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Envisioning a Collaborative Energy System Planning Platform for the Energy Transition at the District Level

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Abstract:

Residential and commercial buildings account for more than one-third of global energy-related greenhouse gas emissions. Integrated multi-energy systems at the district level are a promising way to reduce greenhouse gas emissions by exploiting economies of scale and synergies between energy sources. Planning district energy systems comes with many challenges in an ever-changing environment. Computational modelling established itself as the state-of-the-art method for district energy system planning. Unfortunately, it is still cumbersome to combine standalone models to generate insights that surpass their original purpose. Ideally, planning processes could be solved by using modular tools that easily incorporate the variety of competing and complementing computational models. Our contribution is a vision for a collaborative development and application platform for multi-energy system planning tools at the district level. We present challenges of district energy system planning identified in the literature and evaluate whether this platform can help to overcome these challenges. Further, we propose a toolkit that represents the core technical elements of the platform. Lastly, we discuss community management and its relevance for the success of projects with collaboration and knowledge sharing at their core.

Keywords:

Energy System Planning; District Energy Planning Platform; District Data Model; Renewable Energy Integration.

1. Introduction

In the effort to accelerate the transition towards climate neutral energy supply at the district scale, many tools exist that aim to solve individual parts of the district energy system planning process [1], from stochastic occupancy simulation [2, 3] and thermal building simulation [4] via building and district level energy technology sizing [5], to simulations of heat and electrical grids [6, 7]. It is the combination of numerous data sources and tools that is required to provide solutions to the heterogeneous tasks of energy system design.

For each step of the planning process, research is published on how to improve predictions, models and simulations; new models and tools will continue to come. Therefore, whoever wishes to combine tools into a district energy system planning workflow needs to go through continuous efforts to keep up with newly developed tools, improved methods and updated data [8, 9]. The following paragraphs provide an overview of challenges, existing tools and platforms in the field of district energy system planning.

Keirstead et al. [10] review urban energy system models and identify model complexity, data quality and uncertainty, model integration, and policy relevance as the prevailing challenges in urban energy system modelling. They see opportunities in creating an integrated framework where sensitivity analysis, data collection and integration techniques and activity-based modelling, promise advances in the aforementioned challenges. Yazdanie et al. [11] review gaps and solutions for advancing urban energy system and modeling approaches. They state that numerous models and planning tools as well as review articles discussing their features exist, but the gaps and corresponding solution suggestions are rarely discussed. They identify key methodological solutions to be: integrated modeling approaches and comprehensive energy modelling scenarios including social factors and system imperfections and data collection using privacy control, robust and secure communication architecture and improved data sharing platforms.

In between the two review articles, several tools and frameworks have been published, that attempt to solve some of the identified challenges. Bollinger et al. [8] introduce a Holistic Urban Energy Simulation Platform (HUES). They motivate the platform with the need to reuse and integrate existing computational models for urban multi-energy simulation for integrated studies of urban infrastructures. Multi-model ecology is the defining concept of their platform. Fonseca et al. [12] present the CityEnergyAnalyst, a framework for the analysis and optimization of city and district energy systems. It supports the analysis of energy, carbon and financial

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benefits of competing design scenarios of optimal distributed generation systems by estimating local energy potentials and simulating energy systems and building energy performance. El Kontar et al. [13] present URBANopt, an open-source software development kit for community and urban district energy modelling. The developers argue that a wide variety of building modeling tools exist, but to address planning problems at an urban scale, these tools need to be combined, which motivates a platform where multiple input formats are supported and this data is mapped onto underlying simulation engines. The combination of modules allows for customized workflows. Wehkamp et al. [14] analyze the challenges of planning and evaluating district energy systems and present a workflow using open-source tools and special purpose models that were demonstrated on a district in northern Germany. The authors identify complex stakeholder structures as an issue requiring further research.

Coming from this state of the literature, we provide a brief overview of the challenges faced in integrated district energy system planning. We then present the components of the collaborative district energy system planning platform as a suitable starting point for further development. Due to the ever-changing landscape of tools under current and future development, we expect different tools to extend or replace the initial toolkit. Finally, we discuss how community management is a potential differentiator between failure and success for this vision.

2. Problem setting

District energy system planning is an interdisciplinary field where planning problems vary widely in terms of the scope to be considered. For clarity, we introduce the system boundaries of district energy systems (DES), which frame the challenges considered in this work. Related literature sometimes refers to urban energy systems (UES), which we consider to be a superset of DES. We address the considered scope of DES planning and the challenges associated with it.

