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How Danish communal heat planning empowers municipalities and benefits individual consumers

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HIGHLIGHTS

- Danish district heating has cost-effectively reduced the country's emissions.
- Danish heat planning has been critical to the district heating sector's success.
- Danish heat planning confers substantial power to municipalities.
- Empowering cities offers significant benefits to cities and consumers.
- Danish planning practices can be implemented today in the U.S. and other locations.

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ABSTRACT

Danish municipal heat planning empowers municipalities to implement locally appropriate energy solutions that are the best fit for the locality as a whole and the individual consumers served. Supportive policies and actions at the national and local levels have encouraged heat planning that confers significant autonomy to local governments. By examining how power is distributed and shared by different levels of governments in the planning process, this paper investigates how comprehensive energy planning in Denmark has supported the development of highly cost-effective district heating systems. Lessons from the Danish approach to heat planning are considered for their relevance to the United States, where significant technical district heating potential exists, yet remains well outside the typical energy policy discussions. While the specific Danish political context may not be transferable to other locations, the practical aspects of power sharing, socio-economic cost–benefit analyses, and communal decision-making may inform approaches to local heat planning around the world.

1. Introduction

In the past two decades, cities and nations around the world have established aggressive new goals for reducing harmful greenhouse gas (GHG) emissions. Increased deployment of renewable energy generation is necessary to meet these goals, but such resources are not always cost-effective when compared to other alternative dirtier energy resources, especially at the individual-building scale (Chow, 2009; Dyrelund and Overbye, 2013).

Many energy system analysts identify district heating (DH) networks as a critical prerequisite to cost-effectively integrating the zero- and low-emissions energy technologies necessary to meet GHG reduction goals (Baber and Damecour, 2008; Chow, 2009; Dyrelund and Overbye, 2013; Lund et al., 2010; Østergaard et al., 2010; Østergaard and Lund, 2011; Voss and Thorsen, 2012). DH networks aggregate loads and provide economies of scale for a wide variety of heating and cooling supply streams, as well as provide balancing capabilities for the electric system when integrated with technologies such as combined heat and power (CHP) (Lund and Østergaard, 2000).

The aggregating capabilities of DH systems reduce per-customer costs and make certain resources economical that would be uneconomical on an individual customer scale. Costs of new heat resources, such as drilling a geothermal well, are the same whether the resource serves one house or many, and DH helps spread those costs amongst a larger group of customers.

Denmark has done more than most countries to maximize the benefits of DH, which provides heat to about 60% of Danish households. DH has been critical to the decoupling its energy

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use from economic growth better than almost any other country in the world (Energistyrelsen, 2009; Lund et al., 2010; EIA, 2014). One analysis found that the increased use of CHP and DH in Denmark reduced CO_2 emissions in the heating sector by 60%, from 25 kg/m^2 of heated floor space in 1980 to 10 kg/m^2 in 2010, while another found that DH has reduced the overall nationwide emissions by 20% since 1990 (Christensen, 2009; Dyrelund et al., 2010).

Despite the many benefits of DH, few countries leverage its benefits extensively. Where excess heat from power generation and industrial processes is largely wasted in countries like the U.S. – where the average electric generation efficiency is 32% (Laitner, 2013) – heat plays an important role in Danish energy planning. Indeed, the Danish energy success story is largely one of heat: planning for it, distributing it, maximizing the efficiency of its production, and identifying it as a resource in situations where other countries view it as a useless or even environmentally harmful by-product. In particular, municipal heat plans and planning, which were first required by national law in 1979, have long been credited with providing the policy and regulatory framework that has underpinned the sustained growth of Danish DH (DEA, 2010; Kerr, 2009; Parajuli, 2012).

Heat plans are locally developed plans that identify the existing and future heat demand of buildings in a given area as well as current and potential heat resources. The planning process includes an assessment of which heat supply options are most cost-effective and appropriate to an area (DEA, 1998). The plans inform decisions about land use, DH infrastructure, and other relevant aspects of comprehensive planning (King, 2012; Larsen, 2013; Rand, 2009). In Denmark, it appears the presence of a stable heat plan helps foster long-term confidence in DH systems by reducing real and perceived risks to customers, heat suppliers, the municipality, and DH system owners. Denmark's 400 DH companies enjoy an average connection rate of 82%, which compares very favorably to that of other countries with high penetrations of DH (IEA, 2012). Many Danish municipal DH systems are currently expanding, reflecting an attractive investment environment and steady consumer demand supported by local heat planning actions (Dyrelund and Overbye, 2013; IEA, 2012; Larsen, 2013).

1.1. The national role in local energy planning

It has been widely noted that while early international efforts to address climate change focused primarily on the roles of nation-states, cities have recently adopted their own aggressive environmental goals, often absent corresponding action at the national level (Bulkeley, 2010; Rosenzweig et al., 2010). Additionally, the NGO community has increasingly focused efforts on local actors and their ability to make large strides toward environmental goals. Organizations such as the Rockefeller Foundation, the C40 Cities Climate Leadership Group, and the United Nations have identified cities as critical players in the race to reduce GHGs. However, it is also widely noted that cities' abilities to fully address climate change challenges and opportunities are frequently hampered by the structure of extant national policies (Bulkeley, 2010; Sperling et al., 2011).

In contrast, Danish energy policy tends to confer a high level of autonomy and flexibility to local energy actors to reduce GHGs and respond to climate change-related challenges. This is especially true in the development and planning of DH systems, where local decision-makers are clearly delineated as the chief arbiters of system design. However, this local power relies on a centralized policy and technical framework maintained at the national level. This framework includes policies such as national building codes and the nationwide transmission system maintained by Energinet.dk (Sperling et al., 2011).

