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Energy plans in practice: The making of thermal energy storage in urban Denmark

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ABSTRACT

Much of the academic literature that investigates energy planning focuses on the development of plans but overlooks how they shape actors' situated sensemaking in the field. This paper followed the process of realizing a sector-coupling investment in a thermal energy storage in Copenhagen from 2017 to 2020. The analysis shows that while plans may help to define technological qualities and purposes, they do not always convince actors. Plans simultaneously close down technological uncertainty and open up others and through this cycle the energy planning process moves forward. The paper concludes by outlining new perspectives on the making and use of plans and provides recommendations for those who are participating in increasingly complex energy system transitions.

1. Introduction

Energy plans are central to energy transition processes towards low-carbon and efficient energy supply. They are made to inform, guide, and steer energy transition processes. For example, plans are acknowledged to provide insights for steering transitions [1], guide decision-making under high uncertainty [2], or promote alternative technological pathways [3]. This paper analyses how energy plans help to guide actors who are navigating uncertain and ambiguous energy transitions [4]. Actors in the middle of ongoing energy transitions need to make decisions while lacking knowledge about what effect their actions may have, and they, therefore, often turn to knowledge generation in order to reduce uncertainty, assess their options, or predict the consequences of their actions. While plans are used extensively both in scientific and professional energy planning communities, the way in which they are used has not received much attention. In order to address this research gap, this paper takes a novel approach by investigating how energy plans informed the sensemaking processes of actors investing in an innovative technology. This paper contributes to the existing energy planning literature by reflecting upon the actual use of plans, instead of assuming their usefulness in uncertain situations. This is achieved by way of a case study that follows the process of investing in a Thermal Energy Storage (TES), from it being outlined as one among many important technologies for low carbon energy systems to the final decision to invest in the TES.

Drawing on the existing perspectives on models and plans [5,6], we understand plans as narrative and calculative devices which, through their circulation among actors, build and maintain socio-technical imaginaries [7]. Concretely, several energy scenarios (e.g. business as usual, specific technological trajectories or ambitious policies) outline a number of possible development paths and are inscribed into energy plans [8]. These scenarios are generated by practitioners who, using energy modelling software, simplify and highlight certain aspects of reality [9]. Taking a pragmatic approach, this paper understands energy plans not as mirroring an outside and pre-defined reality, but instead, as actively contributing to creating it [10]. Energy plans can thus be understood as boundary objects, i.e., objects that are flexible and obdurate enough to allow coordination between actors [11]. For example, Taylor et al. [12] describe how the MARKAL energy model functions as a boundary object that enables communication between UK academic and policy communities.

The aim of energy plans is often to describe optimal system developments. They may include techno-economic designs for decarbonized national energy systems [13], ways to integrate intermittent electricity production across Europe [14], or outline a decarbonized worldwide energy supply [15]. While energy plans outline different technological pathways, the way in which these plans are applied in the 'outside world' is far from straightforward.

In this paper, the attention to how plans are used and their role in energy transitions is inspired by Weick [16]. Weick relates a story of a

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lost group of soldiers in the Swiss Alps who, luckily, find a map that helps them make their way back to camp. Once they have safely returned to camp, the soldiers realize that the map they used was actually not one of the Alps, but one of the Pyrenees. Weick [16] then concludes that, instead of simply prescribing geographical information, the map enabled the soldiers to generate action in particular ways which, eventually, stimulated them to return to their camp. He concludes that "*an imperfect map proved good enough*" [16]. Maps may stimulate emergent action in a specific context, provoking thoughts about what has happened and what should happen next. The map helped the soldiers find their way back, not by giving correct information, but by giving them belief in their actions, which stimulated reflexive action in reading the landscape and a sense of success. By analogy, plans can assist actors in situations of uncertainty because they provoke actions and set directions and not because they impose certain conclusions. Energy planners, modelers and practitioners often advocate calculating optimal solutions and use complex models that can capture the inherent 'reality' of a situation [17,18]. Instead, we argue that the use, potential efficiency, and ability to apply these plans does not merely depend on the accuracy of the plans in measuring an 'outside' reality. This argument is also supported by recent contributions to energy plans studies. For example, Ben Amer et al., in their study how Danish municipalities use energy models, show that the models are too complicated, too narrow, and lack synergies across energy domains when used in practice [19]. Taylor et al. argue that the MARKAL model facilitates communication across a number of actors, despite having a limited techno-economic focus [12]. Furthermore, other scholars have argued that municipalities may lack the resources and knowledge to comprehend and integrate complex models into their day-to-day planning activities [20].

Therefore, increasing the complexity, scope or boundary of energy plans does not equate to the successful realization of the conclusion and recommendations of a plan. Studies of urban energy planning show that even cities with ambitious energy plans fail to connect long-term visions with short-term action [21]. In a literature review of Strategic Energy Planning, Krog and Sperling [20] found that most of the literature focuses on technical aspects and neglects the implementation of technologies in real-world applications. Plans often promote specific paths of development, which may conflict with other proposals such as choosing between paths of new low-carbon supply or energy savings [22], or between centralized nuclear power supply and decentralized wind power energy systems [23]. Braunreiter and Blumer [24] show that energy scenarios are, broadly, either used as plausible futures or as data sources, but with a lack of guidance from the authors, scenarios can also be misrepresented when used. In other words, energy plans are not the result of objective engineering computations, instead they are intertwined with the specific purposes, agendas, analytical assumptions and discourses of their authors [25]. While not much attention has been given to the situated use of plans, there is growing recognition in the energy planning literature that plans work in more complicated ways instead of just following a linear path from the finished plan to the materialization of their conclusions.

This paper thus asks the following question: How do energy plans participate in energy transitions processes? In order to answer this question, this paper follows the investment process for a Thermal Energy Storage (TES) in the Greater Copenhagen District Heating (DH) system, from the publication of a national decarbonisation strategy in 2012 until the final investment decision in the TES in 2020. The paper investigates how several plans participated in the process of establishing the TES. In technological terms, TES is a rather simple technology; an area is excavated to make room for storing large amounts of heated water, which is then used in a district heating system. While the technology itself is not new, the organization, business model, usage and operation are challenging dimensions of the technology. Energy storage is a technology that has significant potential for energy system integration across sectors, achieving energy efficient and low-carbon supply [3]. Energy storage applications often need to engage with stakeholders in novel ways, which may require new partnerships to achieve adoption [26], or consider the practices of their users [27] to overcome social and cultural barriers [28]. Energy storage therefore might face different challenges compared to electricity generation such as wind turbines and photovoltaics, due to their new role in the energy system. The majority of the literature with social science perspective on energy storage either deals with electrical storage [29–32] or TES on a household level [27,28].

