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Article

Designing Tools for Energy System Scenario Making in Municipal Energy Planning

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Abstract: Energy planning increasingly revolves around the use of tools for energy system modelling and analysis with a view to generating scenarios to show implications and possibilities for decision makers. Municipalities engage in the transition to renewable energy systems through the formulation of strategies and goals at a local level despite often lacking appropriate tools and resources to conduct the needed complex analyses. Tools for energy system analyses have traditionally been designed either with the scope of national energy systems or detailed project-specific analysis in mind, leaving municipal planners in a state of flux. This study aims to identify important specifications and critical design principles for future energy system modelling tools designed for municipal planners. Through a qualitative case-oriented approach, this study investigates the planning practices of four municipalities. It is found that future tools for municipal planning purposes need to combine the need for systematic analyses with concrete and implementable initiatives while balancing analytical complexity with operational simplicity.

Keywords: energy planning; energy system modelling; tool design; energy scenario making



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1. Introduction

Transitioning the energy system to renewable energy supply is a complex challenge due to the nature of the transition; going from storable and dispatchable fossil energy sources to variable renewable energy sources and sector integration. With this transition follows a growing need for long-term strategies, along with higher requirements for analytical complexity and temporal resolution of energy system modelling; complicating the process of the decision making and planning of the transition [1].

An exclusive definition of what constitutes energy planning has not yet emerged [2,3], and while authors approach the subject of defining energy planning differently, it is clear that balancing the technical supply and demand for energy with economic, environmental, and social concerns is a fundamental pillar [4–9]. One purpose of energy planning is to improve the decision basis for important policy decisions in both a short- and long-term perspective [4], and thus the importance of good and reliable energy planning should not be underestimated. They and Zarate [7] argue that the complexity of energy planning is a result of its multi-criterion and multi-scale issues, and the resulting need for coherence across multiple levels and time horizons.

Energy planning, while increasingly necessary at all scales, has traditionally been conducted at the national level; in part due to a previous emphasis on centralised production of energy from, e.g., central power plants [10], but also due to vested competences in established planning and policy-making authorities. Municipal energy planning and energy system modelling, on the other hand, is a research field that has traditionally been

de-emphasised in favour of national energy system modelling [5]. However, energy planning is no longer solely a centralised, national task. Local authorities and actors such as municipalities and city planners are increasingly incorporating energy planning aspects into their practices [11,12]. This is underlined by the growing body of research and literature on the decentralisation of energy planning, stressing the role of municipalities and challenges faced by municipalities in the transition to renewable energy systems [13,14].

These challenges include a shift in focus for municipal planning which previously revolved around heat planning, and in particular planning of district heating systems [15], to planning for the transition of the entire energy system including the interrelations of diverse energy sectors such as electricity, heating, cooling, transportation, buildings, industry, and waste management [16,17]. Particularly in countries with district heating, waste management constitutes significant potential for energy recovery, as the district heating infrastructure enables large-scale heat recovery and utilisation of excess heat [18].

The smart energy systems concept [19] encapsulates the idea of sector integration, focusing on holistic integration of all energy sectors to reveal more feasible and affordable pathways toward renewable energy systems. This is opposed to smart grid concepts, typically employing a sole focus on a single sector such as the electricity sector, and thereby lacking the holistic system understanding that technologies and infrastructure has to function within [20]. Hence, the holistic approach employed in the smart energy systems concept is needed when seeking to determine synergies and optimal solutions for both the overall system and for individual sectors.

Maya-Drysdale et al. [11] evaluate the energy vision strategies for eight European cities to investigate the extent to which strategic energy planning is done. The authors find that cities need to explore long-term goal setting more to develop clear energy visions and scenarios, as previous planning has mainly been a result of simplified silo thinking. Cities have been doing short-term scenarios, and focused on technology problem solving, as opposed to system integration and sector coupling solutions with inconsistent links to national targets. Maya-Drysdale et al. conclude that future research should investigate why cities abandon scenarios, and how collaborative approaches can be formed amongst researchers, modellers, and planners.

Amer et al. [21] conduct a study on energy system model usage in Danish municipalities and find that modelling is generally considered to be beyond the scope of interest by municipal planners due to a combination of lacking time and expertise. Like Maya-Drysdale et al., Amer et al. find that future research should emphasise collaboration across both planning levels and actors, as, currently, a chasm exists between modellers and planning practitioners.

Based on the experiences with energy planning in four European cities, Lelite et al. [22] develop a guidebook for conducting sustainable energy planning in municipalities, aimed at assisting municipalities in fulfilling the commitments to the Covenant of Mayors movement. The guidebook presents several key stages of planning, including identifying and engaging stakeholders, setting and reviewing targets, and implementation. The study does emphasise how energy system analysis is a pivotal component of sustainable energy planning, but at the same time acknowledges that obtaining the necessary data and conducting the analyses are challenging tasks for municipalities, but no tools or models are presented for assisting municipal energy in overcoming this.

Municipalities could benefit from using energy system modelling at a local level in their communication with local energy actors and citizens as scenario modelling can assist in visualising and comparing different solutions to be implemented in the local system and thereby highlight the effects and consequences of system changes [23]. In that sense, energy system models can become an important part of a transparent dialogue with the local community [24].

