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Integrating the urban planning process into energy systems models for future urban heating system planning: A participatory approach

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Abstract

For local governments and municipalities, both urban and energy planning are required to make the transition to more energy efficient cities with lower carbon emissions. However, energy planning and urban planning are usually under the responsibility of different departments and have their own planning processes. When dealing with energy plans, this separation could lead to a less effective impact on cities in reaching climate goals since a lack of coordination may result in different strategies set out by the two plans. In consideration of the fact that space heating dominates the energy use in buildings, this study has a focus on urban heating systems in the building sector. We propose an integrative municipal heat planning methodology investigating which features of the urban planning process that could be integrated into a spatially explicit energy systems model and how. The proposed methodology is then applied to a specific case: the heating system in the municipality of Lyngby-Taarbæk, Denmark. The inclusion of stakeholders from both the heat and urban planning departments in the case study enabled us to reflect on their preferences and expectations for the future heating system. Finally, the applicability of the methodology and the application results are discussed and compared to other methods.

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Keywords: Municipal heat planning; Urban planning; Energy systems models; Urban heating systems; Local energy transition

1. Introduction

Urban authorities are recognized as important stakeholders in urban energy system planning processes since they often have better knowledge and understanding than national authorities on the local context and implementation of efficient energy policy for the area [1–5]. Urban energy systems planning is not a sole discipline but rather an integrative topic encompassing questions from technical substitution in energy planning to urban forms and density

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in urban planning. However, energy planning and urban planning are usually under the responsibility of different departments and thus have their own planning processes. This separation could lead to a less effective impact on cities in reaching climate goals since a lack of coordination may result in different and sometimes conflictual strategies set out by those individual planning processes [6].

Energy planning is the process of setting out long term visions for a future energy system at a local, national, regional or global scale. It is often carried out by governmental organizations and energy providers at both national and local levels [7]. Energy planning considers a wide range of elements such as technical potentials of low carbon supply from renewable resources and demand reduction through energy efficiency savings; environmental factors such as expected carbon reduction trajectories; and socio-economic factors, including population characteristics and investment costs [8].

Urban planning is the process of developing and designing urban areas regarding features of the use of land, air, water, the built environment, and economic and social functions for development of settlements. An urban area is a highly populated human settlement with infrastructure of built environment. The term urban is often exchangeable with municipality which is an urban administrative unit having corporate status and powers of self-government. An urban plan makes decisions that specify the land use and the layout of the area, the size and the type of buildings, and transportation networks [9]. Thus, urban planning is an important tool for urban development since it guides the direction in which the cities are to be developed while addressing existing and future challenges.

Urban areas consume nearly 75% of the global primary energy supply and the vast fraction of it is used in the building sector [10]. Considering that space heating is a major and the most carbon-intensive building end-use [11], urban heating system development has a huge potential to play a critical role in achieving climate goals. Additionally, the close involvement of urban plans in the building sector gives grounds for the need for an integrative approach in the municipal heat planning process taking urban plans into account. The necessity of such approaches to a sustainable urban energy transition has been recognized by several authors as presented in Section 2, although the scope of this study is limited to heating in buildings.

2. Integrative approaches to a sustainable urban energy transition

Cajot et al. [12] stressed the need of a combination of interconnected solutions, which reinforce each other to tackle the issues of urban and energy planning in a comprehensive and dynamic way. They proposed a systematic framework to describe the varied and complex aspects of energy planning in cities. Similarly, Zanon and Verones [13] argued that urban spatial planning and energy planning should be closely linked together because the urban plans are strongly linked to energy consumption and potential local energy sources.

How urban and energy planning processes should be integrated is an ongoing research field and several authors have contributed to this topic with different approaches and critical reviews [2,6,14–16]. It is observed that the previous integrative approaches have a thing in common: employment of energy systems models. Energy systems models are widely chosen as a tool to support the decision-making process in energy planning to achieve the user's objective, e.g. minimizing the total system cost, the total emissions, etc., within selected sectors and time horizons. There is a considerable amount of previous studies which adopt energy systems models to investigate consequences in various sectors under different conditions at the urban scale [3,17–19].

However, such models usually have a tendency to focus on technological/economic factors which are represented with numbers and fail to capture other aspects, e.g. socio-political, non-financial aspects, of reality that could have the same or a larger impact on energy systems [20]. Innovative approaches and tools are developed to tackle this limitation and tested to support urban energy systems planning [1,21–26].