Though the Danish energy story has long captivated academics and policymakers (Garforth International, 2009; Kerr, 2009; Sovacool, 2013), little academic attention has been paid to two significant aspects of Danish energy policy: the specific tools and powers granted by the national government to Danish municipalities that have resulted in the expansion and continued investment in cost-effective DH systems, and the unique autonomy of cities to make their own long-term decisions about their energy future as it relates to heat. Several published energy planning guides offer important suggestions for project development and local planning, but lack discussions of the best practices in long-term heat planning and local empowerment (Garforth International, 2009; King, 2012; DOE, 2009). Rising interest in DH around the world and a growing recognition that locally developed DH systems are critical to climate change mitigation efforts suggest that a detailed analysis of the Danish approach to heat planning would be a useful addition to the academic literature.

1.2. Scope of this paper

This paper's focus is how powers and responsibilities are bestowed to and used by local actors in Danish heat planning, and how those actors reflect and represent local priorities to best enable locally appropriate and cost-effective DH networks. It is argued that the flexibility granted to local actors helps to provide communities with the most cost-effective heating solutions available for *that specific community.*

The overall objective of exploring the Danish approach to such planning is to identify and better understand which characteristics are relevant and perhaps applicable to local, regional, and national policymakers in countries beyond Denmark. The target country for this particular paper is the U.S., but findings also apply to many other countries. This paper emphasizes the practical aspects of Danish heat planning that could ostensibly transcend specifically Danish constructs. For instance, the substantial taxes levied on energy products are not a focus of this paper, as Danes are generally more supportive of higher tax rates and a generous redistributive welfare state than citizens of other countries (Bay et al., 2013; Copenhagen Post, 2013; Diamond and Lodge, 2013).

The first half of this article examines the policies and practices that form the foundation of Danish heat planning. Section 2 summarizes the methods used to assess these policies and practices and presents the relevant historical and current policy context. Section 3 identifies the results of the investigation into these policies, including the current planning framework, and the powers, responsibility, and tools held by the main actors involved in Danish heat planning.

The second half of this article then examines the 'effects' of these policies and practices. Section 4 discusses and analyzes how the costs, benefits, risks, and rewards of heat systems are shared among actors. Section 5 explores how aspects of Danish heat planning might be useful to policymakers in the U.S. and other countries, and suggests some areas of further analysis.

2. Methods: Examining the Danish policy framework

Denmark's extensive DH sector is no accident, but was instead very intentionally pursued after the oil shocks of the 1970s, which especially affected households that relied solely on oil for heat (DEA, 2012). Prior to these policies, over 90% of the country's entire energy supply was based on imported oil (DEA, 2010). Afterwards, Denmark began a concentrated effort to increase reliance on domestic fuel resources and improve overall energy efficiency. While an alternative scenario heavily reliant on new

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nuclear power was initially proposed by the Danish government in 1976, a group of academics championed a more distributed scenario, which prevails even today (Blegaa et al., 1977).

A more distributed model and periodic efforts to encourage residential retrofits have served Denmark well. In the thirty years between 1980 and 2010, Danish overall energy consumption remained nearly unchanged while the economy grew by 78% (DEA, 2010; Parajuli, 2012). This coincided with a steady decrease in energy intensity and a steady increase in the share of distributed CHP for DH and electricity production (Energistyrelsen, 2009). The growth of DH at the expense of other less desirable resources for space heating, such as individual oil furnaces, can be seen in Fig. 1. Electric heating in Denmark is of minor importance, being generally the most expensive mode of heating and discouraged within heat planning.

To understand how DH became such an important component of the Danish energy story, it is necessary to examine the origins of Danish heat planning. To do so, we examined historical policy documents, current and past legislation, and historical energy plans. We also conducted interviews with over one dozen practicing Danish heat planners and district heating developers, who helped identify the critical policies and programs that have most directly shaped Danish heat planning activities. Certain policies and actions clearly emerged as the critical aspects of the Danish heat planning foundation.

2.1. Historical Danish heat planning legislation

Several pieces of national legislation helped usher these dramatic changes in the Danish energy landscape. The *Electricity Supply Act of 1976* stipulated that all new electricity production must be CHP (MOE, 1976). Many power plants were converted to CHP as a result, and today about two-thirds of Danish-produced electricity is cogenerated with heat. This has provided Denmark's DH systems with highly efficient and low-cost heat nationwide, which has formed a critical basis of heat supply on which expanded DH systems could be based (DEA, 2012).

The *Heat Supply Act of 1979* was another landmark piece of legislation that established specific zones of heat networks throughout the country, regulated the heating sector for the first time, and required municipalities to conduct an analysis of their local space heating needs and available heat resources (Energistyrelsen, 2010; Rand, 2009). This and similar legislation in Sweden marked the first time in the world that local governments were given the responsibility to engage in such local heat planning (EAP, 2011; Magnusson, 2011).

Municipal and regional authorities were then responsible for assessing future heating needs and supplies, allowing for a

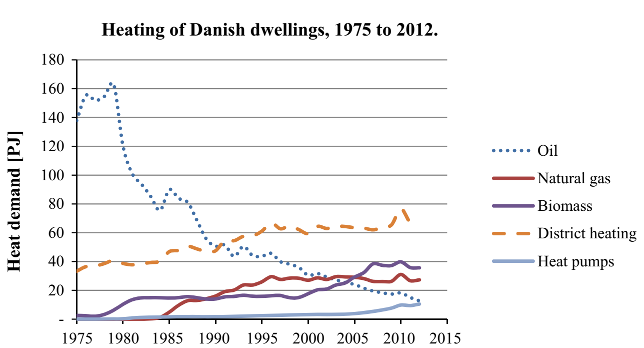

Fig. 1. Trends in heating Danish homes by different fuels and technologies. Note: Insignificant uses of solid fossil fuels are not shown, nor is electric heating, which is being phased out in Denmark. NG, biomass, and oil are shown as primary energy supply; heat pumps and DH as final energy supply. Chart based on data from DEA (2012).

seamless regional analysis of where certain aspects of heating infrastructure, including natural gas (NG) pipelines and hot water pipes, might be developed over time (MOE, 1980). Municipal heat plans, shaped by regional plans, were developed in cooperation with existing energy utilities. The plans provided guidance when changes and expansions of existing energy infrastructure were proposed, and gave local agencies the authority to approve or reject changes to both the DH network and the NG infrastructure.

