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IMPLEMENTATION OF POSITIVE ENERGY DISTRICT CONCEPTS AND ENERGY MASTER PLANS FOR DECARBONIZATION OF DISTRICTS

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Abstract. In order to achieve a holistic approach to community energy planning for neighbourhoods and districts, it is crucial to provide planners, decision makers, and stakeholders with the necessary methods and instruments. However, there is a research gap in terms of planning and implementation strategies and models. To address this gap, our research used literature and document analysis as well as qualitative interviews to identify implementation models and energy supply options for Positive Energy Districts (PEDs), and to determine which market actors are needed for PEDs. We also discussed the consequences of scaling up the PED concept.

Our analysis highlights the importance of integrated energy planning, which is critical for reducing energy consumption, securing the location of energy infrastructure (generation, distribution, storage), and achieving long-term sustainable development and climate neutrality. Therefore, understanding the different dimensions of sustainable development in combination with energy supply and consumption is more important than ever for planning and realizing settlements.

Keywords: Positive energy districts (PED), energy master planning (EMP), implementation plans.

1. Introduction

As policy makers set increasingly ambitious energy-related building and community requirements and standards based on the Sustainable Development Goals of the United Nations (UN) [1], climate change presents challenges to achieving these goals. The concept of Energy Master Planning (EMP) – a roadmap for planning energy efficiency and grid optimization – can facilitate better planning and implementation to meet these goals. Stakeholders at all levels, from nations to communities, face the challenge of reducing greenhouse gas emissions to meet the goals of the Paris Agreement.

A promising approach to reducing energy demand, increasing efficiency, and lowering the carbon footprint is through bottom-up approaches to energy planning at the neighborhood level [2]. Cities and communities play a crucial role in achieving global sustainability goals as they are the main source of emissions and have the power to implement global goals at the local level while also considering site-specific demands and settings.

1.1. Energy master planning (EMP)

Holistic solutions for meeting the heating, cooling, and power needs of energy communities on a district scale can result in significant energy savings, reduced emissions, and increased energy security. While there is considerable literature available on energy master planning (EMP) at the neighborhood and district level, including guidance and assessment tools for campuses [3], existing guidance and tools do not fully address the challenges of EMP.

Energy planning involves determining the optimal mix of energy sources to meet a given energy demand, spanning over the lifetime of a neighborhood. EMP comprises six steps, as illustrated in Figure 1, starting from goal-setting during the early strategic long-term planning phase and continuing through the operational phase characterized by measurement and verification activities. EMP focuses on the tactical mid-term planning and implementation phase, encompassing assessment, scenario building, planning, and implementation [4].

The multi-scale aspect (temporal and geographical) of a holistic approach to neighborhood and district energy planning poses major difficulties, as it requires consideration of both quantitative (economic, technical) and qualitative (environmental impact, social criteria) criteria [5]. To apply this approach and provide necessary methods and instruments for master planners, decision makers, and stakeholders, it is crucial to identify and frame the constraints that bound the options towards an optimized energy master planning solution [6].

Existing guidance on master planning emphasizes the critical first step of identifying and establishing project goals [7]. Sharp et al. (2020) analyzed EMP in several countries and identified the importance of a thorough understanding of local and regional goals and constraints in achieving successful EMP [6]. As

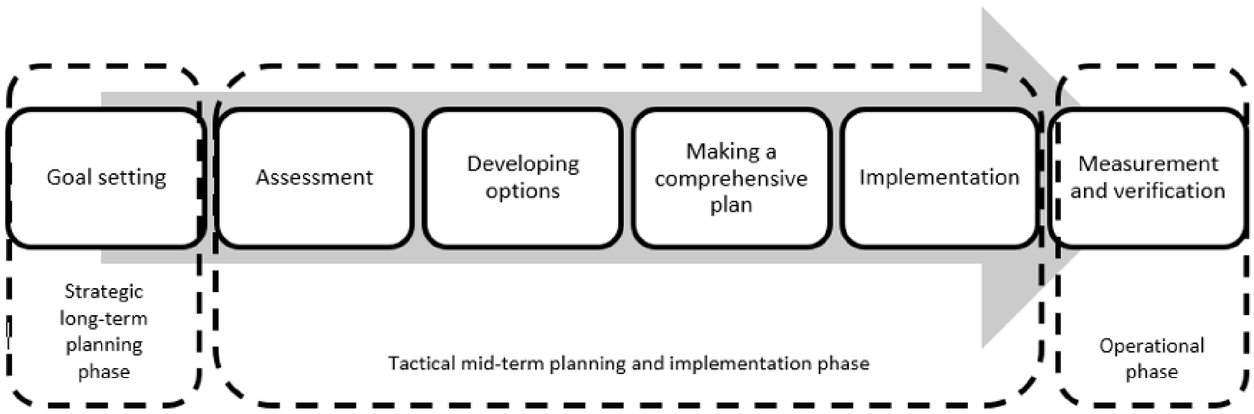

Figure 1. Energy Master Planning process [4].