The need of an integrated approach to comprehend both energy and urban planning for an effective energy transition is raised by previous studies and EU-level documents and initiatives. However, the awareness of the need does not automatically influence the practical planning processes of urban and energy department and how they should be integrated is not explicitly described [6,12]. This is due to a lack of appropriate decision support tool and clearly defined methodologies to integrate the two disciplines in a practical manner [12].

The aim of this study is thus to propose a methodology of integrating specific features of the urban planning process into a spatially explicit energy systems model for municipal energy planning with the involvement of both energy and urban planners. While the previous studies tend to consider integrating energy aspects into urban planning process, this study addresses the converse, i.e. integrating features of urban planning into energy systems model. Features of the urban planning process identified from previous literatures are addressed in the next chapter. Two research questions are discussed in this study: (1) How may urban planning be integrated with the energy systems modelling process? (2) Which features of urban planning may/can be integrated with the energy systems modelling process?

Given the need for an integrative planning process with the inclusion of urban and heating system planning, the methodology proposed in this study should integrate and accommodate the multi-disciplinary nature of both the urban and heat planning processes. The methodology consists of five steps and the first two steps are the scope of this study. The methodological flow of the study is presented in Fig. 1. and each step is explained below. It is important to note that this method is needs-driven, meaning that the starting point is the needs for knowledge as formulated by municipality stakeholders' participation which also enables the inclusion of their views, preferences, and expectations of the future heating system.

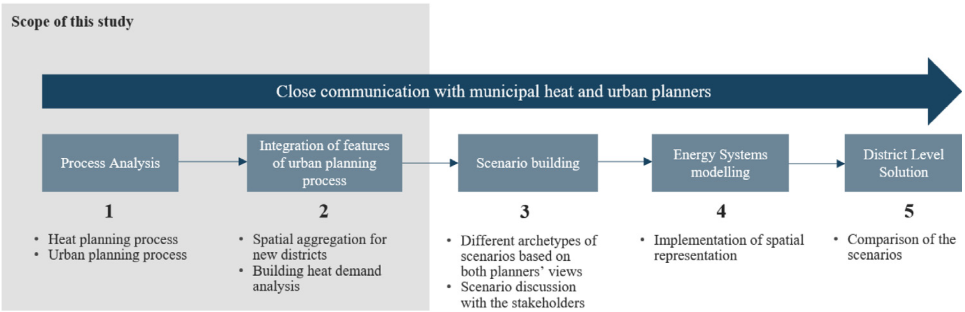

Fig. 1. Methodological flow of this study.

2.1. Step 1: Process analysis

The objectives to be reached in the first step is to understand the present urban and heat planning processes, and to identify the gaps and needs in the planning processes. The identified gaps and needs are expected to point to the direction of energy systems modelling process towards an effective and cohesive heat plans in a municipality. To this effect, it is necessary to communicate with municipal planners to understand their planning processes from the incumbents' views, preferences, and expectations that reflect municipal contexts. Reviewing official documents of urban plans and heat plans can be also useful in this step since those documents contain information related to local heating systems and detailed urban plans.

Table 1 presents features of the urban planning process that are included in the previous energy systems planning studies. In this methodology, the features of spatial/zoning plans, density, and building size/type are integrated into the energy systems model through spatial aggregation for new districts and building heat demand analysis which are elaborated below.

Table 1. Features of the urban planning process.

Features of the urban planning process	Integration into energy systems models	References
Spatial/zoning plans Density	Spatial aggregation for new districts	[2,6,12,13,15,27] [13]
Land use	–	[9,13]
Urban form/layout/morphology	–	[13,14,28]
Building information (type/size/age)	Building heat demand analysis	[2,9,13,15,16]

2.2. Step 2: Integration of features of the urban planning process

The second step consists of spatial aggregation for new districts and building heat demand analysis. It is necessary to define new districts in accordance with the official urban territorial subdivision to generate district level heating solutions by linking the urban plan and heat plan. This is because urban spatial features are connected to heat consumption and to the access to district heat supply technologies [2,6,12,13,15,27]. It should be noted that there are deterministic characteristics when adopting heating supply technologies, e.g. building types, density, etc. and they need to be considered when aggregating new districts [29]. For this task, urban spatial plans containing information such as large construction plans and its maps, heat plans, and national/local statistics on heating technologies can be useful sources. Different forms of communication with the municipal actors can be also carried out to obtain their preferences and related information that is challenging to acquire from openly published sources. The identified districts with different characteristics need to be implemented in spatially explicit energy systems models to generate district level heating solutions at a later stage.

