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The International Energy Agency (IEA) is an intergovernmental organisation that serves as an energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens. Founded during the oil crisis of 1973-1974, the IEA was initially established to coordinate measures in times of oil supply emergencies. As energy markets have changed, so has the IEA. Its mandate has broadened to incorporate the “Three E’s” of balanced energy policy making: energy security, economic development and environmental protection. Current work focuses on climate change policies, market reform, energy technology collaboration and outreach to the rest of the world, especially major consumers and producers of energy like China, India, Russia and the OPEC countries. With a staff of nearly 200 who are mainly energy experts and statisticians from its 28 member countries, the IEA conducts a broad program of energy research, data compilation, publications and public dissemination of the latest energy policy analysis and recommendations on good practices.

ABOUT IEA DHC

The Energy Technology Initiative on District Heating and Cooling including Combined Heat and Power was founded in 1983. It organizes and funds international research which deals with the design, performance, operation and deployment of district heating and cooling systems. The initiative is dedicated to helping to make district heating and cooling and combined heat and power effective tools for energy conservation and the reduction of environmental impacts caused by supplying heating and cooling.
Plan4DE Literature Review
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1 Purpose
The purpose of this paper is to take stock of the literature on district energy, focusing on existing models and the influence of planners. The first step is to understand the mandate of planners and the field of planning, and the second is to consider the relationship between the built environment and energy intensity, and subsequently energy intensity and the feasibility of district energy. Included in the brief is an exploration of the tools available to planners in considering the impacts of their work on district energy, looking specifically at the state of the modelling field with respect to district energy and at methods (which we term archetypes) to generically characterize the built environment. To conclude the package, we also consider the co-benefits, or the ancillary benefits that may arise if planners decide to factor district energy as a consideration into their planning decisions. In other words, if the built environment works for district energy, will it also deliver additional dividends to the community?
"SPATIAL ORGANIZATION OF LANDSCAPES DETERMINES HOW MUCH RENEWABLE ENERGY IS ACCESSIBLE AT WHAT QUALITY, WHERE, AND AT WHAT TIME IT IS ASSIMILATED AND USED" (Stremke & Koh, 2011, p. 209).

The primary focus of this section is the role of planners in optimizing land-use to support district energy. As a first step, the power and role of planners is considered.

2.1 The discipline of planning

Planning has three key characteristics (Rydin, 2003): Firstly, it is a future-oriented activity and it devises strategies that will lead to desired end states. Secondly, it is primarily a public sector activity at central, regional and local levels. Thirdly, it is strongly related to the physical environment and the implications of the physical environment for human society. Its underlying theory is a mix of philosophy and sociology, often based on untested or naive assumptions, as described by Taylor (1980), who cites the example of the aim of increased personal mobility in order to enhance wellbeing. As a discipline, it is a combination of many other disciplines in that “planning covers too much territory to be mapped with clear boundaries. It overlaps far into the terrain of other professions, and its frontiers expand continually” (Hudson, Galloway, & Kaufman, 1979, p. 388). As such, urban planning is a sphere that consists of wicked problems, that is, problems to which there are no definitive or objective answers. Decisions are often taken not because the rational outcome has been identified but because of external constraints such as time, resources or politics (Rittel & Webber, 1973). The trends and focus of planning, however, parallel those found within other aspects of social policy, shifting from “the applied science perspectives in the 1960s to the political approach in the 1970s, to focus on communication and participation in the 1980s, and to collaborative planning and design approaches in the 1990s and beyond” (Foth, Bajracharya, Brown, & Hearn, 2009, p. 98). Another notable and current paradox is that much of the urban growth today is taking place in Southern countries, whereas many of the theories of urban planning have emerged in the North (Roy, 2002).
2.2 The role of planners

Planning is empowered by a legal and regulatory framework and is implemented through an administrative system, both of which vary considerably from country to country (Newman & Thornley, 1996). In general, planners have influence on urban form through: the direct administration or implementation of zoning control in existing areas; the changing of zoning control (through amendments) in existing areas; and the development of new zoning control, alongside urban design and street pattern, for new urban developments.

In these settings, the planner’s role is either as administrator of an existing control framework, or developer and/or proponent of new or different control framework. Generally speaking, major influence or change to urban form comes through the development of a new set of principles or control that is then followed by development that follows this control. In this instance, planners tend to play either an expert role (making recommendations on appropriate changes) or a facilitation role (consolidating widespread recommendations, achieved through engagement, on what should be changed). These recommendations and expert opinions are often grounded in the contextual planning approach. It is very seldom, however, that planners have ultimate decision-making authority, as this is typically retained at the political level. In the political realm such factors as politics and economics may have a strong influence on zoning control and patterns, and therefore the resultant urban form.

2.3 Planning and energy consumption in buildings

“Urban design, including the clustering of buildings and mixing of different building types within a given area greatly affect the opportunities for and cost of district heating and cooling systems” (Levine & Ürge-Vorsatz, 2007).

A building’s energy performance is dependent upon a number of factors, which will be addressed in more detail in section 5. As illustrated in Figure 1, these factors include climate, urban structure, building morphology, buildings systems and occupant behaviour (see also section 5).
These factors are influenced by, and under the control of, different professional actors in the urban context, at building and neighbourhood scale, namely: planners with respect to urban structure, architects/designers with respect to urban morphology, systems engineers with respect to building systems, and occupants/building owners with respect to occupant behaviour. The division between the private and public sector in the actual construction of the built environment varies by jurisdiction, but local governments have a significant influence, as is illustrated in the case studies and policy catalogue developed in IEA's Annex 51 (Strasser et al., 2011). Local governments can carry their policies relating to the urban structure through to building morphology, building systems and even to occupant behaviour.

As discussed above, planners have the most influence and control over urban structure and density. However, through zoning control, some aspects of planning can influence building morphology, such as height (Wende, Huelsmann, Marty, Penn-Bressel, & Bobylev, 2010). At the building scale, architects and engineers are bound to not only follow zoning and bylaw requirements, but also building-code requirements. Building code can (and often does) have an influence on energy consumption, particularly as it relates to envelope performance.

Another way to conceptualize the different spheres of planning operations refers to geographic scale (Vandevyvere & Stremke, 2012a). Interventions at the building level are the micro scale, interventions in the larger scale energy infrastructure occur at the macro scale, whereas the discipline of planning focuses primarily, but not exclusively, on the built environment, which could be considered the meso scale.

When considering energy consumption in the context of urban form, zoning control, urban pattern and building-code regulations need to work together (Dobbelsteen, 2007). Dwelling density can increase as a result of deliberate policies under a compact-city philosophy. However, if building code and energy performance standards are not improved, overall energy efficiency may not be achieved.

Urban form refers to the spatial and physical pattern or structure of developed areas, and the distribution and relationship of uses within this structure. Urban patterns are made up of a number of elements (buildings, parcels, open spaces and streets) that are linked by a consistent, repeated set of systematic relationships.
Variations to these elements and their functions or uses generally occur within an organized set of principles or control, which reflect the development approach.

There are two main determinants of urban form: What gets built on a parcel of land (zoning control) and how those parcels fit together (urban geometry – street pattern and block size).

Table 1. Description of common planning strategies.

<table>
<thead>
<tr>
<th>Planning strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zoning Control</td>
<td>What gets built on a parcel of land is generally determined by the zoning control and other regulatory requirements that apply to that land.</td>
</tr>
<tr>
<td>Land Use</td>
<td>Residential, commercial, industrial, institutional, recreational, open space, agricultural, right of ways (roads, rail, utilities).</td>
</tr>
<tr>
<td>Density</td>
<td>Number of residents, households, employees, units, or building area per total parcels (e.g. floor space ratio (FSR), dwelling units per area).</td>
</tr>
<tr>
<td>Setbacks (which can also be a function of density)</td>
<td>Influences the distance, and therefore spacing pattern, between buildings and between buildings and streets.</td>
</tr>
<tr>
<td>Building Typology (which can also be a function of density)</td>
<td>E.g. detached houses, semi-detached houses, apartment blocks.</td>
</tr>
<tr>
<td>Building geometry</td>
<td>Vertical and horizontal distribution – height, volume, perimeter distance.</td>
</tr>
<tr>
<td>Building character</td>
<td>Architectural look and feel – in certain contexts, this can be prescribed through control, in other circumstances, designers are given more artistic freedom to create individualistic designs.</td>
</tr>
<tr>
<td>Urban Geometry</td>
<td>How parcels of land fit together within a developed area is determined by street pattern and block sizing.</td>
</tr>
<tr>
<td>Street Patterns</td>
<td>Street patterns make up the spatial structure of urban areas.</td>
</tr>
<tr>
<td>Block sizing</td>
<td>Block sizes determine the length of a block (or collective parcels) of land between intersecting streets, and therefore, a corresponding length in street. No one street pattern is associated with a particular block size – block sizes can vary within the same street pattern. For example, a traditional grid street pattern may have 100m x 50m blocks, or 100m x 100m.</td>
</tr>
</tbody>
</table>
Urban forms, and approaches to urban form, vary depending on context, in other words, across different jurisdictions, countries, climates, due to a number of elements. These include differences in architectural style and building materials, planning approaches, policy, codes and regulations, local and/or federal politics, economics, and approaches to environmental sustainability.

2.4 Planning and district energy

Planners and other local authorities have a number of tools to encourage district energy development and connection, using bylaws and local building codes to ensure building design and systems are compatible with district energy.