By using interviews and following the plans published, the paper follows the actors and their activities and traces the effects of the plans that promoted TES as a low-carbon and sector-integrating technology in Greater Copenhagen through three instances. First, a low-carbon pathway for the Greater Copenhagen DH system was outlined in a series of studies, in which TES was promoted as one among many solutions due to its ability to connect the electricity and heating sectors. Second, the operation of the TES in the Greater Copenhagen DH system was decided through energy system calculations and discussions about the specific use, qualities, and potential benefits of the TES. Third, the actors had to establish a viable business model for the new technology and split investment costs and benefits between the involved actors in the Greater Copenhagen DH system.

The paper is structured as follows: First, our theoretical approach to sensemaking in energy planning is presented. Section two outlines the methodological approach and the research design used for investigating how plans participated in this case of energy planning. The third section provides a general introduction to the Greater Copenhagen DH system. The main case is then presented, which is split into three sections. The article finishes with a discussion of the research and conclusions.

2. Sensemaking in energy planning

Sensemaking is the processes by which individuals and groups attempt to interpret, make sense of, and navigate novel, uncertain or ambiguous situations [16]. Processes involving innovation, strategy-making or "future-oriented" decisions are often characterized by several cycles of sensemaking and sense giving, in which members of the collective attempt to influence the common understanding of the situation [33]. As such, sensemaking processes may both entail processes at the level of the individual or the collective, whereby information, arguments and positions must be communicated and exchanged between actors [33].

A central notion in sensemaking is that action is required to produce knowledge [34], and that the inquirer can only learn about the object of inquiry by manipulating it [35]. Trying things out can be expensive, time consuming, if not outright dangerous and, therefore, energy planners, researchers, and scholars have developed epistemic devices, in the form of energy models, calculations and simulations, to be able to test their proposals, actions, and ideas before implementing them in real world applications.

Processes of sensemaking, therefore, depend on both the actors, their situations and the socio-technical equipment [36] such as the plans and other knowledge devices brought to the process to make sense of the situations [37,38]. Such dynamics in processes of knowing or sensemaking always shape actors whether they are lost (as the soldiers in the mountains), are making sense of uncertain situations or negotiating between different positions. Making sense of an object is a collective effort, which takes place between heterogeneous actors, all of whom have their own particular understanding of the situation [36].

Knowing an object requires establishing and bringing forward properties through measurements, analyses and judgements, which can be achieved by the use of analytical models, simulations, data and statistics [37,38]. A central point is that the qualities are not intrinsic to the technology but are instead constructed through the analytical model. Bringing a technology into being often follows the standard requirements used by planners to make its effects plausible but also to highlight its use within a socio-technical complex, e.g., defining the technology in legal, operational, economic, and material ways, taking into account specific knowledge, habits, and routines of the users [39]. These activities are not neutral as it is the analytical models and epistemic equipment that bring out the technological qualities in specific ways. For example, Garud et al. [40] show that nuclear power has been categorized as being *"emission-free", "un-safe", "too-cheap-to-meter"* and *"expensive",* depending on the methods used to describe the qualities of the technology. Similarly, in this paper energy models and methods are understood as being actively involved in generating knowledge about the objects, even if this results in different interpretations of the same technology [41,42].

The purpose of technological appraisal in processes of sensemaking can generally be described as either *opening up* for new inputs, discussions or viewpoints, or *closing down* processes to take decisions or produce agreements [43]. Therefore, making sense of a certain situation and how to act in it relies on knowledge and expertise, the specific socio-technical configuration, the specific type of question and uncertainty, and also how actors will attempt to resolve it and with what equipment. While processes that open up seek to involve new viewpoints and opinions, the aim of technological appraisal for closing down is to choose between options, advocate specific solutions or make suggestions. However, such conclusions are rarely stable for long, and can shift, change or produce new emergent effects [44,45].

The ability to reach closure among heterogeneous collectives of actors can be described as the convergence of a network [46]. Convergent networks gradually develop over time, during which common epistemic practices, trust, communication infrastructure and boundary objects are established and agreed upon. In contrast to weakly convergent networks, in which all practices, theories and knowledge production are contested, debated and are particular to the individual actors, highly convergent networks benefit from an agreement on common measures, calculation practices and a history of working together [47]. In highly convergent networks, all actors do not necessarily do the same task, but they are able to work across diverse disciplines such as economics, engineering, public policy, etc. towards the development of the socio-technical system [46]. Therefore, the outcomes of planning processes are not necessarily the result of rational, optimized paths that have been outlined in a scenario. Outcomes such as 'how to think and what to do with a technology' may be the result that emerges from sensemaking processes involving interaction and negotiation between actors with different understandings [48].

Therefore, our theoretical approach places epistemic devices centre stage in processes of sensemaking in uncertain situations. Actors seek to *close down* uncertainties by defining them in technical, legal, operational or economic ways, thereby producing different categorizations of technology. Such efforts take place in collectives of actors with their diverse understandings, objectives and epistemic approaches to uncertain situations. The ability of these socio-technical actor collectives to work together and coordinate efforts can be described as the convergence of the network. Convergent networks benefit from trust, long-time cooperation and a common language that enables coordination.

3. Research design and methods

Using a longitudinal case study approach, this paper follows the way in which plans are used in energy transitions [49]. The case study approach allows the researcher to explore phenomena in depth; it allows one to follow the actions *in medias res,* amid their unfolding [50]. With this research design, we could study how abstract challenges such as climate change and low-carbon transitions materialize in specific action "*on the ground*" [51]. Following the implementation process of the TES, a new technology, enabled us to explore the ways in which plans are mobilized and used by energy practitioners in situations of high uncertainty [52]. It allowed us to follow the struggles and controversies faced by the practitioners in their attempts to make the world known and actionable as it unfolded, whereas a retrospective historical analysis would only have allowed us to aggregate facts *a posteriori*. [53]. Therefore, the case study is a valuable approach as it can bring new insight into the challenges faced by energy practitioners at a specific time and place [54].