However, tools suitable and designed specifically for a decentral or municipal context remain scarce, and tools have traditionally been designed based primarily on technical optimisation principles with little acknowledgement of local challenges faced by munic-

ipal planners [25–28]. Hence, understanding the municipal planning practices from the perspective of the planning practitioners may be the first step towards uncovering critical design principles and designing tools appropriate specifically for the municipal level.

Article Scope and Structure

This study examines how energy system modelling tool characteristics correlate to the planning practices of local authorities. The aim is to identify important specifications and critical design principles for future energy system modelling tools in this context. The study focuses on the early stages of tool development by gathering the necessary insights into municipal planning practices to establish critical design principles for future tool development.

To uncover established energy planning practices, the study considers the context of four different municipalities; Osimo (Italy), Oud-Heverlee (Belgium), Valladolid (Spain), and Eilat (Israel). These four case municipalities are central cases in the MUSE GRIDS project [29] which the present study is based on, and thus the primary reasoning for the case selection.

The present study attends to the requirements of the user in very early-stage tool development, taking as a starting point the practices and needs of municipalities, thus providing practical guidance to researchers and model developers looking to develop tools relevant for municipal energy planners. The study further adds to the existing research on decentralised energy planning by bridging the gap between municipal energy planning practitioners and energy system modelling tool usage. Secondly, the global context of the investigation uncovers common trends and delivers results applicable on a broader scale, adding to the previous country-specific results in the existing scientific literature.

Section 2 presents a review of existing literature on energy planning and the emerging emphasis on decentralised planning, followed by a review of challenges to related tool usage in decentralised energy planning. Section 3 describes the methodology and in particular the multiple-case research approach employed in the study and the interview data collection. Section 4 presents the investigated case municipalities both in terms of their institutional context and their local energy system. Section 5 presents results for the municipal planning practices and the tool design principles that can be derived from these practices. Discussions, conclusions, and suggested future research are presented in Section 6.

2. Literature Review

This section further expands on the context of municipal energy planning by first reviewing existing literature to define energy planning and to outline the inherent complexity of such planning. Secondly, this section reviews how challenges related to tool usage in decentralised energy planning have been documented in previous research, serving as a starting point for the assessment of planning practices and tool design principles in this particular study.

2.1. Energy System Planning and Energy System Modelling

Energy planning is widely used in countries and local communities around the world. Krog and Sperling [28] identify different understandings and definitions of energy planning used in the scientific literature including strategic energy planning, community energy planning, and integrated energy planning and find that it is not possible to identify one uniform understanding of energy planning. Therefore, it is important to emphasise that for this study, energy planning is considered as the act of developing the energy system with a view to balancing the demands and requirements of multiple energy (sub-) sectors while maintaining a holistic overview of the entire energy system, as outlined in the smart energy systems concept presented in Section 1. Hence, this form of holistic energy transition planning differs from traditional expansion planning by utility companies in that the entire

energy system and its appertaining interrelations must be considered, as opposed to solely the aims of a single utility company or sector.

The complexity of such integrated energy planning approaches stems from the need to co-ordinate consumers and producers of various energy sources while ensuring the security of supply [30]. Because of the diversity of the involved energy sectors and actors, the planning process needs to incorporate not only a variety of technologies, but also energy grids such as district heating grids, district cooling grids, electricity grids, and gas grids, to properly address the energy system development [31]. However, the planning process needs to at the same time balance a variety of actors and their ambitions for the planning and development of the municipality, or conflicts and local resistance, related to, e.g., the spatial planning for wind turbines or solar photovoltaics, that could arise [32].

In a study examining the correlation between decentralised and centralised energy planning, Sperling et al. [33] observe an increasing interest among Danish municipalities to carry out energy planning. However, they also find a need to outline the role of municipalities more clearly to enable coordination of national and municipal planning activities. The authors further conclude that navigating the national institutional framework of policies and regulation is challenging to most municipalities; a viewpoint further emphasised by Krog [34]. Municipalities are an important part of implementing national renewable energy strategies, but to enable this, an institutional framework supporting this development and reducing the gap between national and local policy must be formulated at a centralised level beforehand [15].

Based on practical experience of modelling four European cities, Simoes et al. [35] argue for the benefits of combining qualitative analysis with quantitative modelling at an urban level to identify an optimal mix of measures. Further, it is concluded that an approach relying solely on quantitative energy system modelling would result in substantially different scenario recommendations compared to a more holistic approach. Likewise, in an effort to analyse cities' progression towards smart energy systems, Kilkiş [36] established an indexing tool for benchmarking performance. Based on the results from the index benchmarking, Kilkiş argues that for cities to reach the sustainable transition goals, a combination of well-rounded policy efforts, energy efficiency improvements, and structural energy system changes are needed.

Similarly, the integrated energy planning procedure as described by Mirakyan follows a combined quantitative and qualitative approach [37]. This is supported by Morlet and Keirstead [38] and Neves et al. [24], concluding that while energy system modelling tools are valuable for cities planning transitions to renewable energy systems, quantitative assessment should be complemented by a holistic appreciation of the local context. Thus, when conducting energy planning in an urban or municipal setting, it is important to keep in mind how the municipal setting differs from a national setting such as an increased emphasis on appropriate utilisation of local resources and attention to local demands [39,40]. Decentralised, bottom-up planning could be a source of development in the transition to renewable energy-based energy systems, leading to changes in the institutional practice of energy planning, and a continuous need for both decentralisation and centralisation in energy planning [33].