The Heat Supply Act and subsequent revisions underscored the importance of local authorities in making determinations about which aspects of energy infrastructure should be built, and which resources should be prioritized, though it did specifically instruct local planners to promote CHP wherever possible (EAP, 2011). A nationally developed and maintained technology catalog helped municipal and regional governments to develop accurate cost estimates to strengthen the cost–benefit analyses conducted as a part of the planning and approval process (DEA, 2012; Styregruppen For Forsyningskataloget, 1988).

Originally, the structure of municipal heat plans was a more rigid one, requiring municipalities to determine where the boundaries of a heat network would be, and who should connect to it. Subsequent Heat Supply Acts in 1990 and 2000 loosened this a bit, allowing municipalities to determine whether or not to require certain buildings to connect to a system, and whether or not to develop the DH infrastructure themselves (Dyrelund and Overbye, 2013; EAP, 2011; Larsen, 2013).

In the 1980s energy policies that identified the importance of full accounting of energy projects' costs and benefits emerged, and in 1990 the national government issued an energy plan specifically indicating the role that a full socio-economic accounting of costs and benefits should play in any energy project planning (Energiministeriet, 1990). These policies established the decision-making framework that is still in place today, ensuring that the full societal costs of energy projects are calculated, and that only projects showing the best net benefit to society are prioritized. This is in stark contrast to basic business cost–benefit analyses, which only assess whether a project is in the best interest of an individual company. While companies looking to invest in energy infrastructure must make their own internal business case, DH companies and municipal planners must only pursue projects that show a high value within the socio-economic cost–benefit framework.

2.2. Current heat policies

Originally, local heat plans were binding public planning documents, and projects were subject to approval by the DEA prior to municipal acceptance. The plans served as a basis for investment and were not just mere suggestions. Beginning in 2000 the plans were no longer required as outlined in the 1979 Heat Supply Act (Energistyrelsen, 2010). Plans today are developed by municipalities and DH companies, who are empowered at a very local level to guide the local heat strategy (DEA, 2012). The Heat Supply Act in force today still aims to promote heat networks that maximize CHP and, more generally, socio-economic and environmental benefits in the service of reducing fossil fuel dependence (MCEB, 2011a). Municipalities are still the arbiters of which new heat network components are built or substantially altered, and may still require heat suppliers to undertake certain projects or use certain fuels or technologies (MCEB, 2011a).

Today Denmark has an official goal of being 100% reliant on renewable energy resources across all sectors by 2050 (Danish Government, 2011). Renewable resources presently supply about 41% of the heating sector, and the government's official plan to increase that share includes heavy reliance on individual heat pumps and solar thermal where prudent, and to increase the share of renewable energy in DH systems (DEA, 2012). Though the exact role of DH in the future Danish energy system is still being debated, recent analyses of potential scenarios indicate that DH is required for a cost-effective 100% renewable Danish energy future (Dyrelund et al., 2010; Lund et al., 2010). Denmark now is also embracing a strategic energy planning model, which considers a comprehensive energy system, including DH (Sperling et al., 2011).

Denmark's European Union membership adds an additional layer of binding energy goals that have been adopted by EU member states, compared to business as usual. These EU-wide goals are to be met by 2020 and include: a 20% reduction in GHGs; a rise to 20% of the total share of energy consumption provided by renewable energy resources (that number was 9.8% in 2010); and a 20% increase in energy efficiency (EC, 2013, 2012). An independent analysis found that DH is a prerequisite for the EU to cost-effectively meet its CO_2 goals (Connolly et al., 2014).

2.3. *Building confidence with cooperation and consensus*

Beyond specific policies, the Danish tradition of political consensus is one aspect of the Danish framework that bears mention. According to one company heavily involved in the planning and development of Danish heating networks, the three most important factors in the country's reductions of CO_2 emissions have been: “stable energy policy since 1976, municipal planning, and a tradition for co-operation in the society” (Rand, 2009). About a dozen political parties collaboratively craft national policies, and the country has not seen a single party with a parliamentary majority for over 100 years (EAP, 2011; MOFA, 2013). Political consensus is found at all levels of government, and the energy policies developed decades ago are still strongly supported by most national and local politicians. As one DH expert put it, to suggest a policy that would run counter to the goals of collective heating networks would be “political suicide” (Dyrelund and Overbye, 2013). Additionally, a nontrivial portion of the voting population – 10% in the 2009 election – views environmental issues as the single most important problem facing Danish politicians (Nygård, 2011).

Danish cities generally continue to pursue the established approach to heat planning regardless of political changes at the national or local level. Heat planning is not regularly subject to changing political whims, and developers and consumers can be fairly confident that investments made in DH infrastructure, such as individual household equipment, will be prudent investments (Dyrelund and Overbye, 2013; Larsen, 2013). The Danish Energy Agreement of 2012, which established Denmark's official goal of being 100% reliant on renewable energy by 2050, was the product of political consensus. A full 95% of members of Parliament joined the agreement, and Danish political agreements are rarely broken (DEA, 2012; Danish Parliament, 2012).This is important because it continues to provide a platform on which the public and private sectors can confidently build and invest in cleaner and more efficient energy systems.