The research process stretched over a period of 4 years from 2017 to 2020. The research can be divided into three phases, which we term *exploration*, *continuation* and *follow-up*. In order to delve into the challenges faced by the implementation of the technology, 13 interviews were conducted from 2017 to 2020, which were supplemented by documents retrieved from different sources and at specific points in time. The next sub-section presents the ways in which the empirical materials were generated. The second sub-section presents how the data was analysed and the last sub-section presents the limitations to this approach.

3.1. Empirical data generation

The *exploration phase* took place during 2017. During this phase, we identified and mapped the DH practitioners involved in the project: the transmission utility VEKS, the DH utility HTF, the heat producers and energy consultants. Six semi-structured interviews were then carried out with the professionals. As the TES was a completely new investment, the interviews were designed to address the uncertainties and challenges confronting the actors. Interviews were conducted with directors, vice directors and energy planners at the transmission utilities, heat producers at utilities and waste incineration plants, the heat production scheduling organization and energy consultants. This first round of interviews enabled us to get an initial idea of the uncertainties and main difficulties and how these were related to the different actors' positions regarding the TES investment. During this time, new reports were also published by the DH practitioners [55], and these provided 'stabilized' information about the project. We then adjusted the design of the interviews to explore the role played by plans in reducing uncertainty, i.e., how they were actively used by the involved actors and why they were commissioned in the first place.

The research process gradually shifted to the *continuation phase* in 2018. During this phase, we kept track of the implementation project through secondary sources, email correspondence with the involved DH practitioners, and we conducted one interview. Furthermore, we followed the challenges faced by the actors in terms of agreeing on the business model. The expectation at the time was that their calculations would provide closure to the process, but in the end they did not achieve this alone. We were unable to gain access to the internal financial calculations due to confidentiality, which presents a limitation to this study.

This phase gradually led to the final decision about whether to invest in 2019 and 2020, the *follow-up* phase. During this time, we carried out six interviews, and we again adapted the questions in order to understand how the agreement to invest was reached and to summarize the entire process. Given the iterative nature of the interviews, which also influenced our own sensemaking process, the follow-up phase was important because it allowed us to verify the quality of the data collected and our own understanding of the field. Therefore, this helped us to validate our findings and conclusions.

The main empirical material in the form of interviews as well as an overview over the actors' role and equipment is summarized in Table 8.1 in the appendix. References to the interviews are given in text and the interview guides are presented in section 8.2 of the appendix.

3.2. Analysing data

Each of the semi-structured interviews was transcribed. The primary and secondary documents were read and searched for content on intended use, purpose, and specific methods of the energy plans. As the amount of empirical data was relatively limited, there was no need to use any coding programs. Instead, we chose to approach the generated material 'abductively', a method which "*alternates between (previous) theory and empirical facts (or clues) whereby both are successively reinterpreted in the light of each other*" [56]. Abductive work is based on rigorous empirical data combined with theoretical and methodological insights to facilitate understanding and the interpretation of the data. This approach allowed us to apply theoretical concepts in a research design solidly based on empirical material [57].

Consistent with Weick's sensemaking, the process leading up to the TES investment involved both shifts in our own sensemaking of the process, while following the sensemaking of the interviewees. For example, we did not know at the beginning that the sensemaking of actors using plans would be a finding that would be so important in the work of professional energy actors. This process allowed us to identify when actors either agreed or disagreed on certain topics, the voices existing in the field, and the different representations of a 'reality'. Once the main voices, controversies and interpretations had been identified, quotes illustrating the issues at hand were then highlighted, and the *final phase* was used to verify our conclusions with the practitioners in the field.

3.3. Methodological limitations

The most recognized limitation to the case study approach is its lack of generalizability [57]. The context in which the TES implementation occurred is specific to the Greater Copenhagen DH system, which limits the conclusions that can be drawn about the role of energy plans in general. This is discussed further in the conclusion of the paper.

Another limitation to the case study approach is that it can be difficult to define the relevant time period for longitudinal studies of energy transitions as they rarely have a clear start or end [58]. Research papers are also limited in length and can only cover a limited perspective. In this paper, the beginning was found through reference to the empirical material, and was chosen as the earliest mention of plans that informed the process. In the following section, we elaborate on the case and its historical development in order to provide some context. The end of research process was also determined through reference to the empirical material and was taken as the point when the final decision to invest in TES was taken. Nevertheless, as discussed below, such implementation and sensemaking processes are never truly completed.

The confidentiality of the calculations and the business models of the DH practitioners represent the final limitation. As they contain information that is regarded as trade secrets, we did not gain access to the actual contracts signed by the involved DH actors. Gaining access to decision making arenas is a challenge for social science energy research, and it needs to be an integrated part of the research design [59].

4. The background of district heating in Copenhagen: A system of pipes, plants, legislation, actors and organizations

During the oil crises in 1973 and 1979, DH began receiving increased attention from the Danish government, which instructed the municipalities to plan for their heat supply [60,61]. Since the introduction of the Heat Supply Act of 1979, DH has been regulated by a *True Cost* (*Hvile i sig selv*) economic principle [62], which stipulates that no profit can be made from heat production, transmission or distribution. Therefore, the utilities can only charge the *True Cost* of heat, including production, operation and maintenance, salaries, and investments. The Heat Supply Act also requires all investments in heat production units to be assessed based on a socio-economic analysis, which encompasses a systems perspective instead of a cost-benefit analysis from the perspective of the individual actors. The Danish Energy Agency provides the methodological and analytical basis for the socio-economic analysis [63].

The Greater Copenhagen DH system is relatively complex in comparison to most of the other Danish DH systems, which are predominantly operated by a single utility, responsible for production, distribution and billing [64]. Fig. 4.1 illustrates the transmission system operators and heat producers in the Greater Copenhagen DH system. In Greater Copenhagen, two transmission system operators (TSO), CTR in the East and VEKS in the West, are responsible for delivering heat from the large CHP and waste incineration units to their respective distribution companies, which send the heat to their customers.