Green building or neighbourhood standards can be set to establish various targets for energy efficiency. For example, a standard that sets an electricity conservation target will naturally discourage the use of electric heaters, and a renewable energy procurement target will naturally discourage the use of fossil-based fuels (Bradford & King, 2013).

The ability of local government to encourage or, in some cases, require district energy ‘ready’ (DE-R) buildings varies considerably across jurisdictions. In parts of Europe and Asia (e.g. Denmark, South Korea), local governments can mandate energy utility services across districts (Spurr, 2012). The Canadian context provides both a legal framework and environmental values that help support the development of district energy. The City of North Vancouver in British Columbia established a Hydronic Heat Energy Service Bylaw to create a district heating service area for the Lower Lonsdale neighbourhood. The bylaw requires all new or retrofitted buildings greater than 1,000 square metres be connected to and use the district energy system.

Recently, the City of Calgary undertook changes to its zoning bylaw, featuring landmark updates to the Green Building Features section. Green building features are identified as physical components that contribute to improving the local environment adjacent to the building, and focus on enhancing air quality, reducing stormwater runoff, and improving the visual environment. The City has incentivized adopting green building features with an increase in density for new development. The bylaw stipulates the following requirements to qualify for the additional density:
Connecting the building to a district energy system and use of the thermal energy from the district energy system in the building;

Connection to infrastructure that includes the following:

- Space allocated for an energy transfer station at ground level or below;
- A heat distribution system that can accommodate the primary heat source at ground level or below; and
- An easement with a minimum width of 4.0 metres registered on the certificate of title for the parcel for a thermal pipe from the property line to the building and through the building to the allocated energy transfer station location.

Similar incentives and requirements are also provided for on-site cogeneration facilities in the City of Calgary. In cases where district energy services are not yet available, the bylaw includes incentives for developing DE-R buildings, where the ability to connect to district energy in the future is preserved.

In response to the rapid urban growth underway in Surrey, British Columbia, the City of Surrey has developed a new district energy system to service the city centre. In June 2012, the City passed the City Centre District Energy bylaw that mandates compatible hydronic systems be installed in new buildings throughout the district. It also mandates connection to the city’s district energy system within a core service area. Authority for this type of bylaw comes from British Columbia’s Community Charter. In an effort to mitigate some of the additional costs associated with hydronic heating systems, the City has implemented an Early Adopters Policy that provides financial assistance of up to $1.50 CAD per square foot of the dwelling unit (no more than 50% of the cost premium to install the hydronic system).

While the United States is often less prescriptive about mandated district energy connection, some jurisdictions are taking steps to support the growth of thermal energy networks. The City of Cambridge in Massachusetts has adopted new zoning requirements to help facilitate the connection to existing district energy services in the Kendall Square area as part of the development approval process. The Kendall Square PUD-5 District Zoning (26 acres), adopted April 8, 2013, now states: “A Development Proposal for a commercial building shall include a study, prepared by the Developer, considering the feasibility of connecting the building identified in the Development Proposal to the existing district steam system”.
3 District Energy
This section reviews the idea of district energy, its opportunities and challenges, and the context in which it is best used.

### 3.1 What is district energy?

At its most basic level, district energy is defined as an approach to energy provision “in which heat is produced centrally and hot water is piped to the buildings” (Davies & Woods, 2009). In fact, district energy can provide either heating for space heating and hot water or chilled water for air conditioning. District energy systems generally consist of three sub-systems including the collection and/or generation of thermal energy, the distribution of the thermal energy from plant sites to a network of energy consumers, and the transfer of the thermal energy to the energy consumer (Gilmour & Warren, 2008; Rodger, 2010). A district can consist of a small neighbourhood or a large part of a community (Rodger, 2010).

### 3.2 The Impetus

There are many existing and future energy demands for low temperature heat that are currently being satisfied by employing combustion of fossil fuels, which provides high temperature heat – a mismatch. Similarly, the use of electricity for these heat loads means using a high-quality energy source for a low-quality heat demand. It is therefore preferable to use the difference between the high temperature heat and the low temperature demand to generate electricity. However, this is not generally feasible without a centralized system like district energy, which facilitates the capture of additional and significant efficiencies (Rogner, 1993). The improved efficiencies translate into economic benefits and reduced pollution. Further, district heating helps overcome three barriers to the wider dissemination of renewable energy, namely: periodic fluctuations associated with the generation, the low energy density of renewable energy carriers relative to fossil fuels, and the limited utilization of renewable energy by consumers, including provision, conversion, storage, transport and use (Stremke & Koh, 2011).

In its synopsis of an upcoming report on district energy, the United Nations Environment Program (UNEP)
identified the following policy goals that cities hoped to achieve in applying district energy (UNEP, 2014, p. 5):

Reduce greenhouse gas emissions: Achieve rapid, deep and cost-effective emissions reductions, with reduction of primary energy consumption by 30–45 per cent.

Improve air quality: Address indoor and outdoor air pollution and their associated health impacts, by reducing coal and oil consumption.

Improve energy efficiency: Achieve operational efficiency gains of up to 90 per cent, by using district energy infrastructure to link the heat and electricity sectors.

Local and renewable resources: Harness local energy sources, including from waste streams, reject heat, natural water bodies and renewable energy. Pilot new technologies, such as thermal storage, to integrate renewables.

Resilience and energy access: Reduce import dependency and fossil fuel price volatility. Manage electricity demand and reduce the risk of brownouts.

Green economy: Achieve savings from avoided or deferred investment in generation infrastructure and peak power capacity. Create wealth through reduced fossil fuel bills and generate local tax revenue. Create jobs for design, construction, operation and maintenance.
3.3 Geographic extent

Around the world, federal governments exert varied degrees of influence over energy policy, particularly as it relates to district or thermal energy. Some governments, such as Denmark and the United Kingdom, have been very proactive in establishing district energy policy and setting sector-specific targets.

Table 2. Market status of district heating in Europe (Rosa, 2012)

<table>
<thead>
<tr>
<th>Status of DH market</th>
<th>Market share (%)</th>
<th>Examples</th>
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<tr>
<td>Consolidation</td>
<td>50-60</td>
<td>Denmark, Finland, Sweden</td>
</tr>
<tr>
<td>Refurbishment</td>
<td>10-50</td>
<td>Croatia, Czech Republic, Lithuania</td>
</tr>
<tr>
<td>Expansion</td>
<td>3-15</td>
<td>France, Germany, Italy</td>
</tr>
<tr>
<td>New Development</td>
<td>&lt;1</td>
<td>Ireland, Spain, United Kingdom</td>
</tr>
</tbody>
</table>

More often, federal governments establish direction for energy policy, and may make international commitments to greenhouse gas emission targets, the increased adoption of renewable fuel sources, or implementation of a carbon pricing program. Currently, coal power remains the least expensive energy source and is abundant in Canada and the United States of America (Reeve et al., 2010). However, the pursuit of environmental protection and concerns over human health undermines the continual burning of fossil fuels (Makansi, 2007).

3.3.1 United Kingdom

Although the United Kingdom (UK) has historically been slow to adopt district energy, more recently its government has introduced a range of policies to reduce energy use across the residential, commercial and public sectors. Energy consumption across the UK has fallen for eight of the last nine years, with energy consumption 13% lower today than in 2003 (DECC, 2014). The UK’s declining energy consumption serves as an international model for energy efficiency leadership, featuring the least energy intensive economy of the G8 countries. Forecasts suggest that by 2020 final energy consumption in the UK will be 20% lower than 2007 levels (NEEAP, UK’s Article 3 target).

In 2013, the UK Government launched its Energy Efficiency Strategy to identify barriers to energy efficiency. Given that heat accounts for roughly half of total energy consumption, and contributes to a third of the UK’s greenhouse gas emissions, the strategy identified heat networks as having a key role in improving energy efficiency. Building on this momentum, the government released a publication titled The Future of Heating: Meeting the Challenge, which sets out a number of actions to increase the deployment of district energy across the UK (2013). The report found significant potential for additional natural gas Combined Heat and Power (CHP) capacity, and carbon savings when displacing more carbon intensive generation.

The UK Government requires all Member States to carry out a comprehensive assessment of the
potential for the application of high-efficiency
cogeneration and effective district energy networks
by December 31, 2015. Assessments must include
a cost-benefit analysis based on climate conditions,
economic feasibility and technical considerations.
The obligation to complete this assessment is being
transposed into UK law via an implementing statutory
instrument (DECC, 2014). While the methodology
hasn’t been finalized, the UK will be able to build
upon a significant body of existing district energy and
CHP research.

Northern Ireland’s Department of Enterprise, Trade
and Investment (DETI) has the responsibility of
achieving 10% renewable heat by 2020 (DECC, 2014).
Established in November 2012, the Northern Ireland
Renewable Heat Incentive (RHI) provides long-term
financial support for non-domestic users wishing
to switch from conventional heating to renewable
heating solutions. Domestic renewable heat
installations are supported through the Renewable
Heat Premium Payment (RHPP) program which
provides grant support towards the cost of specified
renewable technologies.

In January of 2013, Scotland published the Outline
Heat Vision document, committing the state
to a largely decarbonized heat sector by 2050.
Working with several local authorities, the Scottish
Government carried out a Heat Mapping Programme
and released the associated national heat maps.
The expansion of district heating provides the
foundation for Scotland to strengthen the impact of

The Scottish Government has committed to provide
more than £8 million in funding over the next two
years for the District Heating Loan Fund. This is
part of a £10.5 million package of support for heat
policy. However, while it represents a step in the
right direction, this amount on its own would be
insufficient to kick-start a district energy system in
most cities.