2.1. Considered scope of district energy system planning

Several dimensions need to be considered when planning DES. DES planners have to take into account not only energy conversion, but also policy frameworks, stakeholder interests and business models [10]. Key issues to be addressed during planning include sector coupling, centralized versus decentralized energy supply, demand forecasting, building refurbishment and competing stakeholder interests.

In DES, the energy consumption sectors (e.g. households, commerce, and mobility) as well as the energy supply sectors (e.g. electric power, heat and gas) co-exist. During the planning of energy systems, synergies can be leveraged by considering all sectors at once. Whether it is the use of waste heat from nearby industry or the integration of bi-directional e-mobility into a district power grid, successfully linking the consumption sectors requires the development of appropriate business models, which may be complicated by regulation. Coupling the energy sectors, especially heat and electricity, enables the efficient use of locally generated renewable energy. Therefore, both electricity and district heating networks are crucial for DES planning.

Local energy generation (energy hubs) can play a central role in this [8]. Since conditions vary in each district, various technologies (e.g. heat-pumps, photovoltaic, fuel cells) with different operating and investment costs and both decentralized (building supply) and centralized energy systems (energy hub) should be investigated.

In order to be able to plan DES, the energy demand of the district must be known or determined. Since the available demand data is often incomplete, many methods to generate load profile data have been developed over the recent years [12]. The energy demand depends, among other influences, on building types, type of use, refurbishment status and user preferences [15]. For this reason, optimizing the refurbishment status of the buildings is another important research field and part of a holistic DES planning.

Figure 1 illustrates the system boundaries of DES planning. A district usually consists of a heterogeneous building stock or newly planned buildings. As the type of use and the state of renovation have a strong influence on the energy demand, both are part of the system boundaries. The secure energy supply of the district is guaranteed by transmission networks. In the context of energy transition, heating networks play an increasingly important role, as does the consideration of e-mobility.

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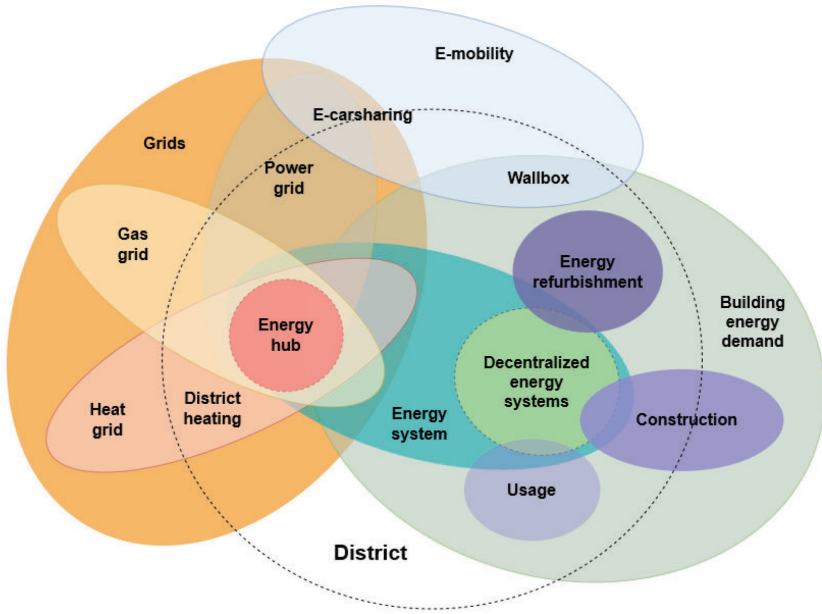

Figure 1. System boundaries of district energy system planning

DES planning is largely influenced by political and institutional decisions. Whether an energy system or business model is economically viable depends not only on technical and economic factors, but also on influences by government subsidies and the regulatory framework; such as carbon pricing or fees and taxes for the use of the electricity grid. Furthermore, many stakeholders are involved in the planning of district projects, such as investors, proprietors, residents, as well as district operators, e.g., residential real estate companies or municipal utilities [14, 16]. In an optimal planning process, all these perspectives are taken into account.