District heating supplies almost 98% of the heat demand in Copenhagen [65]. In 2017, the DH production came from 5 CHP plants (69%) and 3 waste incineration plants (28%), with the remaining heat (3%) being produced by peak production units [66]. The voluntary collaboration, Varmelast ('Heat Load'), schedules the heat production among the CHP and waste incineration plants and peak production units. Varmelast is operated by two TSOs, Greater Copenhagen Utility and the heat production plants, and is staffed by a total of five employees from the TSOs and the utility [67]. The actors engaged in Varmelast agreed that a common organization for scheduling heat production would improve the overall system and benefit all involved actors. Varmelast is thus an example of a new organizational entity facilitating sector coupling and is the outcome of the long-term cooperation between the actors in the Greater Copenhagen DH system.

VEKS and CTR have been collaborating with the other actors to develop a common system since the 1970 s. They are tied together through materially connected infrastructure and are subject to common legislation and regulation, which suggests that a high level of expertise and know-how is present in the Greater Copenhagen DH system. A certain level of trust can be assumed to exist in the Greater Copenhagen DH system, as the Greater Copenhagen DH system has been gradually developed over the course of 50 years through cooperation between the two TSOs, the CHP plants, the waste incineration plants and the local utility companies. Cooperation between the actors manifests itself in several ways. The actors and their infrastructure are tied together through pipes, production units and pressurized heated water, and they have to coordinate the heat supply on a daily basis. The actors are also the subject of the same regulation, which introduced a common planning practice, i.e., the True Cost principle and socio-economic calculations. According to the interviewees, these factors contribute to the highly convergent nature of the Greater Copenhagen DH system.

5. Analysis: How plans participated in sensemaking processes

This section is divided into three analytical sub-sections, each of which covers an instance when plans participated in sensemaking processes. The three parts each present a different use of plans in energy planning and strategy making and are presented here in a chronological order.

5.1. Making a common future for the Copenhagen district heating system

Since 2009, VEKS, CTR and HOFOR (Greater Copenhagen Utility) have been working on the *Heat Plan Copenhagen* (HPC, in Danish: Varmeplan Hovedstaden), which has so far resulted in the publication of three plans. The aim of these plans was to analyse possible scenarios for developing the Greater Copenhagen DH system and to increase cooperation between the two transmission companies and the largest DH utility in the region, Greater Copenhagen Utility. The first report, HPC 1, was published in 2009 [68], and HPC 2 was published in 2011 [69]. The plans were primarily prepared to coordinate the long-term development of the regional infrastructure between the three actors who had commissioned the work, with a focus on security of supply, base load production units and the integration of renewable energy.

In 2012, the Danish Government's new Energy Agreement outlined the path towards a transition to renewable energy [70]. This provided a new framework for the HPCs. The Governmental agreement foresaw an increase in fluctuating renewable power production, increasing use of bioenergy and a move towards more integrated energy systems such as the electrification of the heating and electricity sector and smart

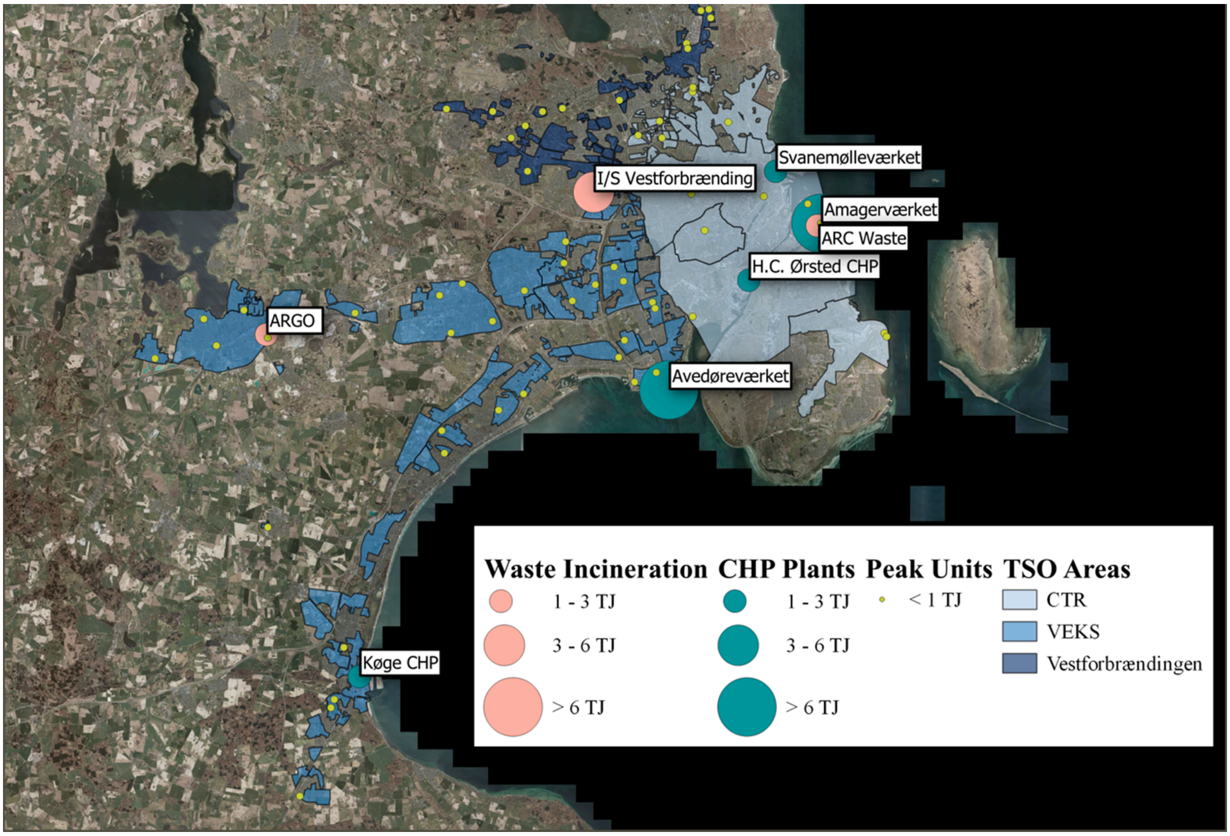

Fig. 4.1. Map of district heating plants and transmission system operators in Greater Copenhagen. Authors' representation based on data from the Danish Energy Agency (2017).

electricity grids [70]. The same year, the Municipality of Copenhagen set the goal to become carbon–neutral by 2025 [71]. These two plans raised the question of how the DH System could be adapted to be in line with the new low-carbon future set by the Danish Government and Copenhagen Municipality. The Danish Energy Agreement thus stimulated action in the Greater Copenhagen DH system: it set the direction towards decarbonized energy systems and prompted VEKS, CTR and HOFOR to calculate and make known how the DH could be decarbonized in time via the preparation of HPC 3.