The UK and its Member States highlight the
opportunity for federal government leadership to set
out national district energy priorities, coordinated
assessment and analysis, and provide the necessary
financial support to implement projects.
3.3.2 Canada

In Canada, the federal government presently plays a limited role in the energy policy arena, particularly with respect to thermal energy. Canada remains without a national energy strategy or carbon pricing system. However, the existing programs delivered through Natural Resources Canada provide a platform and an opportunity for the federal government to develop a suite of supportive policies and financial programs that would facilitate the development of district energy systems. Additionally, such policies and financial programs could not only deliver support, but give direction for the provinces and territories in adopting a consistent approach.

The ability to develop district energy systems is influenced by a complex matrix of local issues including politics, climate and geography, socioeconomic context, local resources and availability, labour market, utility ownership structure, environmental conditions and the size and density of urban areas. For example, electricity procurement can vary by province, state, or region. Although many district energy systems provide thermal services only (heating and cooling), electricity is still required to operate the plant and equipment at the heart of each system. The local or provincial fuel mix for both electricity generation and thermal (heating/cooling) applications will also impact the marketplace for district energy. In provinces with abundant local energy resources there may be additional barriers to the development of alternative generation technologies. In provinces where electricity is primarily derived from hydro sources (British Columbia, Manitoba, Québec), prices are typically cheaper than provinces that rely on non-renewable resources (coal in Alberta and nuclear in Ontario account for large portions of the energy supply mix). Therefore, provinces with access to low-cost electricity may have less of an incentive to explore more efficient energy systems like district energy. However, there are examples to the contrary. BC, where hydro is the predominant energy source, is also the most active market for district energy in Canada. In this case, the environmental agenda, driving provincial legislation, has succeeded to a certain extent in outweighing straight economic incentives. Indeed, the primary driver of district energy development so far, internationally, has been policy and political vision. As a more detailed case study, the following text provides more detailed insight into the policy landscape at a regional level in Canada.
1.1.1.1 BRITISH COLUMBIA

District energy operated under private ownership is regulated by the province under the Utilities Commission Act. British Columbia (BC) is the only province to regulate district energy services, which provides customers with assurance that the rates charged reflect the accepted cost of service methodologies, using cost allocation practices that account for all appropriate district energy service costs. Additionally, utilities in the province may have access to lower-cost capital for investment in district energy infrastructure. This allows for a longer cost recovery timeline, translating into more financially sustainable projects, lower rates for customers, and the ability to engage in system expansion. If the district energy system is owned by the municipality, regulatory oversight is not required.

While British Columbia’s largest utility, BC Hydro, doesn’t own or operate any district energy systems, from 2009–2011, they provided assistance to municipal governments through the Power Smart Sustainable Communities Program to drive market acceptance of district energy within the province. The program provided access to education, expertise and financial incentives, including funding for:

- community energy and emissions planning;
- district energy pre-feasibility studies;
- detailed engineering feasibility studies; and
- an electricity savings-based capital incentive to offset capital costs for district energy systems.

British Columbia has a number of energy-related policies that are positioning district energy as a viable option for community-based energy systems. Amongst these provincial policy tools are an internationally respected carbon tax, Green Communities legislation known as Bill 27 (amending the Local Government Act and Community Charter), and the Climate Action Charter. The Climate Action Charter, in particular, commits all local government voluntary signatories (182 of 190 BC local governments) to creating more complete, compact, energy-efficient communities across the province. This type of sustainable development provides fertile ground for district energy deployment.

British Columbia’s progressive policy environment has generated significant growth and momentum in the district energy sector, along with the emergence of local expertise. The Union of BC Municipalities, for example, offers funding to district energy projects under its Community Works Fund. The growth of district energy systems across the province continues to demonstrate their viability and their potential for netting substantial energy savings. High-profile projects such as the Southeast False Creek Olympic Village, Vancouver’s Cambie Corridor and Dockside Green, the City of North Vancouver’s Lonsdale Energy Corporation, and the City of Enderby’s biomass district energy system have all helped position district energy as part of the public discourse around sustainable community-based energy systems.
1.1.1.2 ALBERTA

The province of Alberta is without existing legislation or policy pertaining to district energy. Similar to British Columbia, Alberta has set a price for carbon. However, at current levels of $15/tonne, its ability to act as a price stimulant for district energy projects is limited. Construction and operation of CHP facilities utilizing heat extraction requires approval from the Alberta Utilities Commission. However, heat generated in a boiler has no specific regulatory framework.

Alberta has made advances on the district energy front, with newer systems in the cities of Calgary and Edmonton, and smaller-scale communities like Okotoks. In Calgary, municipal facilities are serviced by the ENMAX plant (a fully owned subsidiary of the city) and permit applications are filed with the municipality to install district energy piping similar to the process for fibre optic cable installation. Okotoks used a small pilot program to study the viability of a solar-based district energy system for supplying thermal energy and domestic hot water supply within a new subdivision. Today, fifty-two new homes are connected to the system for heating, cooling, and domestic hot water with year-round solar energy storage. While interest in the oil sands dominates the energy discussion in Alberta, waste heat recovery operations with small-scale district energy networks are already in place for several oil sands industrial applications.

SASKATCHEWAN/MANITOBA

Saskatchewan is the third largest natural-gas-producing province in the country, and is well positioned to support gas-fired district energy and CHP facilities to extend the longevity of its reserves. The province permits electricity produced through CHP applications to be exported to the grid. SaskPower is the largest electric utility in the province and has a number of partnerships in place to develop more cogeneration facilities. Additionally, the City of Saskatoon is exploring opportunities to capture waste heat from a local power plant to provide thermal energy for the downtown core and a greenhouse operation through a district energy system.

In Manitoba, the two most recent district energy installations utilize geothermal heat. The first system is privately owned, supplying heating and cooling to eighteen rental buildings in Winnipeg. The second system is municipally owned and located in Île-des-Chênes. The system provides heating and cooling for the local arena, fire hall and community centre. The project received financial support through tax credits from Manitoba’s Geothermal Energy Incentive Program. District geothermal systems serving multiple buildings are eligible for refundable tax credits of up to 15% and a provincial grant up to a maximum of $150,000 CAD.
1.1.1.3 ONTARIO

Ontario’s energy policy was developed in part out of low-cost electricity associated with hydroelectric facilities at Niagara Falls and other major rivers. This attracted energy intensive industry, forming the foundation of the province’s economic development until the late twentieth century (Reeve et al., 2010). Eventually, demand outpaced supply and by the 1960s Ontario had begun investing in fossil fuel and nuclear power plants.

Today, the economy and population of Ontario continues to grow, and electricity demand is being met with the continual development of higher-cost sources (Reeve et al., 2010). As a result, the current scenario dictates a desire for an increase in electricity efficiency and an investment in conservation strategies (Fawkes, 2007). According to industry data, Ontario has the highest number of district energy systems in any province or territory, representing more than 40% of all Canadian systems. Many of the systems were developed through the 1970s and 1980s as a result of the oil crisis and energy pricing volatility. The vast majority of systems are natural gas fired. Ontario’s district energy systems include some of Canada’s largest systems, such as Enwave’s deep lake water district cooling system, the largest system of its kind in North America.

Ontario is without specific policy or legislation related to district energy and it is regarded as a non-regulated activity. However, the province has set policy for combined heat and power operations. In 2005, the OPA was directed to negotiate individual CHP contracts for projects over 20 MW and to procure projects of 20 MW or less through a standard offer program. The 2009 Green Energy and Economy Act is often regarded as one of the leading pieces of energy legislation in North America. Whilst it does encourage renewable energy by permitting electricity distributors to own and operate renewable energy generation facilities that do not exceed 10 MW, it does not directly support district energy and largely ignores considerations for thermal energy. Further, Ontario’s Municipal Act restricts the municipality’s ability to borrow capital for a variety of projects, including district energy, limiting their ability to initiate such projects.
1.1.4 QUÉBEC

District energy is a non-regulated activity in Quebec. More recently, the province has become interested in community-based energy systems utilizing biomass. For example, La Cité Verte is a sustainable community project in Québec City that will develop a district energy system with four biomass (wood pellet) boilers with an installed capacity of 5 MW. The project has received $5m in funding from Hydro Québec in addition to financial support from Canada’s Clean Energy Fund. The emphasis on biomass facilities is in part a product of Québec’s large forest industry.

Québec has a number of programs that support efficient energy projects and the incorporation of renewable fuels. The province’s Régie de l’Énergie will provide financial assistance for feasibility studies for sustainable urban development projects incorporating renewable district energy systems. The program provides proponents with $0.45/kWh saved up to a maximum of $8m per project. Additionally, the Québec Energy Strategy provides energy reduction strategies through sustainable urban development. The program includes an optional component designed to incentivize developing renewable district energy systems.

1.1.5 ATLANTIC CANADA

Atlantic Canada has district energy systems in New Brunswick, Nova Scotia and Prince Edward Island. In total, these represent approximately 7% of the country’s district energy systems. The majority of the systems are located in Nova Scotia (five). Newfoundland and Labrador currently have no systems. Much of Atlantic Canada is a net fuel importer. This could be a driver for future growth in their district energy sector.