The feature of building information such as building type, size, and age influences the building heat demand and energy performance of buildings [2,9,13,15,16]. The total heat demand of buildings in each newly identified district can be calculated using the building information combined with other sources, e.g. national building registry databases, statistics, average annual heat demands of different kinds of buildings. The result will provide a detailed analysis of building heat demand which is an important parameter in energy systems models.

3. Application to a case: the Lyngby-Taarbæk municipality

3.1. Overview of the Lyngby-Taarbæk municipality

The Lyngby-Taarbæk municipality in Denmark, used as a case of this study, is located in the northern suburbs of Copenhagen and has 56,000 inhabitants. The municipality has a goal of reducing CO2 emissions from all sectors by 25% by 2025 compared to 2015 level. It has achieved its 2020 reduction target of 20% CO2 emissions reduction compared to 2008 5 years ahead of time. The Lyngby-Taarbæk municipality has joined the Danish Society for Nature Conservation, a membership organization, which obliges the municipality to reduce 2% of CO2 emissions from buildings every year.

The heating system of the municipality has a great potential for reducing the use of fossil fuels and the influential role of the municipality as an authority [30]. 45% of the total heat consumption is district heating supply and the rest is natural gas boilers supply and district heating is expected to be responsible for most of the CO2 reduction in the municipality and more buildings are being connected to the district heating network.

3.2. Step 1: Process analysis

We have collected qualitative data from semi-structured interviews and personal communications with four municipal stakeholders. The interviewees have been chosen based on their direct involvement of the heat and urban planning process in the municipality as main agents so that they can provide us information related to the topic from each point of view: former heat planner [31]; climate coordinator [32]; heat planner [33]; and urban planner [34].

3.2.1. Heat planning process

Municipalities in Denmark are encouraged to voluntarily prepare municipal strategic energy plan as a tool that gives them the opportunity to plan a transition to a flexible renewable energy system in a socio-economically appropriate way [35]. Municipalities can use these plans as a basis for achievement of the long-term national targets of phasing out fossil fuels and locally set climate and energy objectives.

The current Strategic Energy Plan (SEP) in the Lyngby-Taarbæk municipality was developed in collaboration with different energy suppliers in the municipality in the year of 2013. One of the challenges in the heat planning process is that the plan is highly dependent on district heating consultants, where the contents of the plan focus heavily on technical aspects and interaction with other related actors is not sufficient [31,32]. In addition, [32] has commented that more interactions between heat/urban planner and consumers in the heat planning process to take into account certain local considerations will benefit the heat plan in containing a more holistic view ensuring cohesion with the urban planning department and be easily understood by different actors.

The heat planning process in the Lyngby-Taarbæk municipality has several steps. First, the heat suppliers submit a proposal of their project to the municipality which includes their suggestions and estimations showing what the socio-economically optimal heating options are. Here, the low natural gas price was an obstacle in the local energy transition. However, as of January 2021, there was a change in the regulation that the utilities do not need to include natural gas as a heat source in their estimation. This change is expected to give more opportunities to district heating utilities and the municipality to expand their district heating network [33]. With the district heating expansion being prioritized in the municipal heat planning, [32] has expressed the need for defining new districts and its heating characteristics which are described in Step 2. After project proposals have been submitted, the municipality stakeholders review them based on the national law. The proposals need to be approved by the politicians to be sent to the next step: a public hearing. The municipality presents the proposal to the public and waits four weeks to receive feedback. Finally, the politicians approve the proposal after the feedback from the public has been considered. The process usually takes five to six months and the point is to ensure that everyone has been able to examine the proposal [33].

3.2.2. Urban planning process

Municipalities in Denmark are in charge of developing municipal plans which is the framework for the detailed local plans (urban plans). It must be ensured that the urban plans comply with strategic plans prepared at regional level as well as the national plan set by the Minister of the Environment.

The municipal plan has been increasingly focused on environmental aspects compared to the last few years [34]. While the municipal plan provides a comprehensive overview of development plans for housing, transport, workplace, and protection of the natural environment, urban plans describe how each district can be developed and used. Some of the elements that are regulated by the urban plan includes the size and extent of properties, track, pipes and transmission lines, location, size and appearance of buildings, building density, and requirements for new buildings to be low-energy buildings [36]. The districts in the urban plans served as a basis for defining new districts in Step 2 since it includes important elements such as new building plans and building characteristics that affect the heat demand.