Work on HPC 3 took place between 2012 and 2014. The plan was based on the new premise, derived from the Danish Energy Agreement, that the energy system had to be carbon neutral by 2025. Therefore, VEKS, CTR and HOFOR identified which investments and conversions were necessary in the short (2025–2030) and long term (2050). The three actors predicted a future with a high proportion of fluctuating electricity production and analysed the impact of this on the Greater Copenhagen DH system [72]. One of the main conclusions of the report was that it was necessary to increase the TES capacity by ten in order to increase the flexibility of the system and to accommodate an increased share of fluctuating electricity resources in the DH system [72]. HPC 3 demonstrated that the implementation of a TES could create the needed flexibility for the energy system to accommodate more fluctuating wind power production and that it could be beneficial for the overall economy of the system:

> *"The analyses indicate that thermal energy storage capacity of several times the current capacity may be economically well-founded. This should be analysed further."* [72]

HPC 3 demonstrated and concluded that an increased TES capacity was economically feasible, and that it would reduce the heat prices and CO_2 emissions. The HPC 3 plan participated in the sensemaking process to determine how the actors could decarbonize their production by identifying suitable new technologies and the necessary capacity needed. However, HPC 3 also left uncertainties as it did not specify who would gain from these investments or how the TES should be operated. These factors were to "*be analysed further*" [72]. Thus, while closing down uncertainties in terms of which technology was necessary for a low carbon future, the HPC 3 simultaneously opened-up and introduced new uncertainties for the actors in that it demonstrated that the TES was central to realizing the decarbonisation goals (closed down) but left room for uncertainties concerning how the TES should be operated (opened up) [43].

5.2. From multiple understandings of energy storage usage to a single operation strategy

The second instance of uncertainty among the actors was related to how the TES should be operated and who would benefit (and how much) from the technology. Three actors in the Greater Copenhagen DH system assessed how additional TES capacity could benefit their operation. Specifically, a DH utility wanted TES capacity in order to improve their power plant operation by allowing flexible electricity production (District Heating Utility 1 Interview 2017). Another DH utility envisioned TES capacity to store excess heat from district cooling production during the summer months (District Heating Utility 2 Interview 2017). Finally, a waste incineration plant wanted to store excess heat during the summer, when heat consumption is low, for the winter period when demand is higher (Waste Incineration Plant Interview 2017). The considered usages were tied to the respective actors' facilities, the technologies they used, and their respective means to increase efficiency.

The actors' socio-technical situation influenced their envisioned use of the TES and, consequently, several different understandings of the technology were present at this time of the process. The TES could potentially be used to store excess heat production from waste incineration or cooling production, integrate renewable electricity production, balance the Greater Copenhagen DH system, decrease peak production, or store solar thermal production for the winter months. Some of these uses were complimentary, while some were mutually exclusive. On the one hand, there is *seasonal storage* operation, whereby heat produced during the summer is stored for when demand is higher in the winter. On the other hand, there is *short-term storage*, following the production of the plant or the system, which stores or delivers heat when it makes sense from an economic or technical point of view.

In order to calculate and define which of the two possible storage uses would be the most feasible, VEKS and a DH Utility interested in TES capacity solicited two technical plans. The first report investigated the operation of the TES from an energy system perspective using the same approach as that applied in the HPC 3 studies, deploying the same models but developed further to focus on the TES operation and its benefits for the Greater Copenhagen DH system [55]. The second report was a project proposal for the municipality [73], which approves investments in DH infrastructure. We name the two plans the *TES Operation Report* and the *TES Project Proposal,* respectively.

As it was made by the same consultancy company the made analyses for HPC 3, the TES Operation Report adopted the same methodological approach as that applied in the HPC 3, which was widely accepted by the Greater Copenhagen DH actors. The report reached two important conclusions. The first was that only short-term operation was economically feasible for the TES. The second conclusion was that the storage should be used for the entire system and not for just one single actor. A consultant relates:

> *"It was an acknowledgment process, because the investment alone is so expensive that it would not be feasible to store heat from summer to winter. The only thing that would make the investment profitable was to use it together in the system" (Heat planning consultant Interview 2020, own translation)*

The report also emphasized that short-term operation was the most feasible use; the TES was to be operated as a daily or weekly storage. With such usage, the TES profits were calculated to be approximately €670,000 – €940,000 per year in total. These profits would be earned by the TSOs (55%), the CHP plants (24%), and the waste incineration plants (21%) [55]. The report thus grouped the different actors and companies into three distinct categories without specifying which individual companies would receive which benefits.

The second report, the TES Project Proposal, had to be approved by the municipality. Rather than being a single production unit, the Project Proposal categorized the TES as part of the system infrastructure to optimize operation, and not as a production technology:

> *"From fluctuations in the marginal production price in the district heating system, which in the future will become more and more dependent upon fluctuating electricity prices, it is expected that the storage will go through a cycle of charging and discharging on average every week. [...] The storage will therefore not be a heat producing unit, but a unit, that is contributing to optimize and improve the overall heat production."* [73]

The quote echoes both the HPC 3 with regards to the expectation that fluctuating production would increase in the future, and the TES Operation Report, which argued for short-term operation. By categorizing the TES as a part of the system infrastructure, the report transformed the TES from a stand-alone technology, operated and owned by a single actor, to a common piece of the regional infrastructure to be owned and operated in collaboration. The two reports classified the storage as a new piece of system infrastructure, operating on a short-term basis to manage fluctuations in the energy supply, and located within easy access of the transmission and distribution network. This categorization rendered the project feasible for the entire system and thereby transformed the TES that was to be brought into being.

It can be concluded from this instance that energy plans are instrumental in sensemaking processes that shape energy transitions. In this instance, the TES was re-categorized from a stand-alone technology to a piece of system infrastructure. Categorization work [40] was important in determining the use, technological benefits and operation of the TES.