more countries aim to improve the efficiency, environmental impact, and resilience of buildings and neighborhoods, early and comprehensive energy master planning on the neighborhood and district level becomes increasingly important [4].

However, various constraints can hinder the full potential of decarbonization. In Haase and Baer (2021), we identified differences in the implementation of positive energy districts (PEDs) in two distinct cases of decarbonized district solutions, and noted a research gap in planning and implementation strategies and models [8].

1.2. Positive energy districts and EMP

The Positive Energy District (PED) concept is rapidly evolving as an integral part of the Strategic Energy Transition (SET) plan for European Union member states. While a precise definition is still emerging, the idea of creating energy production plants in built environments that generate more energy than the surrounding neighbourhood consumes is a promising way to advance the clean energy transition and achieve climate neutrality through a holistic approach to reducing energy demand and promoting renewable energy. Positive Energy Districts are based on the fundamental principle of creating an area capable of producing more energy than it consumes over the course of a year, with the flexibility to adapt to changes in the energy market [9]. The Joint Programme of Urban Europe envisions Positive Energy Districts as "energy-efficient and energy-flexible urban areas or groups of connected buildings that produce net-zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. Achieving these goals requires integrating different systems and infrastructures, fostering interaction between buildings, users, and regional energy, mobility, and ICT systems, and ensuring the energy supply while promoting social, economic, and environmental sustainability for all stakeholders" [10].

In this sense, the PED provides a natural area of the application of EMP concepts. The process manager for EMP works with municipal departments and external stakeholders to implement and monitor measures in the plans, evaluate results, and communicate feedback. It is important to note that a local energy planning process should be adapted to suit the context and needs of the local community. The local utility is naturally a major player as it traditionally managed the local energy grids. And the process manager has to understand the different implementation models for local energy supply and how they interact with the PED goal. It lacks a constraints analysis to clearly identify energy supply options for PEDs.

1.3. Issues in energy supply (utility model)

In recent years the understanding of the role of utilities has changed dramatically. While in the early 1980s utilities were comparably simple heating and cooling supply schemes in existing or new built building clusters (utility services or energy supply contracting) which included supply components on the supply side, and never considered to refurbish the user side. The supply schemes usually had a highly efficient supply technology such as Cooling and Heating Plants (CHP), gas-, oil- or coal fired and/or biomass supply boilers for hot water or steam and electricity. Each of these efficient technologies was backed up by "normal" heating boilers (hot water or steam). The power was usually fed into the power grid (no direct retail to end users) while the heating was distributed by hot water or steam grids to the end users. End users paid a heating price per kWh consumed and a heating load price covering investment costs (at least partially). The end users have been responsible for the demand side: the house station often equipped with a heat exchanger or a steam or hot water exchanger, a domestic hot-water station and a control system including a heating meter for the measurement of the consumed heating energy.

With an increasing number of requirements on the national level such as primary or end energy targets for buildings, regulation to foster renewables, partly and temporarily overloaded grids have added multiple complexities which cannot be handled by the utility model alone. In the EU carbon footprint targets are in place and primary energy (PE) targets for buildings. The latter PE targets can in most cases only be responded positively by combining demand and supply side measures. This means, that a building which is connected to a supply grid with a biomass boiler (low primary energy factor) can even reduce his efforts on the level of the building insulation to achieve the required PE target. This option however is shortsighted, as these buildings will consume large amount of valuable biomass and has consequences for a larger rollout of the concept which is still not well understood.

2. Research question

Building on the identified research gaps we ask three research questions:

(i) What are the characteristics of implementation models towards Positive Energy Districts (PEDs)?

(ii) Which energy supply options exist and which are needed for PEDs?

(iii) What are the consequences for a larger rollout of the concept?