2.2. Tool Usage in Decentralised Energy Planning

An emerging emphasis on decentralised energy planning, strategies, and ambitions on a city and municipal scale could prompt the development of the energy system as a whole. This necessitates that municipalities have the needed capabilities to conduct energy planning, including access to suitable energy system modelling tools. A plethora of models and tools are available for the simulation of energy systems and design of transition scenarios, but as established by Machado et al. [41], modellers have been mostly interested in conducting analyses at the regional and national level. Thus, modelling of municipal energy systems remains an opportunity for further research, and as new tools are developed to deal with the increasing complexity of the renewable energy transition,

these should be designed or adapted with compliance to this in mind. Particularly for the municipal context, Krog and Sperling argue that energy system modelling and tool use is only part of the energy planning conducted, and hence tools and models should be accessible to an extent so that their use does not detract from energy planning as a whole [28].

Hiremath et al. [5] argue that energy planning and modelling traditionally have been based on fossil fuels and centralised electricity supply, and instead go on to develop a framework for categorising decentralised energy system models according to key characteristics. The authors conclude that decentralised energy planning models and approaches need to be developed and applied, and further, they argue for the relevance of a bottom-up approach as opposed to a top-down approach, with time horizons preferably being short to medium term, with the purpose of identifying optimal matching of demand and supply. Similar viewpoints are expressed in the work by Yazdanie and Orehounig [42], finding that significant gaps exist in the field of energy system models for municipalities and cities related to, among other factors, a lack of integrated modelling approaches and data availability.

In a study on methods and tools for urban energy systems, Manfren et al. [25] summarise critical challenges in the transition toward efficient district energy systems. These include the balancing of supply and demand while taking into account local specifics related to energy, economic, and environmental resources. To meet these challenges, Manfren et al. argue that there is a need for innovative tools capable of supporting the transition at a community level. This is a point also emphasised in Huang et al. [27], arguing that existing tools do not sufficiently support assessment of energy demands at a community level and applying existing tools such as EnergyPLAN [43,44] or RETScreen [45] is challenging since accurately defining a system is a difficult process for planners. Finally, McDowall and Geels distil ten key challenges for computer models used in energy transition planning [46], and the fundamental challenge of representing transitions in a single framework or approach.

Hence, from this brief overview of tool usage in decentralised energy planning, it appears that despite how a large number of tools are available for energy system modelling and analysis, a gap appears to be present for tools supporting decision makers at a local or community level [47].

3. Methodology

This section first introduces the qualitative framework approach and how it applies to this study, followed by an introduction of the four main topics used to structure the analyses. Lastly, this section presents the process for the interview data collected from the case municipalities.

3.1. Qualitative Framework Approach

This study relies on empirical multiple-case research using interviews with municipal planners and a review of existing municipal plans and strategies. A multiple-case research design includes analytical benefits and potentially greater validity due to the potential for replication and comparison [48,49]. Thus, for the purpose of this study, a multiple-case design is chosen so that the case-specific findings can complement each other, thus presenting stronger findings. A multiple-case research design is particularly applicable given the scope of this study being identifying design principles for a tool that is relevant and helpful to municipalities in general, and not only within a very specific setting and country.

For the data analysis, a qualitative framework approach [50,51] is applied: a deductive approach taking as a starting point the pre-set aims and objectives, and a priori reasoning. Figure 1 presents the five stages of this analytical process.

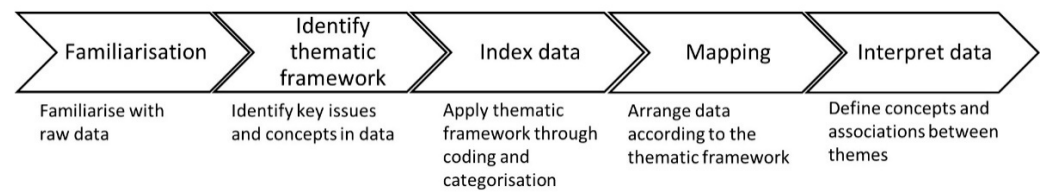


Figure 1. Stages of data analysis in the qualitative framework approach [50,51].

The raw data for this study consist of interview transcriptions and questionnaires from municipal planners at the case sites, supplemented by a review of municipal energy plans or strategies, if available. These data were coded and categorised according to the following four topics, to highlight common themes and issues across the case municipalities [52].

To identify tool design principles, it is relevant both to shed light on what kind of tools and processes are applied presently, as well as the reason for why they are utilised. Furthermore, if the municipalities do not currently use energy system modelling tools in their planning, determining what alternative processes the municipalities then use to prioritise actions or solutions is important. It may also be that municipalities do not consider such tools relevant to their planning practice. In that case, it is important to uncover why, and how tools should be adjusted in the future, to accommodate the planning practices of the municipalities.

The analyses are structured according to four main topics to uncover how the case municipalities approach energy planning and common requirements for future energy system modelling tools. These are selected based on the state-of-the-art review of energy system planning and energy system modelling in Section 2.1 and tool usage in decentralised energy planning in Section 2.2.