By closing down the operation uncertainty and categorizing the TES as system infrastructure, a third question opened up: how to split the benefits and divide the investment costs between the different actors? The actors were now in a situation where they had agreed to establish the TES together and use it to increase system operation, as this would also benefit the individual actors. By shifting production from peak units to CHP plants, the TSOs could potentially reduce fuel costs by decreasing peak production and the CHP plant owners could potentially increase their production. Establishing the TES as a technology for system optimization opened up a new uncertainty: how the benefits achieved on a system scale could be translated into specific benefits for the individual actors and, conversely, how the investment costs of the TES should be split. While the TES Operation Report [55] outlined how the benefits would be split between the actors, categorized as TSOs, CHP plants and waste incineration plants, how to distribute the profits between the individual companies was not addressed.

5.3. Plans and calculations informing negotiations

Closing down the question concerning the TES operation opened up new uncertainty in terms of the benefits for each individual actor. As the Greater Copenhagen DH system consists of two TSOs, five CHP plants and three waste incineration plants, there was still significant uncertainty about who would receive the economic benefits derived from a TES. The task of modelling or calculating such results with sufficient precision proved difficult. Accordingly, the actors experienced difficulties in calculating how the investment costs should be split between the actors As illustrated by the following quote from a DH utility employee:

> "What does it mean if the storage gets more or less heat, if the costs increase or decrease, or to whom they can sell heat to? It is difficult to see if [our CHP plant] will gain any benefits. Perhaps some, perhaps nothing. And that is the same for all the actors" (*District Heating Utility 2 Interview 2017, own translation*)

As explained by the practitioner, it was difficult for them to determine the benefits for each individual actor with sufficient certainty. Due to the number of producers, the size of the network, and seasonal and yearly variations in production, among other factors, it was difficult to calculate exactly the benefits of a TES for each actor in the Greater Copenhagen DH system. Furthermore, because of commercial interests and regulations, there was no common data on the different units' earnings and operation of the DH system. The plant owners, utilities and TSOs all had detailed knowledge of their own units, but these details were not shared as they are regarded as trade secrets. Conversely, different assumptions and forecasts were used when estimating the effects of the TES:

> *"The [electricity] price is extremely important and they each have their electricity price forecast, as an example." (TSO 1 Interview 2018, own translation)*

Therefore, the actors used different analytical assumptions and models to estimate their respective benefits from the TES, which made it difficult to reach a common agreement about how to split the investments. "Splitting the bill" for the TES proved to be a negotiation based on arguments derived from energy system calculations about who would receive the benefits from the investment. For example, in the following, an energy planner from a TSO explains how energy models were used in the sensemaking process:

> *"Yes, through model calculations. Assumptions and long-term forecasts for the next 20 years and some sensitivity analyses, and then we decide on a reasonable place. Then we show the actors our calculations for their production units, we discuss the results with them, we see if they can recognize them, and thus that a storage would have the calculated effect on their production units as intended." (TSO 1 Interview 2018, own translation)*

This quote demonstrates the importance of the assumptions behind the energy model calculations, as well as the difficulty in determining the benefits of the TES. Although the calculations and energy models were central to the collective sensemaking process, it was difficult to reach a common understanding based solely on them. Instead, another dimension of the technology helped move the process forward. Supplying the TES directly from the transmission system entailed high temperatures for longer durations in the storage, which could potentially damage the storage liner. In 2018, the TSO, together with the utility company, energy consultants and a Danish university applied for a research grant to, "*demonstrate a 70,000 m^3 pit thermal energy storage in a new function as an accumulation tank in a district heating system with combined heat and power production from biomass and waste*" [74]. The project received €1.8 m to test the operation of a TES with such a liner in an energy system with CHP and waste incineration units examining how to create synergies between the heating and electricity sectors [74,75]. While offering financial support for technological development, the fact that it was a demonstration project meant that several actors not only saw it as a financial investment, but also as the development of new technology:

> *"There are calculations that showed some different percentages [of received benefits], but we could agree to 56% of the share of saved peak load, although other sensitivity analyses showed around 53%. Because this is a demonstration project." (TSO 1 Interview 2018, own translation)*

The new categorization of the TES as a *demonstration project* re-set the negotiations; being part of a demonstration project resulted in a degree of tolerance among the involved actors as to their expected benefits. The research grant facilitated the sensemaking process. It was easier for the actors to accept a degree of uncertainty with a demonstration project compared to a 'normal' project.

Accordingly, reaching an agreement about how to share the benefits and divide the investments costs of the TES relied on three factors. First, the negotiations were based on energy system calculations. While the calculations could not be used to determine how the costs and benefits should be split, they did provide a basis for sensemaking and deliberation. Second, the label of a demonstration project introduced a certain degree of flexibility to the negotiations. Third, still not able to agree completely on how to share the costs and benefits, it was decided that a follow-up group would monitor the TES operation after it had been built. This allowed all the involved actors to follow how it would actually operate in reality and facilitated ongoing discussions about who would receive which benefits.

6. Discussion: What was the role of energy plans in the sensemaking process?

We argue that the ways of knowing that are enabled and circulated by energy plans influence the way actors make sense of otherwise uncertain processes or technologies. Plans enable actors to investigate different courses of action and their consequences and simultaneously shape the results.

The analysis shows the epistemic role of plans in three instances of sensemaking in the establishment of a TES in Greater Copenhagen. First, uncertainty emerged from not knowing how the existing DH plants, units and infrastructure could be part of a decarbonized energy system, partly due to the emergence of national energy plans that outlined the need to increase renewable energy. The HPC 3 report outlined an energy scenario whereby the Greater Copenhagen DH system could use existing investments and infrastructure to achieve a low carbon energy system. To realize this transition to a future energy system with increased fluctuating electricity production, the HPC 3 highlighted the importance of increasing the TES capacity, thereby closing down uncertainty about how a future energy system ought to be. By outlining a national pathway to low-carbon energy supply on a national scale, the Greater Copenhagen DH actors had to consider what role they would play in this transition.