3. Method

We describe the characteristics of models for the energy supply towards Positive Energy Districts (PEDs) by analysing different recent developments of PEDs. The work is based on literature and document analysis adapted from the iterative model proposed by Bocken et al. [11]. In addition, we conducted 34 interviews with focus groups in four different European countries to understand the role of the different stakeholders. The method was based on structured interviews with different stakeholders from practice, policy and technology provider background.

4. Results

In today's resource-constrained environment, and with the emergence of "Positive Energy Districts" concepts, local stakeholders are looking for creative ways to drive additional efficiencies in energy use and reduce associated costs. However, large, coordinated efforts are needed to gain synergy between different energy initiatives and future planned projects to maximize energy use and cost reduction.

4.1. Characteristics of new energy supply concepts

The transformation of today's electric power sector to a more sustainable energy production based on renewable energies will change the structure of the industry [12]. In this transformation towards a smart energy system interaction between sectors and technologies the main stakeholders as listed above (energy service providers; utilities) will face new challenges in their traditional way of doing business. Therefore, adapting their business models to remain competitive is seen as an important step. When looking at the business model literature reveals that there exist basically two possibilities:

(i) Ownership of renewable energy assets [13]

(ii) Utilities need to develop from commodity providers to energy service providers [14, 15].

According to this idea utilities should evolve to comprehensive energy-solutions providers for residential and commercial customers to create new sources of revenues.

In the energy sector a few characteristics to implement new energy supply concepts are worth noting (see also [11]):

- **Highly resilient community** Energy system considering buildings, supply, distribution and storage as basic components which have to match together.
- **Target value approach** Primary energy, carbon footprint target-oriented system approach for the complete community considering incoming and outgoing energy supply streams
- **Understanding each building as a prosumer** each building is understood to consume, produce and store energy: PV on the roof, detached CHPs in complex grid hub structures may be producing energy.
- **Sectoral coupling** Power produced and not consumed onsite can be attractive to be stored to operate e-vehicle fleets on campuses or delivery services and likewise to match mobility and energy systems.
- **Consequent use of transfer energy systems** The supply will consider supply systems which are able to use multiple fuels in the nearer future. One of the important components is CHP or fuel cell which are market ready usually operated with natural gas but will have to be transferred to system immanent synthesized or PtF based fuels such as Hydrogen or synth gas.
- **Grid-friendly incentivized business model** Stabile mid and high-tension systems require grid-friendly local communities which means that the input from the community into the grid and vice versa needs to be controlled to keep loads and frequencies balanced in the regional and national grids. This requires business models which provide direct (subsidies, feed in tariffs) and indirect (legal barriers) incentives for ESCos and utilities to operate the energy system grid friendly.
- **No more supply-only-concepts** Buildings are actively integrated in the energy concept following the idea, that the resilience and dependence of imported fuels (on national but also local level of the community) can only be reduced if building follow challenging building standards even far beyond the national minimum requirements. Not touching buildings in an EMP business model is obsolete

from the macro- and microeconomic standpoint and also from the position of preserving the asset values in the future.

- **Innovative instant trade energy distribution systems** Besides the known power, heating, cooling grids in communities it is necessary to provide open direct marketing structures for locally produced power. Vienna utilities are one of the front runners to use block chain technologies to distribute energy packages from house to house and apartment to apartment without involving local grid resources which provides first experience-based input [16]. In the US, the Brooklyn blockchain system has been identified as one of leading instant trade systems [17].
- **Remuneration systems** The remuneration system is designed in a way that incentivizes the energy service provider to provide the energy in the simplest way to the end consumer, to focus on the energy target for the single building and the complete community and to integrate and distribute normal supply solutions with detached building based renewable power production in a way which is "grid-friendly" at the time given. Also add-ons such as coupling with the mobility sector, by providing quick charging stations for e-mobility are remunerated separately. The utility or ESCo respectively does not increase the margin by selling more energy to the costumer but by keeping the overall target and the energy mix matching with this demand.
- **User-centric** Besides the before-mentioned remuneration systems and missing performance monitoring, a key factor is the user behavior: any kind of energetic measure can be countered by obvious or unknowingly misconduct of the users. Socio-economic analysis is still not very common in energy science but the few interviews with users conducted show that users are not capable to operate their apartments sufficiently. This is not only the case for end users in their private homes but also for skilled staff in hospitals and data centers. The assumption "building automation will fix it" turns out not to work. This sets the requirement for the new implementation models to provide simple to operate, intuitive end users hand holds to operate and also control the consumption directly. A few examples in modern housing complexes exist already providing end users, both private and professionals simple app based smart building tools to control the power and heating/cooling consumption in their buildings.