3. Results: Top-down policies and bottom-up power

The review of the policy context illuminated the distribution of powers in place today among many different actors. This section summarizes the results of the policy and regulatory assessment, highlighting in particular the European Union, the Danish national government, municipal agencies and councils, heating companies, and individual heat consumers. For each of these actors the powers and responsibilities, and the political and economic tools available are discussed. In particular, the degree to which the existing power structure encourages municipal-level autonomy is explored. Major findings of this section are presented in Fig. 2.

3.1. *European Union*

The 2012 EU directive on energy efficiency requires all member states to conduct a ‘comprehensive assessment’ of both CHP and DH and cooling potential and to develop and deploy policies that aid in the acquisition of all cost-effective CHP and DH potential, and to ensure that power plants larger than 20 MW are assessed for CHP potential (EC, 2012).

Member states must develop national heat plans, which should analyze the potential for CHP and new DH infrastructure to meet identified heating needs. These plans can comprise a single national plan or multiple municipal and regional plans that, in the aggregate, serve the same nationwide purpose. Policies that help meet the plan(s)' identified potential for CHP and DH and cooling are to be implemented (EC, 2012).

In general, in-place Danish activities will satisfy these requirements. Indeed, to some extent the EU policies were modeled on existing Danish energy efficiency efforts, especially during the first half of 2012, when Denmark held the EU presidency (MCEB, 2012).

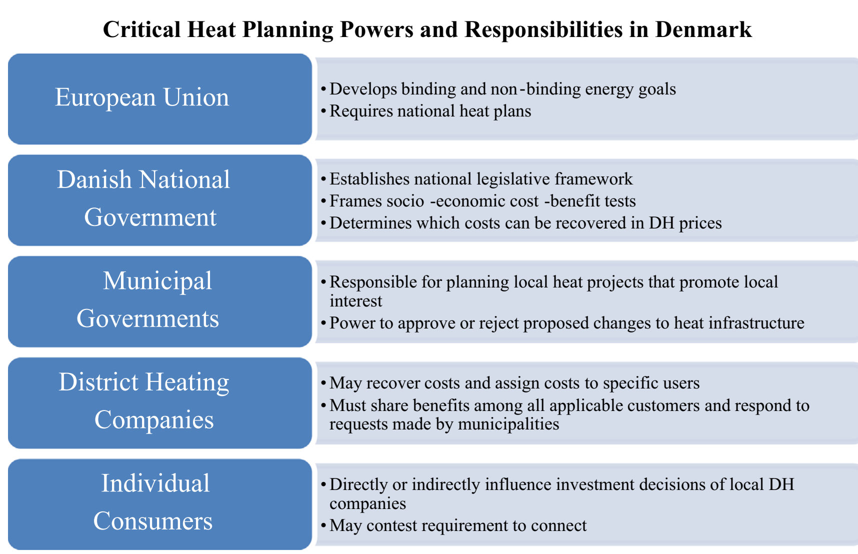

Fig. 2. Powers and responsibilities held by different levels of government and heat system users in Danish heat planning.

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The EU directive offers all members freedom in reaching their energy efficiency targets, allowing each member state to set energy efficiency goals in their preferred format, be it energy intensity, reduction in primary energy consumption, or some other metric (EC, 2012). This complements and supports existing Danish heat planning efforts and energy efficiency policies, which also offer a high degree of flexibility to different sectors of the energy economy.

3.2. Danish government

The role of the national government in heat planning is largely one of establishing frameworks and guidelines: on tariffs, on cost-effectiveness tests, on the degree to which buildings heated by fossil fuels are required to convert to DH, and on the degree to which the heating systems themselves must be supplied by renewable energy (Sperling et al., 2011).

The Ministry of Climate, Energy and Building is responsible for most of this, as it oversees both the Danish Energy Agency (DEA) and the Danish Energy Regulatory Authority (DERA). The DEA is the key energy policymaking and regulatory entity in the Danish government, while the DERA has particular authority over prices of products sold by monopoly energy companies, including DH companies.

The DEA's responsibility spans from energy production to end-user consumption (IEA, 2011). It is tasked with implementing national energy policy, such as GHG and energy reduction goals. In the DH sector, the DEA aims to promote that which increases renewable energy as well as overall system flexibility.

The DEA enforces the contextual policies within which local heat planning must be conducted. For instance, per national statute, heat plants must meet certain efficiency requirements, and CHP may only be based on specific designated fuels. The DEA is responsible for enforcing these rules (MCEB, 2005). However, the DEA has also shown itself to be flexible in the face of changing economics. For instance, while municipalities were required to put proposals together for converting CHP plants to biofuel-based systems, the DEA recognized that unattractive economics of such conversions later necessitated a relaxing of that requirement (DEA, 2014a).

One of the most critical roles played by the DEA is providing the framework for municipalities and regions to assess the cost-effectiveness of future energy projects (DEA, 2005). Each year the DEA issues updated forecasts for future energy prices, as well as forecasts for future energy use, costs of emitting certain pollutants, and other considerations that are necessary for a full accounting of the socio-economic impact of a project (Energistyrelsen, 2012a, 2012b). This supports the framework discussed in Section 2.1 of a full socio-economic analysis of a project's cost-effectiveness (DEA, 2005; Østergaard, 2009).

Within the framework there is ample room for localities to structure their cost–benefit analyses in a way that appropriately reflects local priorities, provided the assumptions are clearly explained (DEA, 2005). For instance, in accounting for the amount of CO_2 emitted by one unit of electricity or DH, the national guidelines note that there are at least four different approaches to measuring the emissions, and that the choice of which approach to use should be based on the specific context and goals of the local project (DEA, 2011).