Second, promoting TES capacity as a way to transition the Greater Copenhagen DH system to a low-carbon energy supply raised questions about how the TES should be used and operated. Energy plans, solicited by a TSO and a utility company, concluded that short-term operation would generate the greatest benefit for the entire system by integrating fluctuating electricity production, and reducing peak boiler production. This process re-categorized the TES from a stand-alone technology owned by one actor, to a shared piece of the DH infrastructure. It also closed down the question about whether the TES should be used as short-term storage or seasonal storage. Third, closing down the question regarding how the TES should be operated resulted in the emergence of a new question; the short-term system operation meant that the investment costs had to be shared between all the actors in the system, which opened up the question of how to split the investment costs and benefits between the actors. The actual benefits of the TES could not be known until it was in operation and, therefore, the share of the benefits and investment costs had to be negotiated based on estimations and calculations. The negotiation of sharing costs and benefits was aided based on an understanding of the TES technology as a demonstration project, using an energy system model to simulate the technology operation and lastly by implementing a follow-up group that could monitor the project.

In the three instances, the TES was categorized in different ways that brought out and highlighted its use and qualities. Concretely, categorizing the TES as a technology that facilitated sector-integration and reduced peak loads positioned the TES as an important element in a low-carbon energy system. Again, the categorization of short-term system operation was framed as the most feasible way for the entire system to build and use the TES, thereby engaging the actors to realize the TES together. Categorizing the project as a demonstration encouraged investment of the behalf of the actors, who could tolerate greater uncertainty. These categories were important throughout the process in that they made the TES known and demonstrated its qualities as well as the problems it could solve. The analysis also shows that categories are not fixed entities but are instead always in the making and brought out through the work of the actors.

Furthermore, the analysis shows that many factors besides the plans themselves helped persuade the actors to invest in the TES. First, the fact that the convergence of the Greater Copenhagen DH system had been developed for many years through collaboration between the actors meant that they were used to working together and a certain amount of trust existed. Processes of sensemaking drove how actors closed down their uncertainties and energy plans played an important role in doing so, but they did not work alone. Collective sensemaking, in the form of negotiations, discussions and meetings was important to promote a common understanding of the TES. An important part of promoting this common understanding was the trust and long-time cooperation between the actors in the Greater Copenhagen DH system. Without this convergence, the energy planning process and collective sensemaking might not have been so effective. Second, the categorization of the TES as a *demonstration project* helped introduce some tolerance into the negotiation process in terms of expected profits. Third, while the energy plans made many facts known about the TES, they did not work in all cases. The energy calculations did not make the share of benefits and investment costs known with sufficient certainty, and the actors had to find other solutions. In this case, a follow-up group was formed to monitor the TES operation and see who would actually receive which benefits. While energy plans and their knowledge-producing machinery of energy models were only one part of the TES investment process, they proved invaluable tools. They decreased uncertainty and answered the questions posed by actors. However, the effectiveness of the energy plans was not due to their accurate representation of reality, instead they worked by bringing the TES into being in a way that made sense to the actors. Instead of searching for optimal solutions for application in an external reality, energy plans and models can begin to explore how they participate in co-creating these particular realities themselves.

The three instances of solving uncertainties reveals a continuous cycle of sensemaking of closing down and opening up [43], where each instance of closing down one uncertainty opens up another. This continuous process of opening up and closing down highlights a characteristic of energy plans, which is that they do not work in a vacuum, but built on each other. Each new energy plan analysed in this study was based on a previous plan. Energy plans can be said to work in relays, where they each answer their own formally administered task, but also ask new questions. As this opens up new questions about how to proceed next, new plans are needed. As such, a conclusion or statement is temporal, and new concerns may emerge and challenge closure. Still, the plans were effective when they built upon the conclusions of past plans, used the same methodology or the same assumptions. The *TES Operation Report* [55] used the same analytical equipment as that used in the HPC studies [72], assumptions about increasingly fluctuating electricity were used in several reports, and the conclusion about using the TES as a system storage informed the investment negotiations.

Fig. 6.1 illustrates this continuous process of closing down and opening up new questions in energy planning processes. This study thus provides new knowledge as to how energy plans can be used to solve uncertainties in energy planning. Plans do not linearly solve the actors' uncertainties, instead they enable the actors to engage in sensemaking processes. Although the plans facilitated understanding and shaped the understanding of the TES they did not work alone. The mutual trust, the long-term cooperation between the actors and agreement about a common goal, i.e., to develop the Greater Copenhagen DH system, were also central to achieving the TES. This finding is of relevance to energy planners, municipalities and governments as it highlights the need for establishing and maintaining planning environments with a high convergence among stakeholders, regulation and responsibilities where communication and coordination facilitates a collective endeavour to develop energy system infrastructures. The processes of closing down and opening up uncertainties highlights how such energy plans engage in continuous cycles of sensemaking.

7. Conclusion

This case has demonstrated how energy plans were able to translate future visions about a decarbonized energy system into a concrete investment in the form of a TES in the Greater Copenhagen DH system. It is a case where long-term vision and short-term action were connected to realize a low-carbon investment in an urban energy system, through several iterations of sensemaking. The actors commissioned plans to answer their questions, gradually closing down uncertainties about their situations. However, the dynamic process of sensemaking is not linear. While these plans effectively closed down the questions posed in the reports, they also produced new emergent questions, thus opening up new uncertainties. Continuously closing down questions as they emerged helped move the process forward towards an investment in TES capacity in the Greater Copenhagen DH system, but it also kept opening up new questions.

Plans were commissioned to close down uncertainties and answer questions for the actors. The plans did this effectively throughout this case by outlining what a decarbonized future might look like and the role of TES in this, describing how TES capacity could be used and operated and determining how the different actors should split the TES investment costs between them. This shows that the plans and their conclusions, in general, were adopted and informed the sensemaking of the actors. While the plans were effective in steering the process, they did not do so alone, but also benefitted from actors who had worked together on developing the Greater Copenhagen DH system for many years, developing know-how, expertise and trust.

The energy plans worked under a number of conditions. First, they answered relevant questions for the actors, who either wanted or had to change their situations. Therefore, the plans helped the actors out of situations of pressure. Second, the plans envisioned active roles for the actors to their own benefits. For example, the HPC 3 investigated how the actors could utilize their existing infrastructure in a decarbonized energy system. It was important to make plans that aligned with the interests of the actors. Third, the plans analysed and categorized some of the different ideas, opinions and understandings of the actors that already existed. This included the question whether the storage should be seasonal or short-term, or if it should be used by a single actor or as a piece of system technology. The plans made an arena where such uncertainties and disagreements could be debated. Fourth, the plans themselves worked in relays, building on past agreed methods, assumptions, and findings. Therefore, they created effective arguments based on previously agreed decisions and findings.

