Research Paper

Structuring the Complexity of Positive Energy District with cognitive maps

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Abstract

The concept of a Positive Energy District (PED) has emerged as a promising solution to mitigate the environmental impact of urbanization. PEDs aim to generate more energy than they consume by integrating renewable energy sources, energy-efficient buildings, and sustainable transportation systems. However, designing and implementing a PED is a complex and multi-dimensional task that involves various stakeholders and requires a holistic approach. This paper proposes the use of cognitive maps and stakeholders' analysis to structure the complexity of PEDs. Cognitive maps are a visual representation of the cause-and-effect relationships among the elements of a system. In the context of PEDs, cognitive maps can help to identify the key factors that influence the energy balance of the district. The construction of cognitive maps involves the participation of stakeholders, who provide their expertise and knowledge about the system. By integrating the different perspectives of stakeholders, cognitive maps can offer a comprehensive view of the PED. The use of cognitive maps in PED design can help create more effective positive energy districts. Cognitive maps can help identify available energy sources, energy consumers, and potential renewable energy producers, as well as identify areas of the city with greater opportunities for the installation of renewable energy generation facilities. In addition, cognitive maps can facilitate communication among the various stakeholders involved in the creation of PEDs, thereby improving collaboration and the effectiveness of the project.

Keywords

Cognitive maps; Positive Energy District (PED); Stakeholders Analysis; Decision Support System(DSS), Fuzzy cognitive maps.

1. Introduction

The European Union has placed the reduction of CO_2 emissions on cities and their related systems. Cities account for over 50% of the world's population, 80 % of global GDP, two-thirds of global energy consumption, and over 70% of global annual carbon emissions. These factors are expected to increase significantly in the coming decades: it is predicted that by 2050 more than 70% of the world's population will live in cities, resulting in a massive growth in demand for urban energy infrastructure. Climate action in cities is essential to achieve ambitious net-zero emission targets. In this respect, it is well known that in the coming years, urban development will have to shift from simple building solutions to positive energy districts and neighborhoods (Becchio *et al.*, 2020). With the new Horizon Europe research and innovation plan [2], Europe aims to strongly address several global challenges affecting our cities and society: health and safety, digitization, energy, and climate change in the first place (Guarino *et al.*, 2022). PEDs fall into this category. In recent years, to support the urban energy transition, the concept has become even more ambitious, moving from high-efficiency to zero-emission buildings. Subsequently, by including energy sharing, waste heat recovery, electric mobility, and energy storage, the goal of a broad implementation of zero-emission neighborhoods has been achieved, or even better PEDs are envisaged (Guarino *et al.*, 2022). In this regard, we introduce the concept of complexity, applied to PEDs and their development at the urban level, by analyzing the stakeholders involved and identifying the structure of the process and how it is articulated in order through cognitive maps.

2. Context of the research

2.1. Features of PED

Research all around the world is still struggling to find a unique definition for PEDs. From an energy-focused perspective, a PED is seen as an energy self-sufficient and carbon-neutral urban district. Indeed, positive energy means that energy districts also play an important role in producing excess energy using renewable energy sources and feeding it back into the grid (Bossi, Gollner, and Theierling, 2020). However, widening the perspective, it is expected that PEDs will increase the quality of life in European cities, help achieve the COP21 goals, and improve European capabilities and knowledge to become a global model (Derkenbaeva *et al.*, 2022). Moreover, considering the keen interest of the European Commission to deliver at least 100 PEDs by 2050 and the current situation of European cities (IEA, 2020), it is necessary to address this concept not only for new areas of urban development and the construction of new buildings and neighborhoods but especially for the redevelopment of the existing building stock (Derkenbaeva *et al.*, 2022). The discussion on how and where to define the boundaries of these entities is still open and conclusions may differ depending on whether one considers physical limits and management aspects or those related to the overall energy balance and energy carriers, ranging therefore from local to regional scale (Bossi, Gollner and Theierling, 2020; Niu and Zhang, 2023). The discussion also often starts from the local dimension of city blocks, up to the urban dimension. In this regard, some interesting research on existing tools to support decision-making toward climate neutrality in cities and districts has been already carried out (Suppa, Cavana, and Binda, 2022). In an attempt for extreme simplification, it can be said that PEDs must strike an optimal balance between energy efficiency, energy flexibility, and local energy production (European Commission, 2022) in turn also achieving integrated sustainability based on environmental, economic, and social features.