The DERA is a nine-member independent body that regulates and monitors prices of monopoly utilities, including DH, NG, and electric companies. It considers customer complaints as well as the overall impact of heat planning on individuals (DERA, 2014; EAP, 2011; MCEB, 2000a). The related Energy Supplies Complaint Board handles some of the complaints made by customers in certain situations, including those related to requirements to connect (DEA, 2014b).

The DERA has the power to review prices charged by DH companies and determine whether they are fair and reflect actual costs. It reviews the required reports from regulated companies for transparency and reasonableness (DERA, 2014). It has the power to impose fines when a regulated entity fails to satisfy aspects of the Heat Supply Act or is not forthcoming with the requested information, and to order a change in price structure if the prices in place are not reflective of the true costs (MCEB, 2011a, 2000a).

Per the current Heat Supply Act, the Ministry retains considerable additional power it could exercise if deemed necessary (MCEB, 2000b). The DEA retains a general power to establish new regulations and require new aspects of heat planning after consultation with municipal governments (MCEB, 2000b). It also retains the power to waive certain rules in unique circumstances, and to implement taxes or policy changes in order to comply with new national or international rules (such as those promulgated by the EU) (MCEB, 2011a).

3.3. Municipal governments and councils

Though no longer required by law to develop heat plans, municipalities and their local city councils are delineated by the current Heat Supply Act as the entities singularly responsible for the continued act of heat planning as well as approval of heat companies' activities and projects (MCEB, 2011a). Municipalities are effectively the local regulators of DH companies' activities.

Danish DH companies are often independent companies that are controlled by or answerable to municipal agencies and councils. In larger cities, municipal governments maintain some control over much of the companies' major decision-making, and the heat companies can function as a quasi-agency within the city government, staffed in part by local heat planners. In situations where the heat companies are fully consumer-owned and controlled, cities still sit on the boards and city councils are empowered to approve or reject projects or require that companies propose a heating solution for a new development, such as the practice described in the Silkeborg Kommune Varmeplan (Silkeborg Kommune, 2013).

Municipalities may thus directly influence the day-to-day activities of the companies as well as their long-term strategic plans. Municipal governments are responsible for ensuring that all projects implemented under local plans are the most cost-effective possible (MCEB, 2005).

Municipalities and city councils may establish requirements that individual buildings connect to the existing or future DH systems. This power has not recently been widely exercised, possibly due to the fact that most of the buildings that are cost-effective enough to connect have already been connected, but it remains a powerful tool (Dyrelund and Overbye, 2013; Larsen, 2013). They may also require that in lieu of direct physical connection, a building owner must pay a connection fee and pay duties to the DH system in order to maintain the integrity of the system and ensure that the system is capable of handling additional load such that a building might demand were it to connect to the system and consume heat in the future (DEA, 2013; MCEB, 2011b).

Along with the national government, municipalities are empowered to collect information that is essential to their heat planning efforts from any private suppliers of heat. (MCEB, 2011a). They can require heat companies to undertake specific projects under specific timelines, and are the final arbiters of where and how new communal heat systems will be deployed, and with what technology (EAP, 2011). Cities that own their own heating utilities have the power to change and alter their incentives and rate

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structures to encourage or discourage certain behaviors. Importantly, municipal governments have the power to prohibit certain types of heating – such as electrical heating – in specified geographical areas in order to support the goals of an existing heat plan.

Municipal government powers are most constrained when regulating heat use by buildings deemed to be 'low-energy.' In such cases, municipalities are expressly not permitted to make prohibitions against electric heating, and they must grant an exemption from any otherwise applicable requirement to connect to a DH system (MCEB, 2011b; MOE, 2007). Additionally, areas of the country designated as NG areas or otherwise well-served by NG for individual heating are difficult to compel to connect to DH, as the NG companies may demand compensation from DH companies for their stranded assets (Energitilsynet, 2012).

Municipalities have tremendous autonomy in the development of their DH systems. Their power to oversee major aspects of system development allows them to regularly assess how a DH system could integrate with future development projects (Sperling et al., 2011), and it is at the municipal level that heat planning is firmly integrated with land use planning. Municipalities must produce 12-year comprehensive land use plans that address development issues such as urban redevelopment, wetlands protection, and, explicitly, 'heat supply' (MCEB, 2005; MOE, 2007). Since the land use planning statutes also require municipalities to consider large meta-systems such as transportation and water resources, municipalities are required to consider local assets and needs in a holistic manner. When local governments plan a new development, they often request that the local DH company issue a proposal to supply heat to the development. The local government then determines whether the solution is appropriate for the area.

Municipalities are also required to consider how their plans interact and complement plans of neighboring municipalities (MOE, 2007). However, since the statutes allow municipalities themselves to establish their own frameworks for the specific content of the plan, and to add 'guidelines for other matters' as desired, there is still a good deal of flexibility embedded into the local planning process. To the extent that regional plans are in place, municipalities retain authority over changes made to their own energy infrastructure to meet established regional goals (DEA, 2012).

Municipalities' powers are granted with a legally binding expectation that the local interest will be pursued. For instance, national legislation dictates that municipalities may not use biofuels or landfill gas-fueled CHP unless there is a clear local desire to do so, and if the fuel cost will not be markedly higher than an alternative like NG (MCEB, 2005). So while municipal planners are able to select the energy solution that they deem appropriate for their citizens, they may not create a heat scheme that uses an inappropriate technology or fuel that could result in unnecessarily high prices.

3.4. District heating companies

Danish DH companies are local entities that operate in close collaboration with municipal governments. Consumers, municipalities, housing authorities, or commercial companies may own them, but they are always directly or indirectly consumer-controlled, and are by law prohibited from generating profit, though they are profitable companies. Profit is returned to customers via reduced heat rates in subsequent years and thus shared among consumers rather than with shareholders (MCEB, 2011a).