4.2. Emerging models

Energy supply for the buildings stands for the supply of both electric and thermal energy. Most of the energy use of buildings is related to space heating (and cooling), therefore the needed thermal energy can be extracted directly from a district heating (and cooling) network (DH(C)) or provided by a heat pump (HP) or even directly converted using electric heaters/coolers. Energy supply companies are responsible for supplying buildings and district with their needs in terms of electric and thermal energy, however still most of the provided energy is mostly electric energy.

Classical electricity supply utilities are suffering nowadays from what is called the "spiral death", meaning a strong decrease in the number of energy utility customers. The quitting customers are served by new market actors operating with new business models, centered on renewable energy and energy efficiency technologies. The electric energy system contains the physical infrastructure (generation, transport, distribution and use together with their components) and an organized electricity market based on different marketplaces. The market consists mainly of the following actors [18]:

- Electricity generator, who generates electricity and sell it to the energy suppliers.
- Electricity suppliers, who purchase the electricity from the generators and sell it to consumers.
- Transmission System Operators (TSO), who are responsible for transporting electricity for long distance and ensuring grid stability and reliability by real time dispatch.
- Distribution Network Operators (DSO), who are responsible for delivering electricity to the consumers and measuring the consumption.
- Regulators, who set the market rules and oversee the functioning of the market.

In the EU countries some energy supply companies operate transnationally, however still a large part of the worlds' electric energy supply is either based on fossil fuels like coal, gas, and oil or nuclear energy.

The production, transmission and distribution of electricity accounts for the largest share of the world's anthropogenic greenhouse-gas emissions, while the use of emission-free nuclear energy comprises serious security risks and unsolved problems of hazardous waste, therefore the role of renewable energies as the most important instrument to mitigate climate change and reduce negative effects of energy production is increasing. Despite the fact that utilities (with national or transnational activities) still have a dominant position they are confronted with disruptions of their current way of doing business and face the challenge to develop new business models for electricity generation from distributed and highly intermittent renewable sources. Electrical energy sector is undergoing a continuous process of transformation where a fundamental shift of energy supply towards renewable, CO_2 neutral energies is taking place, together with a decentralization and digitalization. The classical structure of the electrical energy industry that emerged after the liberalization of the electricity and gas markets in Europe including established business models, is subject to disruptive and massive changes.

4.3. The role of the public

The majority of implementation models for PEDs involve the public sector to some degree, and in many cases the public sector has partial or full ownership of the project. The degree to which the public sector is involved is determined in part by how much it may wish to steer a district energy project towards a variety of local objectives.

PED implementation models that are replicable and scalable both technically and financially at the neighborhood, city and national level are key to the acceleration of district energy production?

(1.) The "WHOLLY PUBLIC" implementation model is the most common globally. The public sector, in its role as local authority or public utility, has full ownership of the system, which allows it to have complete control of the project and makes it possible to deliver broader social objectives, such as environmental outcomes and the alleviation of fuel poverty through tariff control.

(2.) Implementation strategies that focus on "HYBRID PUBLIC AND PRIVATE" energy supply have a rate of return that will attract the private sector, but the public sector is still willing to invest in the project and retain some control. These models can include:

   (a) a public and private joint venture where investment is provided by both parties that are creating a district energy company, or where the public and private sector finance different assets in the district energy system (e.g. production of heat/cooling versus transmission and distribution);

   (b) a concession contract where the public sector is involved in the design and development of a project, which is then developed, financed and operated by the private sector, and the city usually has the option to buy back the project in the future; and

   (c) a community-owned not-for-profit or cooperative business model where a municipality can establish a district energy system as a mutual, community-owned not-for-profit or cooperative. In this model, the local authority takes on a lot of risk initially in development and if it underwrites any finance to the project.

(3.) "PRIVATE" implementation models are pursued where there is a high rate of return for the private sector and require limited public sector support. They are developed as a wholly privately owned Special Purpose Vehicle but may benefit from guaranteed demand from the public sector or a subsidy or local incentives. Few cases are developing "private" models as the majority district energy model, also because there are a number of barriers to be lifted.