2.2. Challenges of district energy system planning

The various dimensions (e.g. technical, economic and political dimension) of DES planning come with a wide range of challenges. In this section we selected important challenges from the literature and categorized them according to the dimensions of DES planning. Yazdanie et al. [11] reviewed over 30 review studies, over 90 local-scale case studies and 40 surveys and interviews to identify gaps and challenges in energy modeling. Keirstead et al. [10] reviewed 219 papers to analyze approaches, challenges and opportunities of urban energy system models. Wehkamp et al. [14] discussed challenges and tools for planning DES using a German district as a case study. Coming from this extensive collection of challenges in district energy system planning, Table 1 contains clusters of these challenges including an assessment of whether they can be solved through our platform approach. The following paragraphs briefly discusses the most relevant challenges.

Model integration – Numerous models address different dimensions of DES planning. Sensibly combining these existing models, rather than modeling larger and more complex models, is a challenging task. A platform can support this task, e.g. by providing interface standards.

Validating models – Validation of individual models is cumbersome and time-consuming. When models are integrated into generic tools of a platform, they can be evaluated more easily. Furthermore, platform standards and community exchange can improve the validation process of models.

Considering data and geometry heterogeneity – Models require data of different form and levels of granularity. The data exchange between models can thus be hindered. In an integrated platform, a central data model can help with the transferability of data by defining a common standard for models' data requirements.

Handling data gaps and data availability – A common problem in DES planning are data gaps and data availability. This platform can hold a variety of tools for generating synthetic data as well as pre-processed data sets from open data sources. In addition, data preparation done by one user or developer does not need to be redone by a second individual.

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Conflicting interests – DES planning centers around conflicting interests. Some models focus on individual perspectives, while others offer multi objective planning. In any case, the more tools are available to compare, the better, different stakeholder interests can be portrayed and represented.

Support for decision making – Decision-makers need reliable and verified results that are presented and visualized in a comprehensible way. By increasing the number of users and benefiting from proof reading of the open-source community, this platform can offer the required level of robustness.

Table 1. Challenges of district energy system planning

	Challenges of DES planning	Platform
Technical and economic challenges	Model integration (combining existing models) [8, 10, 11, 13]	x
	Model complexity and resolution [10–12, 17]	x
	Modelling external factors such as human behavior, economic development and weather [8, 11, 14, 17]	
	Considering novel energy technologies [11, 14]	x
	Improving existing methods [14]	x
	Validating models [8]	x
	Quantifying and handling uncertainty [10, 11, 17]	x
	Considering data and geometry heterogeneity [13, 18]	x
	Balancing model resolution with data availability [17]	
	Handling data gaps and data availability [10, 11, 14, 19]	x
Political and institutional challenges	Conflicting interests [11, 14, 19]	x
	Support for decision making [10–12, 14]	x
	Political uncertainty [10, 17, 19]	
	Sustainable, affordable energy [14, 17]	x
	Energy security [17]	x
	Administrative complexity [19]	x
	Monetizing aggregated flexibility [14]	

The following section presents the tools and technical components of the platform. It also discusses technical considerations that may influence the success of the platform.

3. Platform components

This section presents the components of the platform that would provide a reasonable starting point for the evolving toolkit. This initial collection would be capable of providing meaningful results for standard planning workflows. It would also demonstrate the type of additional methods and tools that could be added in the future. The intention is that the collection of tools and data on the platform will be combined to produce insights beyond the functionality of any individual component. The tools contain data processing logic that leverages various numerical and analytical methods required for DES planning.

The main objectives of the platform are:

- Enabling flexible integration of novel computational methods
- Visualizing planning and optimization interdependencies
- Improving data availability and homogeneity
- Increasing visibility of data uncertainty
- Handling variants and scenarios

The idea of such an initial toolkit is that it can easily be updated, manipulated or replaced, based on the users' and developers' preferences. Each tool is considered a container for many methods to solve a particular problem. Within a tool, a predefined architecture directs researchers and developers, on how new methods can be injected into the tool. The main flow of data would not be altered by switching between methods. The compatibility of tools bases on the commitment to a central data model. To cover the essential elements and processing steps of district planning, we suggest the components displayed in Figure 2. The boxes represent tools and cylinders represent databases; the dashed lines indicate useful extensions, that must not be part of an initial toolset.