In 2010, Nova Scotia adopted its Renewable Electricity Plan, which aims to increase the province’s new renewable energy sources by 25% before 2015 and by 40% before 2020. The plan provides guaranteed feed-in tariffs for renewable energy based on project size and type through its Community Feed-in Tariff (COMFIT) program. Projects must be connected at the distribution level (in most cases, under 6 MW) and community owned to be eligible. COMFIT does not include specific provisions for district energy, although the program does support the development of CHP facilities.
1.1.6 YUKON TERRITORY, NORTH-WEST TERRITORIES, NUNAVUT

Due to the remote location of Canada’s territories, imported diesel fuel is relied on for space heating and electricity generation. As a result, there are both economic and environmental reasons to support the deployment of district energy systems in the North. Currently, there are three district energy systems in the Yukon, eight in the Northwest Territories and nine in Nunavut for a total of twenty across the territories. Canada’s north has a number of unique opportunities for district energy system development. Also, the Northwest Territories Power Corporation and Oulliq Energy Corporation in Nunavut have reduced operational costs by recovering heat from diesel generators used to heat their own facilities.

Considerable interest has been generated around biomass-fired CHP and district energy systems. New high-efficiency boilers have made biomass a reliable source for energy in large-scale applications such as institutional, office, or hospital facilities. However, one of the major challenges for biomass systems in the territories is the cost of transporting fuel. Distribution chains for wood pellets are still in their infancy, resulting in increased cost and exposure to supply interruptions.

Building on the interest in using biomass as a clean and efficient source of heat, the Northwest Territories had developed a Biomass Energy Strategy to promote greater deployment. The Yukon is developing a similar strategy, and local forestry resources could play a role in the development of a regional biomass industry.

3.3.3 Global cities

A recent report from UNEP surveyed forty-five different cities from around the world with operational district energy systems and found that all of them have some form of long-term energy strategy featuring district energy networks (2014). Strategies varied according to the size of the city and the scale of the network, but all of the cities identified the benefits resulting from energy efficiency associated with district energy infrastructure.

Understanding the way energy is generated, distributed and consumed across a city is essential to developing a long-term energy strategy, and critical to identifying the best technologies and delivery methods to achieve associated targets. In many cases, district energy will emerge as one of the most cost-effective platforms for achieving higher energy efficiency, and as such, must be explicitly identified as a key component of the energy strategy, and closely aligned with other local government initiatives.

Developing and incorporating specific targets for district energy helps municipalities track progress on broader energy objectives. Specific policies can be formulated to align municipal activities with long-term energy strategies, goals and objectives. In cities with operating district energy systems, specific district energy targets often relate to one or more of the following: greenhouse gas emissions reductions, energy intensity targets, renewable energy portion of supply-mix, building efficiency targets, energy efficiency targets, and green economy targets (UNEP, 2014).
Some cities have moved forward with goals that explicitly identify quantifiable district energy targets and policies. Vancouver, Canada, has specifically identified a share of total GHG reductions to be met by district energy. Frankfurt, Germany, and Anshan, China, have each set a target to interconnect disparate district energy nodes through additional transmission pipes. Dubai, UAE, and Helsinki, Finland, specify the supply mix of heating, cooling, and electricity to be generated through district energy systems. Similarly, Paris, Bergen and Copenhagen identify specific shares of system heat to be supplied through renewables or waste heat capture (REN21, 2014). Amsterdam requires a portion of the local government’s energy use to be supplied through district energy, while Anshan and Helsinki link district energy system expansion to the total amount of new development in the district.

Table 3. The UNEP District Energy in Cities Report provides a summary of targets and strategies for district energy aligned with broader energy targets and programs (2014):

<table>
<thead>
<tr>
<th>City</th>
<th>$\text{CO}_2$ emissions reduction target</th>
<th>Renewable energy and/or energy efficiency target</th>
<th>District energy-related goals</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amsterdam</td>
<td>40% by 2025; 75% by 2040 (from 1990 base)</td>
<td>All new building development must be climate-neutral by 2015; 25% of power demand met locally by 2025; 50% of power demand met locally by 2040</td>
<td>100 000 residential equivalent unit connections by 2020 (up from 55 000 today); 200 000 by 2040. Fuel switch from electricity and gas in heating and cooling to higher use of waste heat. Target to interconnect multiple systems using a ring transmission network.</td>
<td>Use 90% ownership of land in city to encourage district energy development. Looking to capture waste heat from data centers. Multi-stakeholder partnerships for planning and implementation.</td>
</tr>
<tr>
<td>Bergen</td>
<td>50% by 2030 (from 1991 base)</td>
<td>95% renewable energy supply; replace oil-based heating (14% of greenhouse gas emissions).</td>
<td>Use district heating in all new buildings and major renovations within the concession area for district heating. Waste incinerators must utilize 80% of energy (higher than national target of 50%).</td>
<td>Network developed based on waste incinerator target.</td>
</tr>
<tr>
<td>City</td>
<td>CO₂ emissions reduction target</td>
<td>Renewable energy and/or energy efficiency target</td>
<td>District energy-related goals</td>
<td>Features</td>
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<tr>
<td>------------</td>
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<tr>
<td>Copenhagen</td>
<td>20% by 2015 (from 2005 base); carbon neutral by 2025</td>
<td>By 2025: 100% renewable energy supply, 20% reduction in heat demand, 20% reduction in power consumption in commercial/service companies.</td>
<td>By 2025, 100% share of renewable energy and waste incineration heat in the district heating system (up from 35% today). By 2016, ban oil-fired installations in existing buildings where district heating (or gas) is available</td>
<td>Carbon-neutral target. District heating systems/CHP as cornerstone of energy policy to integrate renewables. District heating currently accounts for 98% of heat demand.</td>
</tr>
<tr>
<td>Dubai</td>
<td>20% reduction of CO₂ emissions from buildings by 2030</td>
<td>30% reduction in energy demand by 2030; 5% renewable electricity by 2030</td>
<td>Meet 40% of cooling capacity through district cooling (up from 20% in 2011) by 2030. Use district cooling in all new developments by 2030. Incorporate thermal energy storage into all new district-cooling plants, with a capacity of at least 20% of the design capacity of the plant by 2030.</td>
<td>Use of effluent water instead of fresh water Reduced investment in power infrastructure</td>
</tr>
<tr>
<td>Frankfurt</td>
<td>40% by 2020; 95% by 2050</td>
<td>100% renewable energy supply by 2050, while reducing demand</td>
<td>Connect waste heat from incinerator and industry; interconnect three district heat grids into a closed-loop system; integrate renewable energy such as biomass and biogas in CHP.</td>
<td>100% renewable energy target Fuel switching using biomass and biogas</td>
</tr>
<tr>
<td>City</td>
<td>CO₂ emissions reduction target</td>
<td>Renewable energy and/or energy efficiency target</td>
<td>District energy-related goals</td>
<td>Features</td>
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<tr>
<td>Hong Kong</td>
<td>Reduce carbon intensity 50%–60% by 2020 (from 2005 base)</td>
<td>By 2020, reduce coal to less than 10% of the electricity generation mix. By 2030, phase out existing coal and reduce energy intensity by at least 25% (2005 base).</td>
<td>Expand use of district cooling such that by 2020 up to 20% of all commercial buildings will be up to 50% better in refrigeration performance compared with buildings using regular air conditioners.</td>
<td>Reduced consumption of coal and power for cooling.</td>
</tr>
</tbody>
</table>
3.4 Opportunities

The role of cities in reducing GHG emissions is gaining increasing prominence. It has been highlighted by the work of the C40, a global network of large cities committed to helping address climate change (Arup, 2011), the first Intergovernmental Panel on Climate Change (IPCC) chapter on human settlements (Seto & Dhakal, 2014) and a new reporting mechanism, the Non-State Actor Zone for Climate Action1 launched in December under the United Nations Framework Convention on Climate Change (UNFCCC). As the IPCC reports, “Addressing climate change has become part of the policy landscape in many cities, and municipal authorities have begun to implement policies to reduce GHG emissions within their administrative boundaries” (2014, p. 970).

These efforts reflect a rapidly urbanizing world in which 54% of the population lives in urban area, a total that increases weekly and is projected to climb to more than 60% by 2050 – an additional 2.5 billion people (United Nations, 2014). Urban areas account for between 71% and 76% of CO2 emissions (Seto & Dhakal, 2014). This continual process of urbanization is requiring and will continue to require massive investments in infrastructure, which, depending on the approaches selected, will either impede or enhance society’s ability to reduce GHG emissions.

Local governments are highly engaged in addressing climate change both in Canada and around the world. The Federation of Canadian Municipalities’ Partners for Climate Protection program has involved more than 250 municipalities, representing 80% of the total Canadian population, in a five-step program that includes developing a GHG inventory, leads to the implementation of actions to reduce GHG emissions and culminates in monitoring and reporting. A database of five years of actions prior to 2012 includes 800 projects totaling $2.4 billion in investment and generating emissions reductions of 1.8 million tCO2e (Federation of Canadian Municipalities, 2012). An annual reporting program for the Government of BC included 1,403 actions to reduce GHG emissions in municipal operations and 2,353 actions to reduce GHG emissions from community activities in 171 municipalities (Ministry of Community Sport and Cultural Development, 2014).

In addition to voluntary efforts by municipalities there are in some jurisdictions legal requirements to achieve certain levels of reductions and in other contexts funding requirements are tied to particular emissions reductions, creating an impetus for increasingly accurate GHG accounting (DeShazo & Matute, 2010).

