope of the analysis. The system approach outlined in this paper provides a robust framework for achieving sustainability goals in urban energy management, ensuring that PEDs not only meet today's energy needs but are also prepared for the challenges of tomorrow.

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