2.2. Stakeholders involved.

For a Positive Energy District (PED) several stakeholders such as cities and public bodies, industry and business, research and academia, citizens and civic society, private and professional stakeholders, and citizens play a central role in the energy transition. Satisfying outcomes of Positive Energy Buildings/Districts requires the involvement of a wide range of different stakeholders right from the beginning. Therefore, increasing the knowledge of PEB, public communication, dissemination and public engagement among the public is vital.

2.3. Concept of complexity

The term “complexity” used by academics is a narrower concept than is employed by practitioners; in fact, certain context-related aspects that practitioners point to as being complex are identified by academics as complicated (Baccarini, 1996). This is because theoretical complexity focuses on emergence, uncertainty, nonlinearity, and interdependence among the elements present in a project. Purposes of this case study, we do not distinguish between the terms “complex” and “complicated” – following the common usage employed by several authors (Volpe, 2015). Complexity will impact project goals and objectives, project planning and organization as well as staff recruitment requirements. (González-Varona *et al.*, 2023)indicate that complexity in the project context has become the focus of attention for several reasons: (a) it impacts the way the project is planned, executed, and controlled; (b) it can hinder the identification of goals and objectives; (c) it also influences how the project is organized as well as the skills required by workers; (d) it can impact project objectives (scope, time, cost, risks, etc.). According to (Baccarini, 1996), one definition of project complexity is that it consists "of many varied interrelated parts". He advocated implementing it in terms of the differentiation and interdependency of varied elements (González-Varona *et al.*, 2023). In their paper (Baccarini, 1996), identified two dimensions of project complexity: structural complexity and uncertainty. In addition, structural complexity has two sub-dimensions: the number and interdependence of project elements, such as tasks, specialists, and components. He also proposed two sub-dimensions of the uncertainty dimension: uncertainty in goals and means(Baccarini, 1996). Structural complexity is the easiest for practitioners and researchers to identify and increases with size, variety, breadth of scope, level of interdependence between people or tasks, pace, or variety of work to be done. Interdependence between people or tasks, pace, or variety of work to be done, number of locations and time slots, work to be done, the number of locations and time zones. The existence of strict deadlines, e.g., closing of a construction site, or opening of an infrastructure, is a source of complexity because it leads to an increase in the pace of work and stress of the people involved (Geraldi and Söderlund, 2018).

3. Methodology

Cognitive maps are a visual representation of the cause-and-effect relationships among the elements of a system(Kok, 2009). Cognitive maps have been used widely in political science, urban management, organizational analysis, and decision-making(Kosko, 1986). In political science and urban management, the cognitive map approach has been to discover the belief systems of political leaders and policymakers. In organizational analysis and decision-making, cognitive maps have been used mainly to analyze the organizational decision-making process(Papageorgiou *et al.*, 2017).

3.1 Cognitive Maps

Cognitive maps usually consist of variables and causal relations among them. In the cognitive map arrows interconnect variables. The direction of arrows means the direction of causal influence. The signs attached to the head of arrows indicate the polarity of the causal relations. If two variables are connected by an arrow causes an increase/decrease in the variable at the head of the arrow. With the variables and causal relations embedded in the cognitive map, one can see the emergent perceptual structure. The perceptual structure can then be analyzed to identify the perceptual bases of policy or urban measures adopted by policy-urban actors. Policymakers or urban managers define policy problems and chalk out measures based on their perception of the real world. In this respect, cognitive maps are directly related to the cognitive aspect of policymaking.