1 See http://climateaction.unfccc.int/
3.5 The Determinants of district energy

In a perfectly rational society with scarce resources, district energy is installed when the cost of constructing and operating district energy is less than the cost of other technologies or strategies to provide the same service. There are a wide range of variables that determine the cost of district energy including the scale of the installation, the density of heat demand, the availability of expertise, the cost of energy generation, the cost of carbon, local geology and geography, the availability and type of fuel sources, the design of existing buildings, the future planning regime, the legal context and others. And there is an equally large range of variables that determine the cost of a building-level system. In an assessment of the potential for district energy expansion in Europe, the key variables that were assessed included heat demands, settlement structures, land-use priorities, excess heat activities, local heat resources, and general geographic properties of any given location (Connolly et al., 2013). However, in addition to the economic logic, there are also externalities that influence the uptake of district energy as illustrated in an analysis of the case of Samso, Denmark (Dalla Rosa & Svendsen, 2011, p. 4).

<table>
<thead>
<tr>
<th>Helpful</th>
<th>Harmful</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strength</strong></td>
<td><strong>Weakness</strong></td>
</tr>
<tr>
<td>Political support</td>
<td>Energy savings</td>
</tr>
<tr>
<td>Internal energy market</td>
<td>No cogeneration</td>
</tr>
<tr>
<td>Local coordination</td>
<td>Municipality administration</td>
</tr>
<tr>
<td>Local ownership</td>
<td>Uncertainty of energy prices</td>
</tr>
<tr>
<td>Organizational structure</td>
<td>Training and education</td>
</tr>
<tr>
<td>Local resources</td>
<td>Protests against placement of wind generators and district heating</td>
</tr>
<tr>
<td>Challenging jobs</td>
<td></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Opportunity</th>
<th>Threat</th>
</tr>
</thead>
<tbody>
<tr>
<td>External investments</td>
<td>Removal of subsidies by new government</td>
</tr>
<tr>
<td>EU incentives</td>
<td>Immaturity of electric car technology</td>
</tr>
<tr>
<td>Lower tax for electricity from RE</td>
<td>Lack of suppliers and companies for maintenance.</td>
</tr>
<tr>
<td>Creation of new employment opportunities</td>
<td></td>
</tr>
<tr>
<td>Contracts avoid price fluctuation</td>
<td></td>
</tr>
<tr>
<td>Positive effect on tourism</td>
<td></td>
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</tbody>
</table>
In considering the role of district energy, countries can be placed in two groups, where:

1. District energy is mature. These countries have relatively higher-priced fossil fuels, policies which support district energy, mature and extensive systems, extensive experience with the technical and financing aspects of district energy, and a history of public acceptance of local energy infrastructure. This group includes Scandinavian countries, Finland, France, and Germany.

2. District energy is emerging. These countries have relatively lower-priced fossil fuels, policies which tend to support energy systems based on centralized utilities, few district energy systems, modest district energy experience, and limited public acceptance of new energy infrastructure entering a community. This group includes Canada, the United States, the United Kingdom, and most developing countries.

Evaluating the feasibility of district energy for countries in the first group is relatively straightforward, based on well-established urban planning policies, a high degree of certainty regarding the accuracy of capital and operating cost estimates, and confidence in public acceptance of new or expanded systems. These factors tend to reduce the risk of developing or expanding a district energy system.

For a proposed district energy system in a country belonging to the second group, the economic and social advantages must be strongly positive to overcome policy barriers and financial uncertainty. Examples of such favourable conditions would include new, high-density developments in northern communities, where the cost of conventional energy sources is high.
3.5.1 Policy and Governance

Policies which support district energy include regulations requiring local governments to understand local energy needs, and to plan to meet those needs with renewable sources. Examples of such regulations that either indirectly or directly support district energy include:

- The Merton Rule adopted by the Merton Council in the United Kingdom. The rule requires new commercial buildings with an area greater than 1,000 square metres to meet more than 10% of their energy needs with renewable sources (Merton Council, 2014).

- The Heat Supply Law in Denmark, which required local governments to identify their energy needs, and to recognize alternatives for meeting those needs (DEA, 2014; IEA, 2008).

- Regulations requiring public sector organizations to achieve carbon neutral operations tend to encourage schools, universities and hospitals to consider low carbon forms of district energy. British Columbia’s Carbon Neutral Government Regulation is an example of this kind of regulation (Government of BC, 2008).

- The cost of carbon taxes and carbon offsets tends to support low carbon forms of district energy by increasing the cost of the business-as-usual (e.g. fossil fuel) option (Johansson, 2000).

- Streamlining the approval process for projects which fit a local government’s criteria for sustainable development (including developments associated with low carbon forms of district energy) tends to support district energy by reducing the developer’s costs (R. Bush, Bale, Taylor, & Gale, 2014).

The legal structure of a district energy organization can take many forms including ownership by a municipality, private company, a hybrid or a cooperative (Portland Sustainability Institute, 2011), and the structure can be adapted to most legal contexts. The feasibility of district energy does require that customers are compelled to connect to the system (Hargraves, 2012).

Municipal governments are required to deliver a variety of public services and respond to direction and mandates from higher order government. As a result, many competing budgetary interests exist. Enshrining
thermal energy priorities as they relate to broader environmental, economic and social objectives is necessary to validate and support local government’s investment and commitment to district energy development. This also helps garner public support. Additionally, having a long-term vision for community energy infrastructure gives confidence to developers and investors (R. Bush et al., 2014).

In many municipalities, urban planning is fragmented among individual local governments and the regional government to which they belong. In addition, plans for land use, energy infrastructure, water infrastructure, transportation, sustainability and climate change are commonly developed by separate departments. This fragmentation presents a structural challenge to implementing district energy systems, the planning of which requires engagement by multiple disciplines (Dale, 2001).

Local governments, however, occupy a unique position from which they can serve as one of, or a combination of, the following: planners and regulators, brokers and facilitators, generators, distributors, consumers and project coordinators. While federal, provincial or state programs may supply targets or provide strategic direction, local governments often are charged with implementing district energy solutions. Even in the case of private sector district energy development, local governments typically provide support through policy frameworks, franchise agreements, easements and zoning, taxation relief, some level of investment or capacity building with the public.

In North America, regulatory frameworks for energy are designed to address issues related to centralized utilities, which can present barriers to smaller, locally owned energy systems. Apart from the regulations themselves, the cost, complexity and duration of regulatory energy processes present a barrier to district energy systems (BCUC, 2013).

In North America, utilities may have mixed responses to district energy and distributed energy, based on concerns over loss of business, increased burden of the cost of common distribution infrastructure (e.g. natural gas pipelines and electricity distribution lines) on remaining customers, higher upfront costs, and the necessity of complex partnerships (Cooper & Rajkovich, 2012).
3.5.2 Urban Planning

The economics of district energy are improved by urban planning that:

- Increases building density
- Increases energy density
- Encourages complementary types of buildings to co-locate, which in turn diversifies the types of energy demand within a district.

Planning for district energy is inhibited by an inadequate understanding on the part of urban planners, consultants and building owners regarding energy in general and in particular the technological possibilities (e.g. trigeneration, adsorption chilling), the full business-as-usual costs of energy systems (including environmental and social costs of fossil fuel exploration and production), and the full cost of providing energy (i.e. owning and operating the building’s boilers, and not just the cost of fuel) (Hawkey, 2009).

3.5.3 Social

Social challenges to district energy include a general lack of understanding, and the necessity of engaging a large number of disparate stakeholders that typically includes individuals as well as private and public institutions (M. R. Bush, 2013). District energy is simpler to implement in communities that are aware of their air quality issues (for example when pollution is caused by open burning of wood waste). District energy planning and implementation is simpler when the local culture places a relatively higher value on the greater good of the community and the environment, versus individual interests.

Public concern regarding new energy sources entering the community can inhibit systems based on biomass. If inadequate time and planning is applied to identifying and addressing public interests during the earliest possible stages of a district energy project, the public consultation process itself can fail to overcome public opposition to integrating low carbon forms of district energy into a community (Comeault, 2011). Also, interest on the part some building owners and community members regarding climate change can be limited.
Since design professionals tend to be commissioned to design individual buildings on a single site, their focus is often limited to that site. Design professionals tend not to look to the left and right for opportunities to share energy and water with adjacent buildings or sites, or to work cooperatively with municipal planners or municipal engineers to find energy schemes which can help both the building site and the community (Ronn, 2011).

### 3.5.4 Economics

District energy requires a major initial investment as well as ongoing operations and maintenance costs. The economics of district energy are improved by the relatively higher energy consumption of buildings in colder climates, relatively higher costs of conventional sources of energy, larger scale projects which reduce the per unit energy costs of systems and availability of district energy equipment (e.g. heat pumps, biomass boilers and distribution piping) manufactured domestically, which reduces the cost and complexity of importing materials.

Exploration subsidies for fossil fuels ($34 billion/year in Canada and $600 billion/year worldwide) interfere with market pricing by using public funding to make fossil fuels less expensive (IMF, 2013; Stern, 2014). Since district energy is capital intensive, the cost of capital (i.e. interest rate) is critical. Economies of scale limit the viability of smaller systems, which have higher costs per unit of delivered energy. The current shale gas boom has increased the availability of oil and natural gas, and decreased the price of fossil fuels.