- Long-term planning goals—uncovering both the nature of the goals that are considered most important by the case municipalities, as well as the planning horizon for these goals.
- Tool and scenario use—knowledge and understanding of whether quantitative and qualitative scenarios are already used to guide prioritisation of technologies and actions, and if so, what type of scenarios are investigated.
- Delimitation and criteria—determining how the case municipalities perceive their own decentralised energy system, and how this energy system is delimited from national energy systems. Additionally, what criteria the case municipalities apply when comparing alternatives with the purpose of identifying optimal solutions.
- Capacity and competences—the number of people actively involved in energy planning, and to what extent they are involved. Additionally, the internal and external resources available and the level of technical knowledge and skill of the people involved in planning.

The four topics together provide insights into the energy planning practices of the municipalities. The planning practices of the municipalities are considered a synthesis of these four topics. The researcher subsequently needs to translate the planning practices of municipal planners to tool design principles and these practices are interpreted so that meaningful tool design principles can be identified.

3.2. Interview Data Collection

Four interviews were conducted with municipal planners from within the municipal organisations; for Osimo and Valladolid from the environmental and sustainability departments, as there are no energy planning specific departments, and for Eilat from the energy planning department. Oud-Heverlee is an exception to this because due to the small size of the municipality and the administrative structure in Belgium, the municipality does not have a dedicated environmental or energy planning office on a municipal level. Instead, a local representative from the Belgian research and development company Think E, in-

volved in managing a demonstration plant in Oud-Heverlee and actively engaging with the local administration, has provided the needed insights for Oud-Heverlee.

The interviews were carried out throughout the autumn of 2019 and conducted as semi-structured interviews based on a pre-established interview guide. The semi-structured interview approach was chosen because of its flexibility, where a rigid interview approach would not to the same extent allow the researcher to pursue important topics that emerge during the interview [53], thus complementing the exploratory nature of the study.

The interview guide was structured according to the four main topics presented in Section 3.1.

For the first topic *Long-term planning goals*, the aim was to uncover goals and strategies relevant for the energy sector in the municipalities. This may include actual energy strategies, as well as strategies for transportation, built environment, land use, etc., in addition to any technological development focus from the municipalities, i.e., do the municipalities have untargeted potentials for implementing wind power, photovoltaics (PVs), energy savings, etc., and if so, how can energy system modelling tools help realise these potentials.

For the second topic *Tool and scenario use*, the questions to the case municipalities revolve around if and how scenarios, tools, processes, and energy system modelling are presently utilised for energy planning purposes. This may include the use of computer tools but could just as well include qualitative planning processes such as procedures for the involvement of local stakeholders.

For the third topic *Delimitation and criteria*, interview questions were aimed at identifying how the municipalities delimit energy planning, both in terms of geographical boundaries, and from a technical perspective, i.e., what energy sectors are considered pertinent to the municipal energy planning practice.

Finally, for the fourth topic *Capacity and competences*, the aim was to uncover the resources available to the municipality both with regard to availability of personnel, energy planning specific expertise, and technical capabilities.

The interview guide used for the semi-structured interviews is included as Appendix A.

4. Case Municipalities

Four case municipalities are included, encompassing a diverse range of physical conditions and institutional settings. The case municipalities of this article are included as demonstration sites (physical and virtual) in the MUSE GRIDS project [29], forming the basis of this work.

Firstly, the case municipalities are located at vastly different geographical locations, thus representing different countries and planning practices. Secondly, the chosen case municipalities encounter vastly different challenges from an energy system perspective. These challenges relate to the fulfilment of energy demands such as heating and cooling, differences in the reliability of the national electricity grid, and differences in the availability of renewable energy resources. However, common for all case municipalities is that they are all engaged in energy planning either through the presence of energy-related goals or through existing energy plans or strategies.

The four case municipalities included in the study are presented in the following.

4.1. Osimo (Italy)

Osimo municipality consists mainly of the city of Osimo with approximately 35,000 inhabitants, located in the Marche Region in central Italy. Osimo is a historic city with primarily low-efficiency buildings, and a weak connection to the national electricity grid. Because of the weak connection to the national electricity grid, the municipality has also established itself as a local micro-grid with a variety of installed technologies, including a 1.2 MW_e gas combined heat and power (CHP) engine serving a small district heating area, 30 MW PV, 400 kW mini-hydro, and two biogas plants. Most of the energy networks

(water, natural gas, district heating, and electricity), alongside an early-stage electric vehicle programme, are managed by a local multi-utility public shareholding company.

4.2. Oud-Heverlee (Belgium)

Oud-Heverlee is a municipality in Belgium slightly east of Bruxelles with approximately 11,000 inhabitants. It is one of 300 independent municipalities of the Flemish region. In Belgium, the municipality is the lowest level of administration and thus the administrative level closest to the individual. Because of the Belgian administrative structure and the generally small municipalities, energy and environmental planning efforts are conducted in collaboration with the regional level. In 2015, the municipality developed a climate action plan as part of the Covenant of Mayors [54], and to contribute to the fulfilment of the European 2020 climate objectives. Within the municipality, a project demonstrating the potential synergy effects for flexibility, grid balancing, and load shifting through the use of electric storage, electric vehicles, and photovoltaics is being undertaken [29]. There is already a considerable amount of heat pumps and electric vehicles present, and the distribution system is not fit for an additional load, which is why such a neighbourhood micro-grid is being established.