DH companies establish prices for their products that include all relevant expenses, including the cost of financing expansions to a system. They are able to self-finance much of their infrastructure investments with internal funds, which enables them to keep prices lower for consumers and to develop systems when they are needed, not when the money is available. Should a company seek external financing, the cost of borrowing to a DH system is very low. Interest rates are below 1% for most projects, because banks are competing to invest in what they see as a highly reliable and robust sector of the economy (Dyrelund and Overbye, 2013). Additionally, DH companies may request that their municipality act as guarantor for the needed loans. This so-called kommunegaranti reduces lenders' risk and thus reduces interest rates. KommuneKredit, a credit union for Danish cities, lends out more than 1 billion DKK annually to Danish DH companies that hold the kommunegaranti. In the previous 23 years there has been no instance of a municipal government called upon to cover the losses of a DH loan (Rasmussen, 2013).

DH companies are responsible for spreading the fixed costs of a system across all relevant customers. In cases where a customer is singularly responsible for a cost – such as the infrastructure to connect a new home to an existing DH system – the DH company must ensure that only that customer pays that fixed cost. However, many other fixed costs are system-wide, and since they are highly regulated entities, DH companies are cautious about adding costs to the communal rate base, as they know such moves will be heavily vetted. Most customers have bills heavily weighted by fixed costs (as opposed to variable), so conservation efforts may not be economically attractive to them. This has been a challenge to DH companies looking to encourage participation in conservation efforts.

Heating companies may assign different prices to different consumers depending on their type or location (MCEB, 2011a). This is important because it allows for the fact that it may be more expensive to serve one area than another, in terms of the required infrastructure investment, and it gives DH companies the confidence that they will be able to insulate uninvolved consumers from costs to serve a particular geographical region or type of consumer (Larsen, 2013).

3.5. Individual consumers

In general, the needs of individual customers are well represented in local decision-making activities and cost–benefit analyses. There are typically very compelling economic and practical reasons for an individual customer to connect to a DH system, as is fully explored in Section 4.

Individual consumers are explicitly given the right to choose – either directly, or indirectly via local council elected representatives – the majority of directors of any company that owns a facility that supplies or is otherwise involved in the transmission of heat (MCEB, 2011a). Individual consumers are then permanently represented in company leadership, and they may be more confident that their needs are being adequately and accurately represented to company decision-makers.

The national oversight of prices charged by DH companies ensures that consumers are paying a fair price for their heat, and not being overcharged for unrelated costs incurred by the DH company. Additionally, every Danish DH company publically reports its prices and breakdowns of fixed versus variable costs each year, ensuring the customers have a good sense of how the prices they are paying compare to those of other areas.

While municipalities can enforce their power to require connection to a system, individual customers have several powers they may exercise in response. First, they must be consulted prior to the establishment of such an obligation. Second, they are within their rights to argue that they may be exempted from this obligation for a particular reason, such as the fact that a building will soon be demolished or is already a low-energy home (DEA,

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2013). They may also participate in an official appeals process (MCEB, 2011b). Finally, if a new building is forced to connect, but the supply of heat is not ready for the building by the time of occupation, the DH company must supply some type of temporary heat solution for the building at no cost to the owner (MCEB, 2011b).

Individual consumers or groups of consumers are given the right of first refusal to buy in whole or in part (via the purchase of shares) a DH system serving their building(s) (MCEB, 2011a). In this way, local power over heating solutions may be retained even if a DH company decides to cease operations, or in the unlikely event that a DH company is put up for sale.

4. Discussion: Shared risks, shared rewards

Since the 1970s Denmark has seen continued support for and a diffusion of power in heat planning, as more parties became comfortable with the concept of heat planning and the definition of socio-economic cost-effectiveness that aims to maximize the cost-effectiveness to all of society (DEA, 2005; Dyrelund and Overbye, 2013). Local actors now make the bulk of decisions that will impact their local heat system. They will benefit from a system's good design and suffer the costs of poor decisions or lax oversight. Since the national government has long eschewed rigid prescriptive energy system design requirements, local actors have a true sense of agency. Local municipalities and heating companies enjoy a flexible framework that gives them the autonomy to leverage market forces and choose the solutions that are most cost-effective for the system as a whole as well as their individual citizen-consumers.

Heat planning helps a community to spread risk around many different technologies and fuels, enjoying the purchasing power of many consumers aggregated together, demanding better prices for fuels and equipment than would be available to an individual consumer.

Communal solutions can leverage multiple fuels and equipment concurrently, reducing the risk associated with fuel price fluctuations and equipment failures (Elsman, 2009). System designers can add redundancy and storage where deemed necessary (Larsen, 2013). This, combined with regular maintenance by professionals, also reduces risk (Andrews et al., 2012). By engaging in regular planning, cities can flexibly respond to changes in economic development opportunities and land use, making DH both a more environmentally and economically sustainable long-term energy solution for communities than most other alternatives (CEA, 2007).

Danish heat plans appear to have helped beget a high level of connection across Denmark. The higher the connection rate, the lower the individual cost to connect to the system (Sandberg, 2004), yielding a virtuous cycle. At the aggregate level, this high connection rate and transparent heat plans give industry partners and bankers confidence that DH systems will be economically viable, yielding the low commercial lending rates mentioned in Section 3.4 that help reduce prices for all (Dyrelund and Overbye, 2013).

Since Danish DH companies do not generate external profit, individual consumers know that their economic interests will not be trumped by the economic interests of executives or shareholders that might stand to benefit from decisions that are not in public interest. Owners and consumers of community-controlled heating systems have little appetite for unnecessary costs, and demand a high degree of transparency. A community of official and unofficial consumer watchdogs can protect individual consumers who might not otherwise know whether they are being overcharged for a service or certain fuel (Dyrelund and Overbye, 2013).