In countries where district energy is mature, the economics of district energy are well understood, and the criteria for viability are well established. The higher costs of business-as-usual energy sources, and the lower cost of widely available district energy infrastructure in these countries combine to make the threshold for district energy viability relatively lower.

In countries where district energy is emerging, the economics of district energy can be marginal, and since the advantages of district energy may be less obvious to stakeholders, those involved in planning systems must invest more effort and be more creative to make systems viable. Lowering the threshold for viability in these countries can involve more opportunism, for example:
Reducing the cost of the district energy source by relying on sources of waste industrial heat.

Reducing the cost of distribution piping by choosing routes through parks, through streets that must be renewed for other reasons, and by sharing the cost of trenching with other utilities such as potable water, wastewater, electrical utilities or communications utilities.

Finding owners of existing buildings with a greater interest in district energy because their boilers need replacing, and finding developers of new buildings who recognize the value of re-programming utility space as revenue-generating space.

The cost of energy from conventional sources has a significant influence on the viability of district energy, and the cost of providing energy to a building includes the cost of conventional fuels, including taxes, carbon taxes, carbon offset costs and the cost of converting fuel to energy, which is influenced by the efficiency of the boiler; the capitalization cost of the boiler (initial cost, financing cost, and life expectancy); the cost of utility operations, maintenance, insurance, licensing; and the opportunity cost associated with the utility space in the building.

The operating temperature also impacts the cost of the system. A low-temperature district heating system reduces thermal stress on the pipes, results in reduced heat loss in the network and storage, increases the efficiency of combined heat and power, and increases the ease of renewable energy integration (Rosa, 2012).

### 3.5.5 Technical

District energy systems are, like all technologies, evolving rapidly. The first generation used steam as a carrier of heat and was introduced in the late nineteenth century in the US. A second generation switched to pressurized hot water, to address the heat loss, high operating and maintenance costs, and safety issues associated with steam. A third generation used pressurized water with lower supply temperatures, twin pipe systems and plastic pipes. The fourth generation is characterized as “low energy district energy” and will supply new low-energy buildings as well as buildings which have undergone deep energy retrofits (Rosa, 2012).

Load diversification tends to reduce the peak capacity of a district energy system, and therefore its cost. Engineering modelling capability and capacity to optimize district energy networks is now well established and widely available (e.g. Natural Resources Canada’s RETScreen International program).
New building technologies and new energy technologies can make buildings energy self-sufficient, which tends to reduce the need for district energy. In the short term, the higher-temperature design of energy systems in existing buildings requires higher-temperature energy sources (e.g. biomass combustion rather than heat pumps) and higher-temperature distribution piping (e.g. steel vs. polymer), which increases both the capital and operating costs of district energy (Dalla Rosa & Svendsen, 2011). Compact, efficient condensing natural gas boilers can be attractive replacements for owners of buildings where the original boilers have reached their end of life.
3.6 Energy density thresholds

Keeping the above variables in mind, it is clear that heat density has a significant influence on the viability of district energy (The Energy Saving Trust, 2008), with a positive non-linear correlation between the increasing proximity of heat demand and the cost of the system (Woods, 2012). Consideration of the extremes illustrates the nature of the relationship: when two heat loads are in close proximity, it is relatively easy to connect them and heat loss is not a critical consideration, but when two heat loads are distant from each other, the infrastructure cost becomes prohibitive and the necessity of minimizing heat loss mandates costly insulation. As a consequence there is, in any particular location, a threshold of heat density at which district energy is cost effective, but this threshold varies according to a wide range of variables. For example, in the UK that threshold has been measured at 200 MWh/ha (Woods, 2012) and 3,000 kWh/km² (Davies & Woods, 2009). In terms of linear heat density, areas with 0.20 MWh/m,year are considered to be feasible in Denmark (Rosa, 2012) and 0.30 MWh/m,year elsewhere (Zinko et al., 2008). Linear heat density is influenced not only by energy density but also by the configuration of the buildings within that area, as this influences the length of the pipes required (Zinko et al., 2008).

Of the three levels of government, it is local governments that have legal jurisdiction over land-use planning, which ultimately determines the proximity of heat loads, or the heat density. As Floater and Rode write, “spatial planning provides a way to engage with the flows of the city in pursuing the optimal sequencing, coordination and integration of infrastructure investments” (2014, p. 23). In order for district energy to be broadly successful, local governments need to incorporate a consideration of district energy, and energy demand in general, into land-use decisions. In an analysis of community energy planning, Jaccard et al (1997) propose that of the various powers available to local governments, land use is the most critical as it has the longest durability, beyond policies on transportation management, site and building design, and energy supply, for example.

Land-use decisions result in lock-in, or path dependence. Lock-in happens when an activity or process continues even though it may not be beneficial but is tied to previous investments or commitments (Liebowitz & Margolis, 2009). Significant investments in bricks and mortar are a consequence of land-use decisions and it is difficult to abandon those investments even if they are impeding other societal goals such as reducing GHG emissions. The pattern of development which cities plan and permit therefore determines the energy consumption and GHG emissions into the future (Creutzig, Baiocchi, Bierkandt, Pichler, & Seto, 2014; World Resources Institute, 2014).

In taking decisions on land use, local governments unconsciously either rule in or rule out district energy
by enabling development that is either less than or greater than energy density thresholds. These decisions have long-term implications as a result of the lock-in that accompanies the capital intensive and durable built environment. Energy density thresholds are, however, dependent on many different variables that reflect the characteristics and use of the built environment.

In the absence of consideration of energy density by planners, proponents of district energy are restricted to those areas of cities which through historical accident have achieved a sufficient heat density or where there is a significant anchor load in close proximity to other buildings to merit a district energy system. This approach, characterized by the use of heat maps or atlases (Möller & Nielsen, 2014), can be characterized as reactive and inevitably results in significant portions of the building stock that cannot be economically serviced by district energy. However, this type of energy planning is critical to developing an understanding of energy density and district energy feasibility. An upstream approach would include an assessment of energy density as integral to the creation of official city plans and approving developments in the same manner that other variables such as transportation, servicing and topography are considered.

Energy density is typically calculated at the building level on the basis of intensity, for example as GJ/m²/year or kWh/m²/year. At the community level, energy density is typically calculated as GJ/ha/year or kWh/ha/year. Energy density is influenced by the climate; the energy efficiency of existing or planned buildings in terms of kWh/m²/year, which is a function of the design and use of the building; the density of floor space in relation to the footprint of the building, i.e. expressed as Floor Area Ratio (FAR) or Floor Space Ratio (FSR); and the use of the building space (see section 5 for more detail on these variables). For example, hospitals and other health care facilities consume a significant portion of a community’s total energy for domestic hot water, the consumption of which is independent of the building envelope design. In addition, domestic hot water is used throughout both summer and winter seasons, which improves the system utilization and therefore the economics of district energy (Natural Resources Canada, 2014).

Another consideration is energy diversification, in terms of the diurnal and annual timing of energy demand, which has a strong effect on the viability of district energy. An ideal diversification factor would result in almost constant energy demand, so that the peak demand and average demand are almost equal. But in practice, actual peak demand can be five or six times greater than average demand.

A lower energy density can be achieved with an anchor load, consisting of a single large energy demand. First, economies of scale mean that the unit cost of providing energy to the anchor load are likely to be the lowest in the system, which provides an early indication of the likely viability of the district energy system, as well as a cost benchmark for other connections. Perhaps more importantly, the energy managers of larger
buildings (e.g. hospitals) are more likely to understand their business-as-usual costs, as well as the benefits of district energy. As a result, the effort required to persuade such managers to commit to district energy will be relatively lower. In addition, the location of the anchor load can have a positive influence over the decision regarding the location of the energy centre for the district energy system. Locating the energy centre close to the largest loads will reduce the capital and operating cost of distribution piping. Finally, the commitment by an anchor load to a new district energy system can reassure owners of other, smaller buildings who may have less understanding of their business-as-usual costs and the benefits of district energy (Davies & Woods, 2009; Rodger, 2010).

Higher urban density improves the viability of district energy as economies of scale mean that the district energy service provider’s cost of connecting larger buildings is lower per unit of energy delivered. And because the cost of distribution piping is one of the most significant components of a district energy system, shorter distances between high-density buildings significantly reduces this cost.

In addition to higher density, developments which include mixed uses also support district energy in interesting ways. District energy systems must be designed to meet the peak energy demand of the system as a whole, and the ratio of peak demand to average demand strongly affects the economics of the system. If all buildings served by a district energy system are of the same type (for example multi-family urban buildings), then the timing of peak energy demand for every building will be similar (e.g. early morning and early evening). If, on the other hand, the connected buildings include a mix of homes and different types of business, then the timing of peak demand will be diverse, which tends to reduce the ratio of peak demand to average demand (Hawkey, 2009).

This effect of reducing the magnitude of peak energy demand has a significant influence on the capital and operating costs of a district energy system. Higher peak demand requires larger capacities for energy generation, distribution piping, and energy transfer stations – capacity which by definition will be under-utilized the majority of the time. In addition, because of the relatively high capital cost of low-carbon sources of heat (for example biomass boilers or heat pumps), it is not practical to size this equipment to meet peak demand. In low-carbon systems, peak demand is typically met with conventional fuels, which increases the operating cost and greenhouse gas emissions of the system.