4.3. Eilat (Israel)

Eilat, a popular tourist city, is the southernmost city in Israel with approximately 50,000 inhabitants. In Israel, the municipalities are one of three types of local authorities, generally for administering cities with over 20,000 inhabitants. Smaller towns and rural settlements are instead governed by local councils and regional councils, but with similar authority and responsibilities as the municipalities. The municipality of Eilat is implementing a plan to become energy independent by 2021. The very substantial tourist sector of Eilat results in large seasonal differences in energy demands between the peak summer and winter tourist season. Further, because of the hot desert climate and year-round high ambient temperatures, the demand for cooling is very high.

4.4. Valladolid (Spain)

Valladolid is a city located in the northwest part of Spain with approximately 310,000 inhabitants, where the Mediterranean climate provides strong solar resources but also large cooling demands. Municipalities in Spain are independent authorities but are also the lowest level of local governance in Spain, exceeded by the provinces and autonomous communities. The municipality has sought to encourage residents to carry out renovation works through urban retrofitting plans. In 2011, the municipality signed the Covenant of Mayors initiative, indicating their commitment to reducing CO₂ emissions.

5. Municipal Planning Practices and Tool Design Principles

This section presents the most important results related to each of the four topics introduced in Section 3.1. While the presented findings are case specific by nature, it is through comparison sought to determine important similarities and differences in the planning practices among the municipalities and from that determine tool design principles.

In the following sections, the findings presented in Figure 2 are elaborated.

5.1. Long-Term Planning Goals

An observation based on the collected interview data is the distinct lack of long-term goals among the municipalities, which is also evident in similar research [11]. The case municipalities generally prioritise some areas for the short term, and sometimes set concrete CO₂ or energy consumption reduction goals. However, the time horizon for these goals appears to be limited to the coming one- to four-year period. This is, for example, the case in Osimo, which as a municipality has defined a goal of reducing energy consumption and CO₂ emissions, but has not decided on a concrete reduction target or an official time horizon. The predominantly short planning horizon is typical in carbon governance and

could stem from the way municipalities are organised and function, where typically a new municipal council is elected every few years (e.g., four) [34,55].

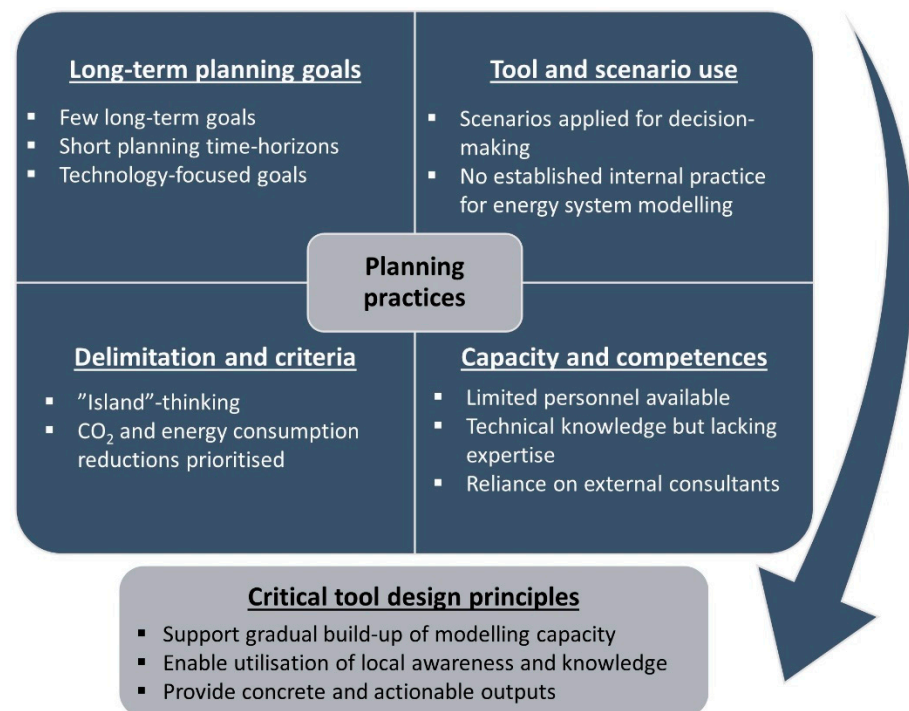


Figure 2. Main findings summarised.

The goals that are in place in the case municipalities are mostly of a sectoral nature, as opposed to holistic or integrated energy plans. As such, the municipalities may mention a number of different focus areas, for instance, increased deployment of electric vehicle charging stations, or information campaigns advocating for increased insulation of residential housing to promote energy savings. The municipal emphasis on technologically oriented goals is verified by Petersen [15], in a study on the application of renewable energy policy in Danish municipalities. Petersen argues that this emphasis is a result of a predominantly top-down planning approach conducted by a few actors, thus leading to limited involvement of the local community in the framing and development of strategies. Focusing on such highly technology-oriented goals can lead to reduced attention to genuine sector integration and holistic energy systems.

For Osimo, Oud-Heverlee, and Valladolid, the European Covenant of Mayors initiative has functioned as an encouragement in the formulation of a climate action plan. Energy planning has otherwise not garnered significant attention here, but the Covenant of Mayors initiative has helped formulate both broad sustainability agendas and specific actions to pursue related to the energy sector. Most central is the 2020 CO₂ emission reduction goal of 20% adopted by these three municipalities. Adoption of this goal has provided the municipalities with a long-term target, which has, however, proven to be unattainable for the municipalities, perhaps in part due to the target not being binding. In Valladolid, for example, CO₂ emissions have only been reduced by 8.21%. The expiration of the 2020 targets left the municipalities in a void—however, new targets have since been established [56].