For the individual consumer, an individual heating solution typically relies on one fuel and one primary type of heat-generating equipment. If a component of the individual system fails, chances are high that the customer will suffer some days without heat. If an individual fuel storage tank leaks, the individual customer must bear the high financial burden of responding to the leak. Emergency repair costs are not easily forecasted, and can be very burdensome to individuals. Similarly, if a fuel price suddenly increases, the owner of an individual boiler typically has few options but to buy the fuel at the higher rate. Communal heat systems negate much of this risk.

This mirrors other communal systems to which such customers might be connected, such as communal sewers and drinking water sources. In those cases an individual homeowner or tenant pays little heed to the maintenance needs of the sewer or drinking water systems, instead outsourcing that work and paying a set rate for competent and reliable sewer and water service and the ancillary benefits of not having to manage a sewage treatment plant in his/her own backyard.

Fig. 3 shows the economic advantages to Danish residents who rely on DH instead of individual heating solutions for their homes. For instance, in Aalborg, the fourth largest Danish city (representing the curve between 0.9% and 5.5% of Danish market share in Fig. 3), home owners enjoy heating costs that are 43% lower than what they would pay if using individual gas, and 64% lower than what they would pay for oil-based heating.

Of the 363 Danish DH companies reporting price data shown in Fig. 3, only three companies' heat product would cost the average Danish homeowner more than the cost to heat the house with oil, while 94 DH companies charge the average house more for heat than the average cost to heat the house with gas. However, these three and 94 companies deliver 0.03% and 5.3%, respectively, of the total Danish DH volume. Therefore, 94.4% of the heat sold by Danish DH companies is cheaper to customers than an alternative individual heating solution.

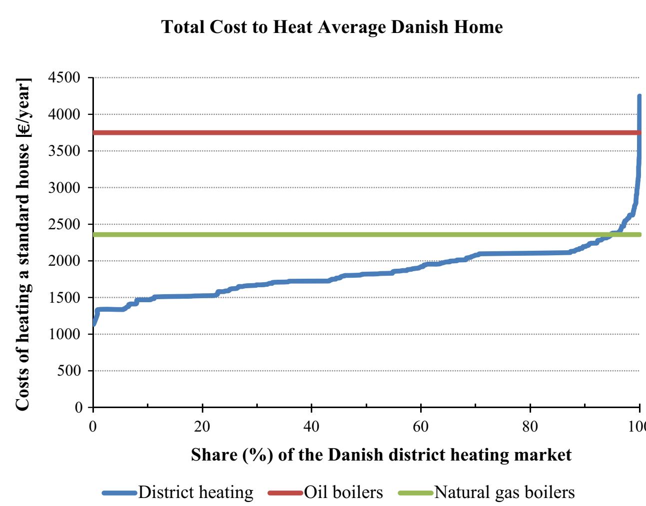

Fig. 3. Total annual cost to heat average Danish 130 m^2 house with annual heat demand of 18.1 MWh, with three different heating resources. Note: The cost for oil-fired central heating is based on a boiler efficiency of 85% and annual O&M costs of 333€. The cost for gas-based central heating is based on an efficiency of 95% and annual O&M costs of 280€. Costs for individual boiler fuels are market prices including all applicable taxes in both cases. DH costs include all cost components and are directly comparable to the costs of the two individual solutions. DH data reflect actual prices charged by the 363 individual companies that supply nearly all the DH in Denmark, according to sales volumes, along the horizontal axis. Initial capital costs for all heating resource types are excluded (Jensen, 2014). Data source: Jensen (2014).

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The Danish demand for communal heat solutions is very robust, and a resulting well-qualified Danish DH industry now looks to trade its competence and knowledge of system design worldwide, such as through export marketing efforts sponsored by the Danish Board of District Heating.

5. Conclusions and policy implications

5.1. Taking the Danish model abroad

Technically, there are substantial opportunities for communal heat solutions and waste heat recovery in the U.S. and other nations that currently lack significant installed DH capacity and have cold or temperate climates (BCS Incorporated, 2008; Connolly et al., 2014; Davies, 2009; Nielsen and Möller, 2013; Ulloa, 2007). In the EU, countries that have never before undertaken significant heat planning or considered whether existing power generation could be converted to CHP are required to do so under new EU energy policies. Many EU countries already have significant market regulations and rules for the DH sector, and the EU-led effort to harmonize energy markets throughout the EU will likely stimulate additional Danish-style heat planning and DH development, which includes strong government intervention (Frederiksen and Werner, 2013).

While citizens of certain EU countries may accept more significant government intervention, a country like the U.S. is less likely to implement such efforts. However, aspects of the Danish heat planning process can transcend policy constructs. For instance, U.S. states and municipalities do not currently assess specific heat resource opportunities and potential heat uses, nor how such heat resources might strategically support other energy-related needs or opportunities.

These kinds of opportunities for change are the focus of this paper's concluding thoughts. In particular, we focus on how certain aspects of the Danish approach to heat planning could specifically be implemented in the U.S. This is due to substantial policy and market changes in the U.S. energy sector, and resultant emerging opportunities for increased DH and CHP deployment. Lessons from Danish heat planning efforts are relevant to many of the great challenges facing the U.S. today.

States across the U.S. are typically facing two new challenges: rising energy efficiency and renewable energy targets as a result of in-place energy efficiency or renewable energy portfolio standards; and retiring coal-based electric generation plants that are themselves facing unfavorable economics and new federal rules that will put a cost on CO_2 emissions for the first time. Additionally, rising rates of fluctuating and intermittent renewable-based electricity are challenging regional grid operators to develop markets and plans to accommodate these resources and maintain grid stability. Finally, U.S. utilities are facing an increased demand for grid resiliency after devastating weather events.