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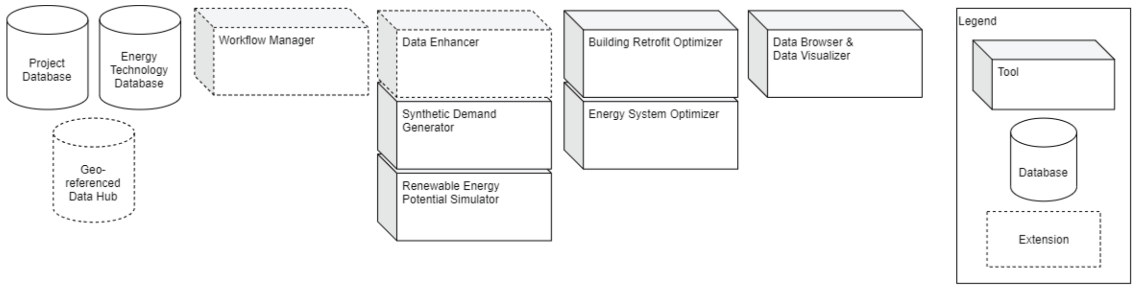

Figure 2. Initial platform toolkit

All tools work with a central district data ontology. The data model is the digital representation of districts including all physical and hypothetical building and energy system components. Tools operate either on a district data object that is transferred between processing steps in an ongoing computation, or they write and read the district data object to and from a database for intermittent processing. The latter would be beneficial for collaborative planning of districts, where multiple planners solve sub-problems successively.

The *Workflow Manager* enforces a structure that separates processing steps programmatically and visually, which improves interpretability and reproducibility. Data sources and functionality can be programmed into the structure of a directed acyclic graph, where nodes represent computations and directed arcs represent information flow and thereby node dependencies. Tools could certainly also be run using a simple script to call the processing steps of the planning problem. This would however result in more heterogeneous planning workflows that would be harder to compare and build upon.

The *Data Enhancer*, *Synthetic Demand Generator* and *Local Energy Potential Quantifier* are all pre-optimization steps, that generate arbitrary data, e.g., timeseries that are fed into energy system simulation and optimization. Usually the available data about existing, and even future buildings is sparse and incomplete. Filling up data gaps using appropriate estimations is therefore a crucial step in the total planning process.

The *Building Retrofit Optimizer* creates plausible retrofit variants by providing adapted building objects to the Synthetic Demand Generator. It either outputs a final optimized retrofit, or it feeds different variants of the building to the proceeding energy system optimization.

The Energy System Optimizer sizes system components based on optimal energy dispatch. This optimization provides answers to the trade-off between decentral and centralized technologies of all energy sectors and thereby defines which form of energy supply dominates. Additional tools could be introduced for more detailed optimizing of heating and electrical grids.

The *Data Browser & Data Visualizer* improve the interpretability of the optimization and simulation results. They output different types of tables, plots and reports, based on the requirements of the audience.

The following paragraphs discuss technical properties of the platform that are not specific to energy system planning, yet greatly affect the quality of the platform and its potential to sustain.

Extendibility – The platform should be easily extendable. By choosing Python as the development language, tools consist of Python packages that run platform independently and are easily updated and shipped to services like the Python Package Index [20]. Interested users, researchers and developers can choose which tools to use, how and where to run them and whether to extend the platform or workflow by some additional or improved functionality. By providing placeholders for typically required tools in district energy planning, it is easy to identify interfaces between processing steps. Documentation can be built into the tools in the form of comments, test cases and demo scripts, and be made available in a web compatible format.

Level of coupling – Introducing a central data model to ensure compatibility comes with advantages and disadvantages. It improves data consistency and integration. This results in fewer errors and inconsistencies while improving efficient development and data flow by reducing transformations. However, a central data model can become very large, having to serve requirements of many different applications. This increases development and maintenance efforts. It further increases the dependency of tools from this data model, which might require updating tools, when updating the data model.

Flexibility and maintainability – Energy system planning is a dynamic environment, where data models and tools regularly need to be updated to cope with novel problems and requirements. Data structures should therefore be flexible enough to cope with unforeseen needs during initial development. Practices that can help are modular data structure components, leveraging industry standards and implementing backward compatibility. Further, the choice of database technology can greatly affect the success of the project due to different levels of flexibility, performance and maintenance effort.