For municipalities such as Eilat, located in weak grid areas, energy independence is considered one of the most important priorities of the future energy system. Other municipalities such as Osimo and Oud-Heverlee have not mentioned this as a priority, likely because of the more reliable local electricity grid in these areas. From this, it thus appears that whether the municipalities actually have ambitions for energy autonomy is dependent on the local context. The ability to assess the capability of a system for island

mode operation should, however, not be deemed irrelevant and could in fact for some municipalities be an important criterion when choosing an energy system modelling tool.

Prioritising future development areas appears to be another challenge for the case municipalities. The municipalities do generally have an idea of what areas or sectors they want to target but find it difficult to prioritise technological solutions and initiatives. Osimo, for example, wishes to prioritise solutions with the greatest economic and environmental benefits to the local community, but have not identified a methodology to do so.

Municipalities have a broad field of interest and range of responsibilities; something to keep in mind when conducting energy planning. Plans and strategies for the energy sector will need to align with a range of parallel efforts in, e.g., water management, spatial planning, or biodiversity, among many others.

5.2. Tool and Scenario Use

The current practice for energy planning in the case municipalities appears to primarily revolve around isolated energy-related initiatives, while coordination across sectors is limited. This can be exemplified through some of the initiatives of Oud-Heverlee such as assistance in home thermoscans for assessing heat losses, or facilitation of group PV purchases. These are sensible and sustainable actions, but their individual influence on the attainment of a larger goal of a sustainable energy system is unsubstantiated.

From the interaction with the case municipalities, it appears that the extent to which integrated energy planning is conducted as part of the typical planning practice in the municipalities is limited. Instead, the municipalities work towards implementing specific technology-centric measures, for example, electric vehicle charging stations or support for the installation of PV panels. While these concrete initiatives are important and needed in the transition to renewable energy, it also appears that the municipalities may not always have the necessary overview of the effect on the entire energy system. This point was also expressed in the previous Section 4.1, but is nevertheless also highly relevant here, as it is also an indication of how and for what purpose tools and scenarios are applied, and not only what planning goals exist. According to Mirakyan and De Guio [37], integrated energy planning, incorporating more holistic effects and synergies, is generally mostly performed at a national level, thus aligning well with the findings based on the case municipalities.

In general, the requirements for energy system modelling increase along with the transition to renewable energy supply [1,11]. The argument behind this is that in the early stages of renewable energy implementation, relying on simple scenarios such as annual energy balances is unproblematic. However, from the discussions with the case municipalities, such an approach seems to be prevalent still, despite the ongoing transition to integrated and renewable energy systems.

The case municipalities do have experience in applying scenarios from external consultants based on annual energy balances as part of their planning practices, however, the municipalities have no or very little experience actually developing and applying energy system simulation or scenario-making tools. This leads to an emphasis on the output: scenarios that are used to describe a plausible energy future. This is likely a result of the lack of experience with model development and thus a lack of expertise needed to critically assess the inputs and assumptions included in the development of scenarios and models. This leads to a simplistic use of energy system models “as is”, as opposed to tailoring of the models.

Energy system modelling and tool usage is not a well-established part of the energy planning practice of the case municipalities. In general, across the case municipalities, it seems that energy planning is not well defined internally, and instead, energy planning tasks are spread across different departments. This results in a large variance in the background of the municipal planners working with energy planning and thus a lack of designated energy planners with the associated expertise.

5.3. Delimitation and Criteria

The case municipalities are very diverse, leading to different prioritisation strategies. A general consideration for energy planning in municipalities is how awareness of local challenges and characteristics is pivotal to successful planning. This is a point that was especially stressed by Eilat Municipality, emphasising how all cities have their own unique business sectors. Eilat, in particular, has a significant service sector as a result of an important tourist sector, which, combined with the high ambient temperatures, leads to large seasonal variations in energy demands due to extensive cooling demands. While this challenge is not present in the other case municipalities, they instead have other local challenges to consider, such as depopulation, or stability of the electricity grid.

Generally, the municipalities consider a range of sectors important to the transition, of which the most often mentioned sectors are the residential, industrial, service, and transport sectors. Sectors which are largely beyond the control of the municipalities, such as electricity generation, are in some cases de-emphasised. This is, for example, the case in the European case municipalities, where the national electricity grid is also predominantly considered stable. On the other hand, municipalities such as Eilat with a desire to become energy independent and even disconnect from the national grid at times, consider the increase in local electricity generation to be a critical part of future energy strategies.

As mentioned, the case municipalities are seemingly aware of how a sustainable development of the energy system requires the continuous development and integration of a multitude of sectors. Some of the case municipalities do, however, describe a narrow focus of their energy planning practices, emphasising initiatives, particularly in the buildings and transport sector. One plausible explanation for the increased attention to these sectors specifically is that the municipalities find that they have the most direct influence on the development here. Therefore, energy system modelling tools should enable the planning and prioritisation of these sectors that are important to the municipalities, but preferably also provide the tools needed for the municipalities to expand on their area of operation.