3.2 Cognitive Maps as a tool for structuring the complexity of a PED.

In the context of PEDs, cognitive maps can help to identify the key factors that influence the energy balance of the district. The construction of cognitive maps involves the participation of stakeholders, who provide their expertise and knowledge about the system. By integrating the different perspectives of stakeholders, cognitive maps can offer a comprehensive view of the PED.

4. Results and discussion

4.1 Stakeholders' Analysis

The relevance of different stakeholders involved in the project gives a clear idea of is very complex the question. As we can see in (Figure 1) the players are divided into the public and private spheres, which have power and influence that varies depending on what stage of the project you are in. Below based on the typical construction site phases I propose an analysis of the different stakeholders involved in the different project phases: Urban planning phase, Integrated build design process, Construction phase and its management, Operation phase, and Building operation process. For our context, the Urban planning phase is more interesting and more important because, by the literature review, we had understand that is the more complex part of the process(De Sousa *et al.*, no date; Mosannenzadeh *et al.*, 2017; Bottero *et al.*, 2021; Dell'Anna *et al.*, 2023).

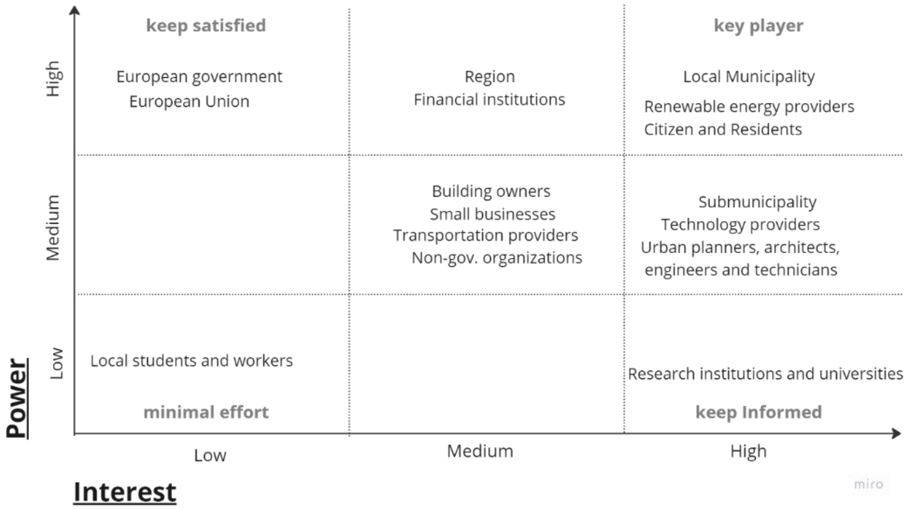

Figure 1: Stakeholders analysis in the power and interest grid used to identify key stakeholders, and their influence in terms of power and interest. Source: drawn by the authors.

The urban planning phase is composed of citizens, citizen groups, NGOs, authorities, municipalities, tenants, owners, Economic Chambers, Labour Chambers, construction companies, politicians, utilities urban planning departments, architects and energy planners, engineers and designers of energy companies, developers, consultants, land owners, water companies, environmental protection agencies as well as building owners and users.