[34] indicated that there is a lack of means in the urban planning department to include heating-related information in the urban plan and in a daily urban planning work that can be useful for the dialogue between the urban planner and developers in making progress on projects. Moreover, since the urban planner tends to pay attention to what they should regulate based on the national law, heating aspects have relatively low focus in the planning process even though the urban planner is aware of the connection between the urban and heat planning. With regards to this issue, [32,34] have agreed that information such as the ideal heat supply options in specific areas would assist the dialogues between the urban planner and developers in pointing a direction that the municipality wants in their heating system. It is more so since the national law enabling the municipality to force new buildings to connect to district heating network has become invalid from 1st of January, 2019, and the municipality can only encourage the building developers with appropriate and supporting information to choose a heat supply option they want [33].

It is observed that the process of urban planning is similar to the heat planning process of the municipality. The urban planning must be based on national regulations, and what the local plan can regulate at the municipal level is stated in the Planning Act. The urban planning department needs to prepare a planning proposal in collaboration with public authorities, citizens, and others for revising the urban plan. The proposals are published and debated on the municipality's website and on the national digital planning registry system to receive public comments and the state assesses whether the proposal conflicts with national interests or not. Municipal officials then assess the public consideration and adjustment to finally approve the proposals [34] (see Table 2).

3.3. Step 2: Integration of features of the urban planning process

In Step 2 features of the urban planning process which are identified as being important or needed are integrated into the heat planning process. Table 3 presents the summary of needs and preferences identified from stakeholder interviews as described in Section 3.2. The subsequent Sections 3.3.1 and 3.3.2 describe how these needs and preferences are implemented in the case of Lyngby-Taarbæk.

Table 2. Summary of process analysis.

	Background/Motivation	Challenge/Opportunity	Planning Process
Heat Planning Process	Voluntary SEP as a tool for urban energy transition	• Dependency on utilities and insufficient interaction with urban planner • Communication with urban planner can improve holistic heating plan	Project proposal Assessment Public hearing Review Final approval
Urban Planning Process	• Urban plan establishes urban districts and how each of them are developed and used • Building plans in each district	Lack of means to include heat related information that is useful in dialogue with building developers	

Table 3. Needs and preferences identified from stakeholder interviews in Step 1.

	Needs and preferences identified from stakeholder interviews in Step 1
Heat planning process	• Establishment of new districts that serves as a basis of spatial representation in energy systems models for district level heating solutions. • Better communication between heat and urban planner when developing new areas to include certain local considerations. • Preferences in future heating technology options are expressed which will feed into Step 3 and 4.
Urban planning process	• A tool that urban planner can use to include heating information in daily urban planning work. • Use of heating planning information in dialogues and discussion with building developers to point to preferred directions of development. • Better communication between heat and urban planners when developing new areas so that both work head towards the same direction.

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3.3.1. Spatial aggregation for new districts

In Denmark, each individual building and residential or business unit's location, purpose, year of construction, technical conditions, layout, and electric/heating installation are registered in The Central Register of Buildings and Dwellings (BBR). According to the BBR, the Lyngby-Taarbæk municipality is divided into 46 districts in the database. The existing 46 districts are aggregated into 15 districts (see Fig. 2.) based on the information and preferences from the interviewees (See Step 1): combinations of cadastral lines in their spatial planning, heating supply technologies, heat demand density and distances between districts. Specifically, the current and planned heating supply technologies are considered as three different categories: currently supplied by district heating (D1–D3); currently supplied by natural gas but conversion to district heating planned within the next years (D4–D5); and currently supplied by natural gas (D6–D15). The districts included in the three categories are then divided into smaller areas based on their proximity to the existing district heating network since it is an important characteristic for estimating the cost for connecting to the district heating network. As a result, 15 districts in total are newly identified which will be implemented in a spatially explicit energy systems model to generate district level heating solutions.

3.3.2. Building heat demand analysis

Some of the variables from the BBR are selected such as building use, floor area, and construction year, and combined with other sources, e.g. maps with neighbourhood borders, heating installation, to identify the heat demand in each type and age of building and eventually to calculate the total building heat demand. With the selected variables, all the buildings in the municipality are categorized into six different types: detached houses and farmhouse; terraced and semi-detached houses; multi-dwelling buildings; student housing and community residential buildings; and non-residential buildings. The buildings are then divided into three different age groups: buildings constructed before 1961; in between 1961 and 2006; and after 2006. The heat demand of buildings is calculated by multiplying the net floor area with the average annual heat demand in kWh per square metre of building in every category stated above. The average annual heat demand per square metre data in each building type and age is obtained from a project Energiforbrug i Bygninger (Energy consumption in buildings) [37]. The calculated annual