Despite differences in how the four case municipalities are connected to the national electricity grid, they all, to some extent, consider their own energy system to be separate entities. This is exemplified through the presence of local energy goals applying the geographical municipality border as a limitation to the energy system. Energy-related goals such as, for example, CO₂ emissions or energy savings, are accounted for on a municipal level, and energy system modelling tools should enable capturing this perceived reality. The extent to which this “island operation” thinking is present varies and is most striking in Eilat where actual ambitions for at least partial island off-grid operation exist. For the tool design process, acknowledging that the case municipalities strictly consider their responsibility area to be within the municipal border is an important realisation and something to incorporate in the tool design.

A number of important assessment criteria have been mentioned by the case municipalities, of which the four most important are outlined below.

- Costs are naturally, and without exception, considered an important criterion to the case municipalities when assessing energy initiatives or alternatives. Incurred costs do, however, constantly need to be assessed in accordance with the obtained benefits to society.
- CO₂ emissions are included as a goal in the European municipalities Osimo, Oud-Heverlee, and Valladolid, but are, for example, in Eilat, not considered to be a critical criterion in the municipal energy planning. This appears to be the case because the development of the energy system is not solely motivated by environmental concerns but to improve the livelihood of the local community.
- Energy savings are generally considered an important target in energy planning strategies due to a combination of economic and environmental concerns.
- Energy independence relates to the ambition of having an energy system capable of operating partially in an off-grid operation mode. Ambitions for energy independence

are most prevalent in weak grid areas and relate to the goal of having high security of supply and energy resiliency, regardless of the status of the national electricity grid.

5.4. Capacity and Competences

In the case municipalities, few civil servants are working specifically with energy planning. Energy planning is often conducted by associated departments such as environmental offices, transport offices, and similar. The people who do work exclusively or mainly with energy planning often emphasise the implementation of specific projects or tasks. This may include PV incentives and support schemes, transport strategies, etc., as opposed to integrated energy planning which is not embedded in the planning practice of the municipalities.

Municipal planners from the case municipalities generally seem to have technical education and thus knowledge, however, the level of expertise needed to conduct energy system modelling and analysis is rarely present within the municipalities. Instead, municipalities rely on external consultancies and experts to supply these analyses. This finding aligns well with the findings in Petersen [15], depicting the nature and application of strategic energy planning in municipalities. Petersen states how often small- and medium-sized municipalities rely on external consultants for the development of municipal energy plans and strategies. A significant drawback of such an approach is the typical top-down methodology applied by external actors; a methodology that might not capture the differences between municipalities.

Relying on an external consultancy requires significant financial resources and is not always an option for smaller municipalities with limited budgets. If, instead, the municipalities were capable of developing the necessary models and scenarios themselves, their understanding and ownership of the plans would likely be much greater and make it easier to include local differences through a bottom-up approach. Ownership of the model and plan would likely also be greater and making future alternations to the model or testing alternative scenarios would be easier.

Tool usage for energy planning and modelling within the case municipalities is limited to basic Microsoft Office applications including Microsoft Excel and, in some instances, geographical information system-based applications. This presents a challenge for tool development since preferably both the inputs for the tool and the results would be in a format that is simple and intuitive for the municipalities to use. This could, for example, be in the form of Microsoft Excel inputs and outputs, or some other form of intuitive interface guiding the user through the process of including the required input data. Likewise, important model outputs providing a general overview of system operation should be easily available, and not hidden in a clutter of complex data points that the user will first need to sort and analyse.

6. Discussion and Conclusions

This study investigated the energy planning practices of four municipalities so that future energy system modelling tools can be tailored to the specific requirements of developing energy system scenarios in a municipal context. The research focuses on the very early stage of tool development, taking as a starting point the planning practices and needs of municipalities to uncover critical tool design principles.

The study provides practical guidance to researchers and model developers looking to develop energy system modelling tools for municipal-level energy planning. Furthermore, the collected practical experiences and insights from energy planning in the case municipalities can be transferred and function as an inspiration to other municipalities aiming to have an increased emphasis on energy planning and strategy creation.

Three principles should guide the future development of energy system modelling tools aimed at the municipal level and municipal planners.

- Support gradual build-up of internal modelling capacity.
- Enable utilisation of local awareness and knowledge.

- Provide concrete and actionable outputs.

The case municipalities generally have a positive attitude towards energy system modelling; they recognise the value of having internal modelling capacity and consider energy system scenario making and analysis to be important in the development of future renewable energy strategies. However, most do not possess the internal resources to conduct such energy system modelling. The municipal planners generally have some technical or engineering background, but still do not possess the energy-specific expertise needed. This is likely a by-product of the diverse area of responsibility for the planners. The case municipalities only have a few people working explicitly with energy planning, and in some cases, there are no dedicated energy planners available. Hence, energy planning tasks are often conducted by planners with a different area of expertise.

Energy system modelling tools should be approachable for municipal planners, or they will not be incorporated in the energy planning practice. A solution could be to have a tool that functions at different complexity levels; a basic level requiring fewer input parameters, and an advanced level requiring a larger range of inputs, thereby enabling more complex analyses and the provision of more detailed outputs. In simulation models, it is more apparent that model outputs are the result of the input data, restriction criteria, and choice of evaluation criteria. A simulation model may thus better enable the build-up of local energy system knowledge and awareness of the range of alternatives available and more active use of energy system modelling, as opposed to an optimisation-based approach emphasising one optimal solution.