5. Discussion

5.1. Implementation models

The electric power sector's value streams are heavily influenced by the regulatory and policy frameworks that govern it. Electricity distribution companies' revenues are regulated by government-appointed regulatory commissions, which can impact the viability of distributed renewable energy businesses (DERs) in distribution networks. Wholesale electricity markets are subject to market rules established by central authorities like Independent System Operators (ISOs) or Regional Transmission Operators (RTOs), which are monitored and regulated by Energy Regulatory Commissions (FERC). DER business models looking to sell services in these markets must comply with established market rules and regulations. Furthermore, the electric power sector is subject to significant national and EU policy support, including subsidies and favorable rules for technologies like solar-based energy generation. Understanding these policy and regulatory interdependencies is critical for sustainable business development.

Community ownership is often seen as a source of income that can be locally controlled, making these investments more socially acceptable as they help develop local supply ownership and prevent value leakage from the local economy. Financing renewable energy technologies is a crucial factor for both microgeneration, where infrastructure investment costs are a barrier, and large-scale renewable energy technologies, where upfront costs are often significant. Alternative financing sources, like energy cooperatives or crowdfunding platforms, can help mitigate financial risk.

In addition to these models, other promising business models include novelty-centered, lock-in-centered, complementarities-centered, and efficiency-centered models [19].

5.2. Supply options for PEDs

The EMP must implement goals and constraints on different levels (national, municipal, neighbourhood) and phases. The measurement and verification depend on a number of criteria:

- Cost-effectiveness of community projects;
- Economic decision-making criteria:
  - ▷ Life-Cycle Cost calculation (LCC) for EMP,
  - ▷ multiple benefits (bankable LCC on the building level),
  - ▷ bankability and risk mitigation of multiple benefits,
  - ▷ cost effectivenes;
- Investment costs and capital expenditures;

- Determination of technical concept and investment costs:
  - ▷ Gathering of accurate investment costs,
  - ▷ developing detailed energy demand and supply scenario by simulation,
  - ▷ specific risks in the calculation of investment costs;
- Optimization of investment cost.

5.3. Rollout

With increasing complexity of the energy supply in building clusters, the partition of Energy Service Companies (ESCo) of the total market is steadily increasing. Today ESCos and a few innovative utilities are able to provide highly complex energy services, including generation, distribution, storage, selling, M&V combined with demand side measures like refurbishment of buildings, distribution grids and other demand side activities. The business scheme here usually is the energy supply contracting which delivers demand and supply side measures for a fixed investment cost-based price per kW and a price for the consumed kWh of energy. The ownership of all investments, except those in buildings remains for the duration of the contract (5–20 years) with the ESCo/utility.

In recent years, the energy savings performance contracting has been developed into a business model which is not only able to tap energy efficiency potentials in buildings (HVAC and thermal envelope) but also provide complex supply, distribution and storage concepts with CHP, PV, biomass and heat pumps. Here, the remuneration is based on the energy savings and other life cycle cost savings provided by the energy service company. But also other value streams are important to notice:

- Energy savings;
- Avoided maintenance and repair costs;
- Operation cost reduction;
- Insurance costs;
- Building comfort and Green Neighbourhood Value;
- Risks and De-Risking methods and tools;
- Key Risk Indicators (KRI) in general;
- KRI in EMP for building clusters in particular.

6. Conclusions

The characteristics of implementation models towards Positive Energy Districts (PEDs) were collected and which energy supply options exist, and which are needed for PEDs was analysed. The results show a clear trend towards community models that concentrate and optimize value streams within the community. From the analysis of the results, the conclusions are that integrated energy planning is more important than ever. Because this will answer the question which energy supply options exist, and which are needed for PEDs.

The understanding of the advanced EMP value stream is providing a different mindset which focuses on the needs of the building owners and the community developer. A few cornerstones of the advanced value stream for PEDs are high resilient community energy system considering buildings, supply, distribution and storage as basic components which have to match together. The main aspects of energy supply models were identified as important to be able to define value streams as basis for successful implementation of decarbonization projects. Publicly owned district heating systems provide the potential for a larger rollout of decarbonization. Associated value streams were discussed and point to the need for a shift from energy and GHG emission savings to increased comfort on neighborhood level and risk mitigation.

To plan and develop settlements that contribute significantly to reducing energy consumption and secure the location of energy infrastructure (generation, distribution, storage), as well as achieve long-term sustainable development and climate neutrality, it is essential to understand the different dimensions of sustainable development in combination with energy supply and consumption. The implementation of Energy Master Plans (EMPs) requires a range of mandatory and optional services provided to the public owner of a building cluster.

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