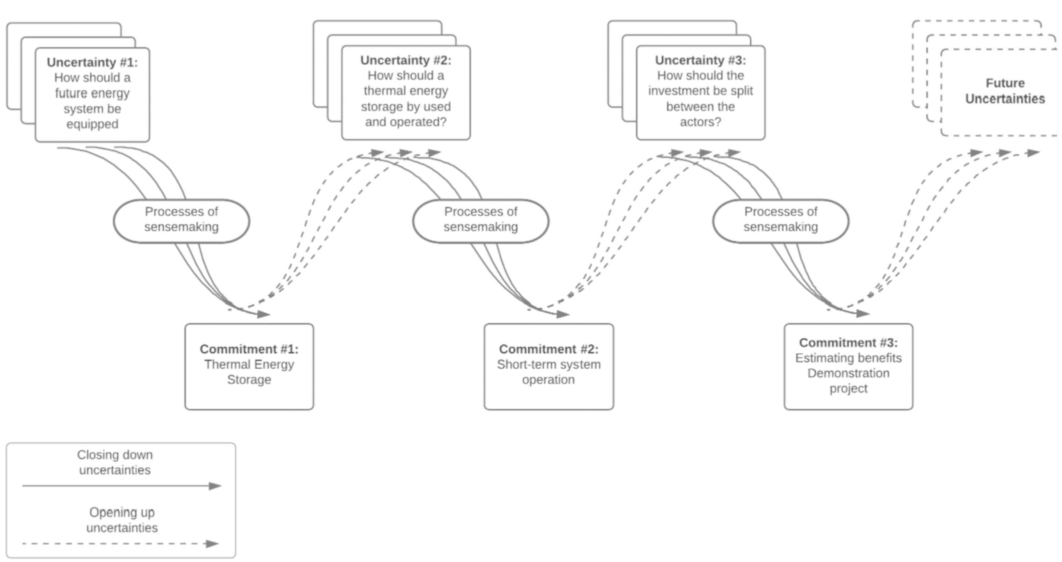

Fig. 6.1. Illustration of the continuous process of closing down and opening up questions in an energy planning process.

This paper has presented a case study of how an investment in TES capacity was realized in the Greater Copenhagen DH system. As with all case studies, it is particular to the specific situation in which the study was conducted. The way the investment was achieved, the business model, and the defined operation of the TES are all specific to this case. Therefore, a significant limitation of this study is that we cannot present a simple model or description of how to realize new investments in sector-coupling infrastructure in the future. However, the case shows some general relevance for energy planners, practitioners and researchers. First, the importance of cooperation, communication and being able to discuss different technical pathways and configurations was central to realizing the investment. A central conclusion for energy planners and practitioners is the importance of making plans that carve out specific roles and responsibilities for actors, close down uncertainties, while also being able to rely on convergent networks of stakeholders that facilitate cooperation and collective development. Second, as energy systems become increasingly connected between sectors, more investments are needed that transcend energy sector borders. This will likely result in new organizational, economic, institutional or regulatory challenges. Third, energy plans are effective tools, but they do not simply result in the materialization of their conclusions.

We hope this study will invite more researchers to investigate the question of how planners, decision makers and policy makers use plans in their work to promote low-carbon and efficient energy systems.

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.

8 Appendix.

8.1. Overview of actors and main empirical material

Table 8.1
Main empirical material from interviews and reports. Interviewees are kept anonymous.

Actors	Main role	Main technological equipment	Year of interviews
Transmission System Operator 1	Responsible for buying and transporting heat from CHP and waste incineration plants to district heating distribution companies	Owns the transmission network in their area Owns small heat production units	2017, 2018, 2019, emails 2019
Transmission System Operator 2	Responsible for buying and transporting heat from CHP and waste incineration plants to district heating distribution companies	Owns the transmission network in their area Owns small heat production units	2019, 2020
District Heating Utility 1	Distributes heat from the transmission system to their customers	Distribution infrastructure Small production units	2017, 2020
District Heating Utility 2	Distributes heat from the transmission system to their customers. Owns a large CHP plant	Distribution infrastructure CHP plant	2017
Waste Incineration Plant Interview	Handling municipal waste through incineration. Heat production an outcome of waste handling	Waste incineration plant	2017, emails 2020
Varmelast	Responsible for the day-to-day planning of heat production Voluntary cooperation between the main actors	Optimization tools Mathematical models	2017, 2020
Heat planning consultants	Providing inputs and expertise Make plans and calculations	Optimization tools Mathematical models	2017, 2020

8.2. Interview guide

8.2.1. Exploration phase (2017)

Can you tell about the reasons for investing in Thermal Energy Storage?

- What are the main benefits for you in investing in Thermal Energy Storage?
- How do you calculate the value for you – and with what tools, methods and categories?
  - o How do different ownership models affect your benefits?

Thermal energy storage specific questions

- What kind of technological solutions are you looking at (pressurized, non-pressurized, temperature, other?) – and why/what are the main challenges and benefits?
  - o Are you looking at collective solutions, e.g., system investments or storage for your own benefit and operation?
- What are the benefits for you – both operational, technical and economic? And how will you operate and use the storage?

Business model

- What might a business model for facilitating the investment look like?
- Who are you cooperating with?
- How does it affect the value (for you and the system) depending on whether it is a system or individual owned storage?

8.2.2. Continuation and follow up phase (2018 – 2020)

Can you describe what happened in the process the last year?

- New knowledge? How did you (and others) come to new understandings and agreements?
- What main challenges have you encountered? E.g. technical, organizational, investment-wise or regarding cooperation?
- What was unknown, uncertain and difficult?
- How is this new knowledge tied to the making of knowledge and the circulation of plans?
- How (with what measures) has agreement been reached?
- Is it still the same actors and stakeholders who are engaged?

Technological questions and deciding on the use of technology

- Did you decide on how to deliver back to the transmission network?
- Did you decide on how to use the storage (system vs individual) and which time horizon (short term vs seasonal)?
- What are main problems now?

How do you see the investment being shared among actors (if collective investment)?

- What is unknown, uncertain and difficult

- How do you see yourself and other actors overcoming these challenges?
- How – specifically with what tools, methods, knowledge and plans – do you create closure among the stakeholders and overcoming challenges?

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