Usability – Usability is to a large extend subjective and experienced differently based on the familiarity with different kinds of interfaces. The main user group is expected to be energy system researchers and engi-

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neers who have basic knowledge of Python. We therefore suggest to either provide tools as Python packages, with command line interfaces, or with a graphical user interface. Python has become one of the most popular languages for tools in the energy academic community [21], providing well-designed high-level functions for newly developed tools can be a good balance in terms of usability and flexibility for users familiar with Python. As a high-level programming language, Python makes it easy for beginners to get started, which is important for interested users to start generating results [22]. Due to the expected rapid development in research and application of district energy planning methods and software, this focus on code-based usability is motivated because of the low overhead in interface design. To integrate tools of different languages command line interfaces are sensible. Providing a graphical user interface comes with a higher level of user-friendliness and is particularly useful for presenting a lot of information at once. Developing and maintaining a GUI adds additional work and is therefore expected to be used mostly for result presentation and not necessarily for data processing. Python packages and command line interfaces are also easier to integrate into automation procedures of recurring workflows.

***Integrated computing* –** DES planning quickly becomes computationally demanding. Therefore, we suggest to integrate computational resources into the platform. While the processing and data handling could all be done locally, it would be sensible to integrate computing capacity that supports tools in highly intensive processing tasks. Using a centralized solution can result in lower overhead due to the stronger integration of software and hardware. The data storage could also be hosted on a central machine, which benefits data availability, integration and performance.

The following section discusses community management and its potential influence on the success of the envisioned platform.

4. Platform community management

Open-source community management is the process of building online communities and facilitating active collaboration. This involves engaging community members, moderating communication, facilitating discussion, hosting community events, responding to user questions and generating informational and promotional content [23]. When collaboration and knowledge sharing are at the heart of the project, technical features and robustness do not alone affect the individual's choice to use the platform or to contribute. A platform that builds on the idea of collaborative development requires a community to be engaged and willing to share information, which his particularly sensitive in the early stages of development and research; this requires successful community management [24].

Open-source community management is a topic that has received attention in the context of the most successful open-source projects [24], but to our knowledge it has not been considered a central part in the effort to engage a community of researchers and users of district energy system planning tools. Successful community management can support compatibility of tools and data, bridge the gap between research and application and support active knowledge sharing and sustainable development of the platform. In efforts towards collaborative research and application in district energy system planning, the level of community engagement can be a potential differentiator between failure and success for a collaborative multi-energy system planning platform.

Community management centers around community managers, who connect various groups such as researchers, practitioners, policymakers to facilitate the exchange of experiences, knowledge and best practices and thereby drive innovation and the quality of the platform.

Important aspects of community management are:

- Clear communication of goals, expectations and policies
- Inclusiveness and empathy within the community
- Active engagement of potential contributors
- Decision-making transparency

A collaborative multi-energy system planning platform’s success not only depends on technical aspects, but also on the level of engagement in the community, the user's choice to commit to this platform and potentially contribute themselves, the willingness to share knowledge and the community's ability to make decisions and move forwards. Community management covers these aspects and can help to accelerate research and application of superior methods in district energy system planning.

5. Conclusion

In the context of district energy system planning, we have motivated the need for a collaborative platform to cope with the rapid development of new models and tools by academia and the requirements of practitioners. Due to the interdisciplinary nature of the problem, we expect individual groups to struggle with providing solutions to all elements of the problem. Some platforms exist with fine or major distinctions, of which currently none seems to be established as the status quo for integration for models and tools in district energy

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system planning. A platform that is modular and extendable can be the common ground for all parties involved.

Based on existing literature, we see model integration, validating models, considering data and geometry heterogeneity, handling data gaps and data availability, conflicting interests and support for decision making to be the prominent challenges to be solved by the envisioned platform. Concretely, we expect the platform to enable flexible integration of novel computational methods, expose planning and optimization interdependencies, improve data availability and homogeneity, increase visibility of data uncertainty and handle variants and scenarios. For consistent data handling we propose the definition of a central data model as the foundation for tool integration and data consistency. Further, we present a set of essential tools, that we consider indispensable to solve a wide scope of district planning problems.

Fostering openness and effective collaboration potentially is a key differentiator between success and failure of such platforms. Collaboration, communication and decision procedures pose a challenge for ventures like this to thrive in the open-source world. Analyzing these aspects of the problem should be subject of future work.

Setting the groundwork for this vision is a complex task, and no one in the sphere of district energy system planning naturally has the obligation to start. However, it does require an initial definition of standards and interfaces, for this platform to manifest in something tangible. Further, a combination of central guidance and community driven decision making is required to maintain the platform and react to future developments.

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