In addition to diversification in the timing of demand, mixed use can result in diversification in the form of energy consumed, such as temperature and end use. For example, hospitals in Canada are designed to use 100% makeup air, which increases energy consumption for space heating, but also presents an opportunity to recover energy from exhaust air. Further, in health care facilities (e.g. hospitals, retirement homes) as much as 40% of the total energy consumed can be used for heating domestic hot water, which presents further
opportunities for energy recovery and energy exchanges with other buildings. Recovered energy which cannot be used by one building can potentially be used by another in an energy exchange arrangement (Chu, Richardson, & Rogowska, 2014).
4 The built environment and energy intensity
As buildings become more efficient, through the adjustment of the factors considered below, the energy intensity decreases and the feasibility of district energy also decreases. Planners, when assessing future built environments, face a complex trade-off in that they need to contribute to and plan for decreased energy intensity at the building level, while increasing energy intensity at the land-use level to increase the feasibility of district energy. To better inform these considerations, the following is a detailed review of the factors that influence energy intensity at the land-use scale.

Heating and cooling energy density are a function of the characteristics and use of the built environment. While these characteristics represent design and planning decisions, they in turn are driven by the level of economic activity, fuel prices, climate and other variables (Creutzig et al., 2014). The growing focus on the relationship between the built environment and energy demand is highlighted in Chapter 8 of the IPCC’s Fifth Assessment Report and explicitly recognizes of the extent of urbanization anticipated and the idea that urbanization can itself be a greenhouse gas emissions mitigation strategy that integrates multiple sectors (Seto & Dhakal, 2014). The IPCC chapter specifically references the urban form characteristics of density, land-use mix, connectivity, and accessibility as drivers of energy and GHG emissions. This section narrows in on a specific aspect of the broader energy metabolism of a city (Pincetl, Bunje, & Holmes, 2012) to consider the factors influencing energy consumption associated with heating and cooling existing and future buildings.

Data on energy consumption in buildings is currently measured by the utilities that provide energy to these buildings, and is reflected in a utility bill. This data provides a reliable and accurate basis from which to understand the energy demands of the existing building stock and to model the energy demand of the future building stock.

Energy demand for buildings is expressed using energy intensity factors, as GJ/m²/yr or eKWh/m²/yr. Higher building energy intensity factors combined with higher built form densities (i.e. more building floor area) result in higher energy demands, increasing the potential benefit and feasibility of a district energy system. Figure 2, adapted from Ratti et al. (2005), Salat (2009), and Miller (2013), illustrates the factors that affect energy consumption in buildings; these are the factors will influence the heating and cooling energy density.

![Figure 2. Factors influencing energy intensity in buildings.](image-url)
Urban form or land-use planning plays a role in building energy consumption in both building morphology and urban structure, and in two key ways: heat transfer and solar access (Miller, 2013). At the individual building scale, building morphology refers to characteristics such as: size and shape of a building, surface to volume ratio (S:V), plan depth, building height, and façade design characteristics (glazing ratios and distribution, building orientation, and envelope performance). At the block or neighbourhood scale, urban structure refers to the arrangement and spacing of buildings, streets, and open space, which include measures such as density (floor area ratio or FAR), land coverage, and spacing between buildings. The neighbourhood scale also captures the cumulative impact of the relationships between multiple buildings (building massing, heights, arrangements and spacing), and their impact on energy consumption. The impacts of urban form on energy at the neighbourhood scale are less frequently considered and have less developed methods available for modelling in comparison with those available at the individual building scale (Miller, 2013).

4.1 Energy and climate

In general, energy demand is climate and context specific. For heating demand, the warmer the climate the lower the operational energy due to the reduction in heating energy required (Newton et al., 2000). However, this does not necessarily imply that buildings in warmer climates use less energy overall, as warmer climates may result in increases in energy demand for mechanical cooling. Further, the most common working fluids in mechanical cooling systems on the market today are hydrofluorocarbons (HFCs), which contribute to global warming. Any analysis of district energy needs to take into account all greenhouse gas emissions associated with the system. The mechanical cooling load is also dependent upon building design and whether non-mechanical cooling methods, such as operable windows, are implemented. Climate has a significant impact on heating and cooling energy consumption, and the extent of this influence is determined by the way in which the built environment responds to the climate, through design, or the lack thereof.
4.2 Energy use and Urban structure

Density is a measure of the concentration of development (residential, commercial, industrial, etc.) per unit of land. Density is measured in a number of ways including people per hectare/acre, dwelling units per hectare/acre (for residential), and floor space ratio (FSR) or FAR. FSR and FAR are a measurement of the ratio of a building’s floor area to the area of the lot on which the building is built (Senbel et al., 2010). As density increases, total energy demand increases (i.e. the energy intensity factor is applied across a greater floor area). It is important, however, to understand how energy-intensity factors, particularly for residential and commercial uses, change as building density changes.

As Doherty et al. (2009) explains, the concept of density is plagued by several definitions that vary depending on the purpose, and confusion arises partly because density can refer to either dwellings or people per unit area, as noted above. Where calculations of people per unit area are used, these are based on an assumed average number of people per dwelling/unit. Most definitions are linked as they attempt to identify low-, medium- and high-density categories in a relative sense for planning purposes, but the precise meaning of such categories varies significantly both within and between countries.

A variety of researchers note that as density increases, buildings typically consume less energy on a per capita or per area basis (Steemers 2003; Salat 2009). That is, energy intensity factors decrease as building density increases. Shared walls and floors/ceilings and shared building mechanical systems contribute to lower heating and cooling loads (Senbel et al, 2010). Newton et al. (2000) show that annual heating and cooling energy per square metre for apartments are very similar to those for detached houses, despite the total floor area of an apartment being less than half of a typical detached house. However, when comparing energy per person (by taking into account people per unit), the energy usage for apartments is significantly lower than for detached houses, as the occupancy per square meter is higher for apartments than for detached houses.

Figure 3 (IPCC, 2014) represents predicted global residential energy consumption and shows how the residential energy intensity factor (or energy used per area) is expected to decrease, even though area per person is increasing, and persons per household is decreasing. This, in part, is explained through the predicted increase in residential density.
Figure 3. Trends in the different drivers for global heating and cooling thermal energy consumption in residential buildings (IPCC, 2009)

In contrast, models examining increased density in commercial buildings have shown potential overall increases in energy consumption per area from increased cooling demands, due to high levels of internal heat gains present in these buildings (Steemers, 2003). These findings are discussed further in section 8.
4.3 Building morphology

4.3.1 Building envelope
The building envelope (i.e. the physical separator between a conditioned indoor space and unconditioned outdoor space) and its performance have a significant impact on building energy consumption. As the majority of energy consumed in buildings is for space heating and cooling, heat transfer between interior and exterior space determines the level of energy required in a building to maintain comfortable levels of heating and cooling. Improving the thermal performance level of a dwelling can have a dramatic effect on its heating and cooling energy consumption. In general, energy use decreases as thermal performance increases (Newton et al., 2000). However, results also show that as envelope performance increases in certain cases, heating demand decreases while cooling demand increases (Miller, 2013). This is in part due to other factors such as glazing ratio, building compactness and local shading, which are discussed further in this section.

4.3.2 Building compactness
A building’s compactness refers to the surface-to-volume ratio of a building, or the ratio between total building surface area and total enclosed building volume. In general, as building density increases (and building height increases), more building volume is enclosed by building surface, resulting in a lower surface-to-volume ratio (S:V), making a building more compact. The predominant effect of compactness is reducing heat transfer, as more compact building shapes enclose more building volume with less surface area through which heat can escape (Miller, 2013).

4.3.3 Glazing ratio and orientation
Glazing ratio refers to the proportional amount of glazing (including windows) on a building, that is, the ratio between total glazing area and total building area. Heat loss through glazed surfaces is higher than typical wall assemblies, and as such is a significant factor in overall envelope performance and building energy demand. In general, higher glazing ratios result in higher heating and cooling demand, counteracting much of the benefit of efficient surface-to-volume ratios (Miller, 2013). During cold weather, heating demand increases with increased glazing due to loss of heat through the less thermally resistive glazing components of the building envelope. However, increased glazing allows for passive solar heating opportunities, where heating demand is decreased as passive zones (areas adjacent to glazing) experience heat gain from sunlight. The loss of heat, however, generally outweighs passive heating effects during cold weather. In contrast, cooling demand primarily increases with increased glazing due to the increase in solar gains during warm weather (Miller, 2013). Buildings with excessive glazing ratios and untreated façades (symptomatic of high-rise buildings) make them particularly vulnerable to overheating during the summer and to heat losses during the winter (Salat, 2009).
A building’s orientation, and the distribution of glazing, relative to the sun’s position, also impacts a building’s opportunities for passive heating. For space heating, glazing oriented to the east and south (for buildings in the northern hemisphere) provides the most useful gains. In comparison, western orientations provide solar gains late in the day when temperatures are at a maximum and buildings are already heated (Baker and Steemers, 2000).

4.3.4 Tradeoffs at the building scale

While increasing compactness and building density generally reduces heat loss, increasing these characteristics does not guarantee overall building energy reductions. The trend for increased glazing as building density increases counteracts some of the thermal performance benefits of more efficient surface-to-volume ratios and shared walls and floors, increasing energy demand (Miller, 2013). Minimizing heat losses during the winter requires minimization of the surface-to-volume ratio; but this implies a reduction of the building envelope exposed to the outside environment, thus reducing the availability of daylight and sunlight and increasing energy consumption for artificial lighting and natural ventilation (Ratti et al., 2005).