The municipal planners are local experts, both in terms of characteristics of their local energy system, but also in terms of the ambitions and strategies guiding the development of the municipality as a whole. These local insights are valuable assets for energy system modelling, and tools should be flexible enough to allow these insights to be included in the modelling process.

Municipalities appear to have a practical approach to energy planning, emphasising concrete measures and initiatives, e.g., in the form of energy-saving measures, or through concrete strategic goals such as energy demand reductions or CO₂ emission reduction. Tools need to support this approach, and aid municipal planners in designing scenarios with measures and changes that are relevant and actionable at a municipal level. Furthermore, tool outputs and results should be concrete and transparent, giving the user an immediate understanding of how strategic energy targets are impacted by the modelled scenarios. Having more concrete and transparent results would also assist energy planners in engaging in discussions and collaborations with colleagues from other areas, or engaging with citizens to strengthen the support for energy initiatives through an increased sense of ownership and involvement.

The established understanding of what constitutes energy planning is an important delimitation to the applicability of the findings from this study. The findings need to be considered from a holistic energy transition planning perspective, balancing the demands and requirements of multiple energy (sub-)sectors, while maintaining a holistic overview of the entire energy system. This is different from traditional expansion planning by utility companies, or building-level energy efficiency assessments, which both can sometimes be referred to as energy planning, but are fundamentally different, and thus require different tools.

The tool design principles established in this study should be considered by tool and model developers when developing future tools targeting the municipal scale, so that the existing gap between planning practitioners and model developers may be bridged. In future research, it would be valuable to document how the municipalities proceed with applying such tools that have been developed specifically for the context of municipal planning, and in particular how quantitative and qualitative aspects are combined.

The tool design principles established in this study will in future research form the basis of an energy planning tool developed for municipal energy planning. This tool will be documented in future research along with the experiences from the four municipalities

included in this article in applying the tool for energy system analysis and developing energy scenarios.

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Appendix A

Interview guide for interviews with case municipalities.

1. Introductory questions
 - (1) What is your position and role in the municipality?
 - (2) What is your professional background?
 - (3) Are you engaged in energy planning? (By energy planning is here meant the process of helping steer the development of the local, regional or national energy system by setting targets and establishing the means of measures for reaching the targets. For local level, it can include setting requirements for what heating technologies may be applied in given district, requirements for solar collectors, or setting minimum insulation standards.)
 - (4) What type of energy planning tasks are you engaged in?
2. Long-term planning goals
 - (1) What is your municipality’s long-term low carbon end target? e.g., 2030 zero carbon; reduction of air pollution, access to electricity, etc.
 - (2) What current energy-related plans/strategies and goals does your municipality have, i.e., mobility, built environment, land-use, others?
 - (a) Which of these will you use within an integrated energy plan/strategy?
 - (b) What is your process to integrate these current plans into an overall integrated energy plan?
 - (3) What technologies do you have a focus on implementing—and what technologies still have an untargeted potential for implementing (for both questions e.g., wind power, photo voltaics, solar collectors, district cooling, energy savings,...)
3. Tool and scenario use
 - (1) Do you work with quantitative and/or qualitative scenarios in the municipality?
 - (a) If no, how else will you identify the “right” technologies/actions/solutions for the future?
 - (2) Do you use any other tools and processes (complementary to scenarios) for identifying technologies and solutions?
 - (3) Do you use energy systems modelling tools in the municipal planning?
 - (a) If not—would that be likely to change in future?
 - (4) What changes do you foresee to influence the energy system? (e.g., if demands are increasing at a certain pace due to population growth and a growing economy and if there already are plans for expansion of certain technologies—e.g., a new wind farm)
 - (5) What changes are relevant within the area? (e.g., what renewable energy technologies have good potential there; if there are savings potentials; if district heating or cooling are relevant there)

4. Delimitation and criteria
 - (1) What assessment criteria are applied to determine best or optimal scenarios? (e.g., cost to residents, external costs (e.g., from pollution), self-sufficiency, ease of implementation, ability to create a system in balance not relying on import/export, . . .)
 - (2) What sectors are considered in present energy planning in the municipality—and if different—which should be considered in the future? (e.g., electricity, heating, cooling/residential, industrial, service, transport)
 - (3) Do you have any thoughts on the geographical delimitation/boundaries of the area for energy planning?
5. Capacity and competences
 1. How many inside the municipality are involved in energy planning—and is this their primary focus or is it secondary to other planning tasks (spatial planning, traffic planning, environmental planning)
 2. Is there access to external consultants?
 3. What types of resources are available internally and externally? See table for examples.

Table A1. Categorisation of municipal energy planning resources.

	Internal Resources	External Resources
Human resources	What are the municipal/city planners' <ul style="list-style-type: none"> • Educational background • Experience with energy (technical) • Experience with energy (planning/implementation) • Level of experience with Excel • Level of experience with GIS tools • Level of experience with MatLab • Level of experience with Python 	Is there access (also e.g., within budgetary restraints) to experts with experience within <ul style="list-style-type: none"> • Energy (technical) • Energy (planning/implementation) • Excel • GIS tools • MatLAB • Python
	Technical resources <ul style="list-style-type: none"> • Access to computer with <ul style="list-style-type: none"> • Excel • GIS tools (E.g. ArcGIS or other) • MatLab • Python • What OS do your work computers use: <ul style="list-style-type: none"> • Microsoft Windows • MacOS • Linux 	

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