4.2. Cognitive map of a PED: structuring the complexity

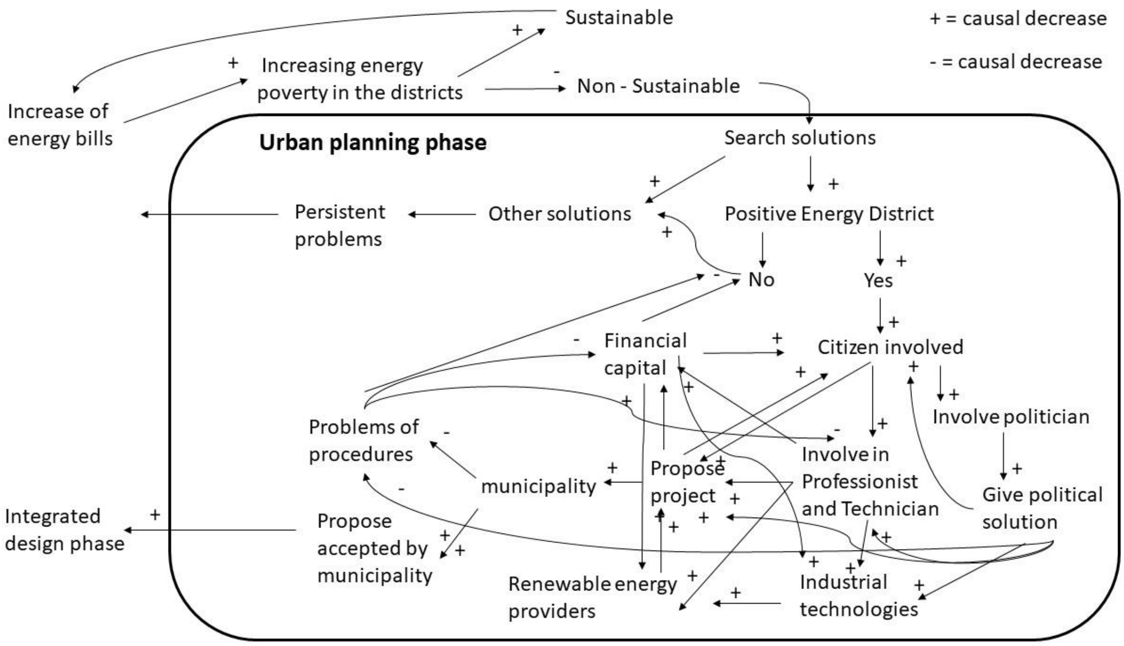

Figure 2: Cognitive map of a Positive Energy District in the Urban planning phase

As can be seen in figure 2, analyzing the main actions that occur in the spatial and urban planning phase involving stakeholders, one can realize how easy it is to see the relationships and their negative or positive causality with cognitive maps. We would have had to write pages and pages just to explain how complex the relationship between citizens, administrations, and professionals involved is, whereas with cognitive maps it is possible to clearly represent how much impact the hierarchy of actions that occur in a multistakeholder decision-making process has. With this scheme, it becomes apparent that the financial aspect, especially in a multi-stakeholder context, is the predominant one and has the capacity to block the development of PED.

5. Conclusion

About the cognitive maps, we can say that is one the best solutions useful for analyzing the complexity from a multistakeholder perspective. Local circumstances and practices also vary, depending on whether the related operations (e.g. energy, water) are private companies or municipally owned ones. In addition, land ownership has a great impact. Another factor influencing stakeholder composition is whether the project is a new construction or the refurbishment of an old building. The involvement of appropriate moderators or mediators to bring about consensus solutions. Also, international collaboration with other cities through city networks or cooperation initiatives would add benefits. A collaborative governance model is imperative to connect different stakeholders and align their interests and priorities. In such a model, an establishment of shared values and a common vision among stakeholders could be achieved, aiming at finding the synergies and unlocking the co-benefits of multiple stakeholders. For the success of PEDs, it is of great importance to ensure the commitment of the people through an open process and broad stakeholder engagement when developing a cities or region's strategy. Further officials should raise the awareness of all stakeholders and educate them on all energy efficiency. Municipalities can support building designers from the beginning through other means than mandating or encouraging PEDs in urban plans: providing practical guidance, initiating discussions, organizing energy nights, bringing stakeholders together, offering one-stop-shop models for project owners and construction firms to launch awareness-raising campaigns, and disseminate knowledge.

For the development of PED, at the national level, it is important to define the general framework and minimum standards. As the general framework is set there, the government must be active in this. In addition to legislating, the national and regional governments have the main financial resources to support the massive deployment of PEBs. Therefore, national-level financing and incentivization schemes play a vital role in encouraging energy-efficient (even positive energy) buildings and districts.

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