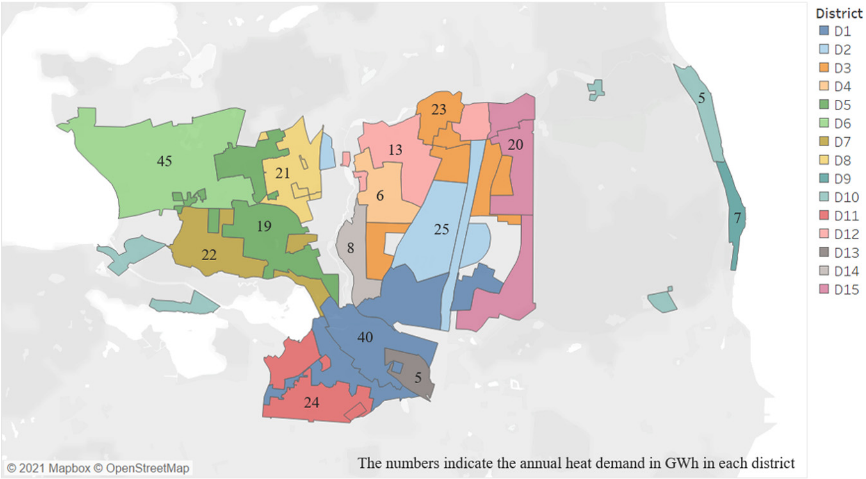

Fig. 2. New districts identified. The map is based on longitude and latitude. Colours show the different districts (D1–D15) and its details are presented in 4.3.2. The numbers on the map indicate the annual heat demand of buildings in GWh in each district. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

heat demand is presented in Fig. 2. The newly defined districts and the estimation of the heat demand of buildings in Step 2 with the information and preferences from the stakeholders in Step 1 give us guidance to formulate different archetypes of heating system development scenarios in Step 3. Accordingly, the different districts can be compared and discussed based on the information above in the spatially explicit energy systems model in Step 4 and 5.

4. Analysis and discussion

A municipal heat planning methodology that integrates two specific features of the urban planning process has been proposed and applied to a heating system in a case municipality. The need to integrate energy and urban planning is expressed in and supported by different studies but as explained in the introduction, there is a lack of proper tools and a clearly defined methodology to integrate the planning processes of the two disciplines [6,12,34] . The main contribution of this study is to apply the proposed methodology to a specific case to address the gap identified. By directly involving stakeholders of both planning departments, the application of the methodology can support both planners to better consider their role in urban energy transitions and to share common visions between the two planning bodies. With this methodology of integrating urban features into heating planning process, the heating aspects can play a role as an important driver in decision making in urban planning processes and vice versa.

First, the spatial plan representing subdivisions of urban settlement is integrated for identifying new districts coupled with other layers of information which are heat plans, heat supply technologies, distance to existing district heating networks, heat demand density. It is expected that energy systems models can represent the spatial aggregation and provide heating solutions at the district level accordingly. Next, the building heat demand which is an important parameter of energy systems models was calculated using building information. Various data sources, e.g. national building information registry and statistics, were key references in the calculation and allowed a detailed analysis of heat demand per building type and age in each district.

The novelty of this methodology is that it integrates the two disciplines of urban and heat planning with the involvement of the stakeholders which enabled us to reflect on their views and preferences in the process of integration. This can mutually benefit urban and heat planners by offering a place to communicate and share their knowledge and visions. As mentioned above, there are several studies dealing with the topic of integration with different approaches, while there is still a lack of methodology that involves the stakeholders from the both departments. In addition, the proposed methodology connects the spatial aggregation to district level solutions through energy systems models which could be an interesting approach to energy systems modellers.

5. Conclusion

One of the benefits of integrating urban and heat planning processes at the municipal level is that it supports a coherent urban heating system planning process through tackling the problem of local energy transition. One such way this can be achieved is by integrating features of the urban planning process into energy systems models. Especially, this study showed how the involvement of municipal stakeholders can be integrated in the process. Besides, the application of the methodology to the Lyngby-Taarbæk municipality shows that integrating spatial plans and building information of the urban planning features can lead to the identification of new districts and heat demand of different types of buildings in each district. This study has provided a novel methodology of integrating urban and heat planning process into energy systems models and it is expected to be applied to other municipalities for urban heating system planning by being customized to their own local contexts.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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