Energy planning in general is a new concept to most U.S. cities, and heat is typically lacking from sustainability or land use planning efforts (Conglose, 2014; Mackres and Kazerooni, 2012; Mackres et al., 2013). Additionally, recent DH development in the U.S. has highlighted the importance of having a local 'champion' of the project, someone in power who takes it upon herself/himself to move the project ever forward (Chittum, 2012). However, as noted by Bulkeley (2010), it takes more than a single individual to continue to move any local efforts forward in the medium- to long-term; approaches to climate protection must be institutionalized at the local level in order to enjoy some degree of persistence.

Given the above-stated constraints, what about the Danish experience might be useful to planners and policymakers from other countries, and the U.S. in particular? Below are five actions that could be taken now to implement some of the lessons learnt from Danish heat planning.

1. *Address the scope and structure of cost-effectiveness tests*. The Danish example of systematically assessing costs and benefits as society, localities, DH companies, and consumers experience them has helped build confidence in heat networks and the heat planning process. These tests often look beyond the individual utility scale.
2. *Build robust national-level tools*. The Danish national government recognizes the important role cities play in the Danish energy system. By providing suggested cost-effectiveness test frameworks, providing annual assumptions and price forecasts, and offering funding and technical support to cities interested in sustainable energy planning, the national government signals to local leaders that they are taking the role of municipalities in energy planning seriously. And by encouraging cities to use a single structure for project assessments, the national government makes it easier to compare projects and learn from other cities' experiences. Additionally, the nationally organized KommuneKredit credit institution, which offers low-cost loans to municipalities for large infrastructure projects, could be replicable, perhaps on a regional scale, and expand on the existing loan guarantee programs available from some U.S. states.
3. *Develop electricity balancing markets that can confer value to DH and CHP systems*. Robust electric balancing and ancillary services markets offer CHP systems integrated with DH systems the ability to offer and be paid for their unique balancing services. CHP can provide highly cost-effective balancing services to enable greater deployment of intermittent resources like wind and build resiliency of the grid. The U.S. and several EU countries have developed these kinds of markets sporadically, but the Danish and Nordic examples of planning for these kinds of resources and conjunction with more traditional energy resources has yielded more liquid markets for these services and higher penetrations of resources like wind.
4. *Encourage holistic energy planning*. Energy planning in the U.S. largely comprises electric system planning, undertaken by individual utilities for their service territories only. While there are notable exceptions, such as the regional electric system planning of the Pacific Northwest, they still ignore heat as a resource. State energy offices and local planners could encourage heat planning, integrated with existing planning efforts, such as sustainability planning, comprehensive land use planning, or electric system planning. This work could be modeled on current efforts to encourage municipal-level strategic energy planning in Denmark, and other local integrated energy planning, as noted in Garforth International (2009).
5. *Consider the impact and design of state energy targets*. Most U.S. states have a renewable energy standard and/or an energy efficiency resource standard (DSIRE, 2014). Both encourage utilities to meet defined targets, usually scaled to a utility's size. Unfortunately the structure of these targets does not allow for a continual assessment of which kind of renewable or efficiency resources for a specific city or region might offer the most cost-effective emissions reductions or enhanced grid resiliency. Energy efficiency targets do not consider system-wide efficiency, such as whether heat might be more cost-effectively provided by a communal NG-powered system instead of electric heat pumps. These standards are important tools to move the American energy system toward a cleaner and more economically resilient future, but alone they fail to address system-wide opportunities. Danish system-wide energy planning efforts, and energy savings targets that allow

sectors freedom in how the targets are met, could be instructive in this case. U.S. states could structure energy efficiency goals to allow for a broader assessment of system-wide efficiency savings opportunities. EU-wide efficiency and renewable energy goals should provide a framework in which system-wide efficiencies are encouraged and rewarded.

5.2. Conclusions

In Denmark, DH systems have played a very critical role in the development of a highly cost-effective sustainable energy system. These systems have benefitted from a long-term stable energy policy, a history of political consensus, and a widely accepted, nationally supported local heat planning framework.

The Danish approach to heat planning is regarded by many as one of the most effective in the world (Andrews et al., 2012; IEA, 2011; Mendonça et al., 2009; Nygård, 2011; Sovacool, 2013; Ulloa, 2007), with good reason. Cities have freedom to pursue the most cost-effective projects that are appropriate for their citizens.

Danish heat planning rests on policies and government decisions made decades ago and continually strengthened through new legislation. While the U.S. and other countries with high DH potential may lack the policy and political context of Denmark, they can still learn much from the Danish experience. The means to get there may be different, but the ends could be the same: high levels of confidence, high levels of cost-effectiveness, high levels of flexibility, and reduced levels of risk across the energy system as a whole.

Substantial future work is required to identify how the U.S. and other countries might leverage existing regulatory authority and policies to reach those ends. An early step would be simply to raise awareness of heat planning and determine how heat planning and comprehensive energy planning fit into the existing energy and land use planning activities. Future analysis might identify the existing authorities at the city and state level that could require such planning, and which technical and financial tools are most needed at the local level for city planners. Additionally, the DH industry in the U.S. does not work with municipalities as a primary constituency, though it is recognizing that it needs to in the future. U.S. cities also need tools to help bridge this divide such as spatial analysis tools and economic impact analysis tools that can help them and the DH industry better communicate the costs and benefits of DH systems.

As cities aim to take control of their energy futures, it would behoove national governments to recognize the importance of empowering local leaders to identify the energy solutions that suit them best. DH systems in particular require hyper-local energy analysis and benefit from local design, but offer tremendous economic and emissions reduction benefits. National governments interested in reducing GHG emissions and providing citizens with reliable and cost-effective heat have much to learn from Denmark, where heat planning has quietly underpinned one of the world's great energy success stories.

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