The relationships between compactness, building density and building energy are further complicated by differences between residential and commercial uses (Miller, 2013). For residential, increasing building density from detached housing to apartments can reduce heating energy demand. However, such density increases typically require increased building depth, increased building height or reduced building spacing that limit access to passive heating and daylighting. In certain contexts, low-density residential design with high surface-to-volume ratios maximized for passive solar heating may provide greater opportunities than density for reduced energy demand (Steemers, 2003). For commercial buildings, increasing the building depth of offices reduces the availability of natural ventilation and daylight, resulting in an anticipated increase in mechanical ventilation and artificial lighting. However, heat losses are likely to decrease as the surface-to-volume ratio decreases with increasing plan depths (Steemers, 2003). In contrast, however, commercial buildings with high cooling demands may benefit from higher surface-to-volume ratios, which can assist in reducing cooling demand (Steemers, 2003).

Notwithstanding the complexity discussed above, Miller (2013) notes that the impacts of building compactness, density and glazing ratios on heating demand are reduced as envelope performance improves. This suggests that at the building scale, there should be a greater focus on envelope performance than on other factors. Steemers (2003) notes that the arguments for and against density for building design are “finely balanced” and dependent on local contexts.
4.4 Building systems

The operational energy consumed in buildings is predominantly used in space heating and cooling, and in running appliances, including heating hot water and lighting (Doherty et al., 2009). Energy consumption changes for different building uses or activities. In general, residential dwellings are dominated by space heating, while commercial buildings have significantly larger requirements for space cooling and lighting.

![Figure 4. End-use of energy in buildings (OECD/IEA, 2013)](image)

Commercial buildings also consume more energy per square metre than both residential and industrial land uses (Steemers, 2003). Differences in space heating and cooling requirements vary climatically, particularly latitudinally (Doherty et al., 2009). As a general rule, the warmer the climate, the lower the operational energy, because of the reduction in heating energy required (Newton et al., 2000). Heating is the major driver of energy consumption, ahead of cooling and refrigeration (Doherty et al., 2009).

Different building-use activities require different types of heating and cooling systems and equipment, lighting and hot water systems, with large variations in capacity and efficiency. In general, as systems and equipment efficiency decreases, energy demand increases. Also, buildings containing different activities do not use energy at the same rate and at the same time of day. In general, commercial and industrial uses consume more energy during working hours, whereas residential energy consumption peaks in the morning and evening, before and after regular working hours, respectively.
4.5 Occupant behaviour

Occupant behaviour affects building energy use directly and indirectly: opening/closing windows, turning on/off or dimming lights, turning on/off equipment and electronics, turning on/off heating, ventilation and air-conditioning (HVAC) systems, and setting indoor thermal, acoustic and visual comfort criteria (Hong & Lin, 2013). Gray and Gleeson (2007) discuss occupant behaviour factors that tend to increase energy demand. These include: increasing affluence or household income (related to larger residential homes and increasing area per person), uptake of more electronic and consumer goods due to declining prices, and, where applicable, low energy prices.

Hong and Lin (2013) note that occupant behaviour is one of the most significant sources of uncertainty in the prediction of building energy use by simulation programs due to the complexity and inherent uncertainty of occupant behaviour. Ratti et al. (2005) argue that occupant behaviour and its effect on energy performance can vary by a factor of 2 between buildings, even among buildings with comparatively similar functions. They theorize that occupants could be more likely to adopt energy efficient behaviour if they live in an energy efficient house and are aware of its efficiency measures. Similarly, Baker and Steemers (2000) argue that good urban form design may result in better occupant behaviour. In contrast, Salat (2009) suggests that if occupants are aware that the building they occupy is very well insulated, they might feel less incentivized to monitor their heating consumption.

Research conducted by Salat (2009) shows that for buildings heated by electricity, occupants consume only half their theoretical heating needs, whereas occupants who receive heat through district energy generally consume 30% more than their theoretical needs. Salat (2009) concludes that occupants who receive individual pricing based on their respective consumption are more inclined to save energy, especially where energy is expensive, compared to occupants who consume energy from collective systems.

In a study completed by Hong & Lin (2013), results showed that occupants of private offices who are proactive in saving energy consume up to 50% less energy, while occupants who are wasteful, consuming energy at will and lacking motivation to reduce energy use, consume up to 90% more energy.
4.6 The block and neighbourhood scale

As discussed earlier, arguments for and against density, balancing the need to reduce heat loss with the need for solar access (resulting in passive heating) are complex and affected not only by factors of building design and use, but also local context.

At the block or neighbourhood scale, building energy consumption is influenced primarily by the shading of adjacent buildings, which limits solar access. This substantially reduces opportunities for passive solar heating and natural daylight, increasing overall heating and lighting demand (Miller, 2013; Ratti et al., 2005; Steemers, 2003). These same shading effects, however, also reduce overall cooling demand (Miller, 2013).

Solar access is influenced primarily by building spacing and arrangements, which are dependent upon a number of urban pattern elements such as street widths, parcel size, building setbacks, building heights, and the distribution of open spaces. A measure of building spacing and arrangement (used in research by Steemers, 2003; Ratti et al., 2005; and Miller, 2013) is urban horizon angle (UHA). The UHA is the average angle of elevation of surrounding buildings from the centre of a given façade, and is affected by the height of and distance between structures. The UHA accounts for building shading and significantly affects solar access; particularly in the winter when the sun is lower in the sky (Baker and Steemers, 2000).

The predominant (yet limited) literature reviewed in this area is by Steemers (2003) and Miller (2013) who conducted research in the UK and Vancouver, BC, respectively. It is important to note that their findings are context and climate specific. Steemers (2003) shows that the UHA can affect heating energy demand by as much as 30%, cooling demand by 20%, and lighting demand by 150%, with the greatest impacts occurring for south-facing façades. Miller (2013) found the following: increased UHA results in increased heating demands and decreased cooling demands, higher density urban patterns tend to require less heating energy and more cooling energy per capita and per unit of building area, and residential buildings will experience larger increases in heating energy demand and smaller improvements in cooling demand with high UHA conditions.

Miller’s overarching finding is that, for the urban patterns and development context chosen for analysis, there is relatively little variation in energy performance among patterns of similar density but distinctly different urban forms, suggesting that urban form may not have the potential for the “factor of 2” impact on building energy suggested by Ratti et al. (2005). The type and mix of building activities included in buildings, for otherwise similar urban forms and patterns, play a larger role in heating and cooling demand.
Miller’s research supports the general assertion of urban-form building-energy literature that higher-density development provides the benefit of reduced heating demand through more compact building shapes and more efficient use of floor area (e.g. smaller residential units). However, this research also identifies several key urban form factors tied to increased density that work against heating demand benefits, such as high glazing ratios, high-rise buildings with lower envelope performance requirements, and increased shading effects due to high UHAs.

Particularly when it comes to local shading, it is important to understand that there will be trade-offs – implementing high-density development may decrease heating demand (per area or per capita) for the new building, in comparison with a lower-density development. But it may also increase shading on adjacent buildings, causing increased heating demand. At the block or neighbourhood scale, positive impacts for one building may have negative impacts for another.

4.6.1 Urban heat island effect and vegetation

Urban areas in many parts of the world are subject to the urban heat island (UHI) effect. Increased densities are generally accompanied by increases in built materials and paved areas, and decreases in natural land cover (e.g. vegetation and bare soil). These conditions exacerbate UHI, resulting in higher temperatures in denser city centres, which lead to increased cooling demand (Doherty et al., 2009). Miller (2013) argues that UHI increases cooling demand, but decreases heating demand, resulting in a net reduction in energy consumption. Doherty et al. (2009) discuss further how vegetation can play a significant role in regulating the urban microclimate and can influence operational energy demand through solar absorption and the cooling effects provided by shade and evapotranspiration.

4.6.2 Renewable Energy Potential

Research by Sarralde et al. (2011) explores renewable energy potential (REP), that is the potential to install several renewable energy technologies (RET) in existing neighbourhoods and cities. The RETs reviewed include “Diffuse RET” – those technologies that once installed will not block any urban space that could be used for other purposes (e.g. buildings or infrastructure) and that will not require any further material flows for their functioning, including photovoltaic panels (PV) installed on roofs or façades, or meso-scale wind turbines installed on rooftops; and “Concrete RET” – those options that use extra urban space and/or generate material flows, such as biomass-fuelled combined heat and power (CHP) systems or macro-scale wind turbines, which might require a non-built safety area around them.

Sarralde et al. (2011) concluded that lower building density is beneficial for REP in existing neighbourhoods and cities. Higher building density means that fewer portions of land are freely available for installing RET; however, this may not necessarily mean that the final renewable energy output will be lower, since it will
depend on what types of RET can be installed. While high density can be detrimental for some types of RET, it can be beneficial for others. For example, a high-density area might not be optimal for installing wind turbines or domestic shallow ground source heat pumps (GSHPs), but it can be very good for the installation of building-mounted PV, due to a larger proportion of envelope area.

In subsequent research, Sarralde et al. (2014) show that while there is more room for improvement in increasing the amount of solar radiation received on façades (by modifying variables such as plot ratio, distance between buildings and building heights), this is still a small portion of what can be achieved on roofs. Miller (2013) explores the role that roof shape plays in the solar potential of urban patterns (i.e. local energy generation potential), and concludes that flat roofs provide the greatest benefit for solar potential due to their reduced dependence on building and roof orientation. Where building height varies (generally associated with higher densities), reduced solar potential occurs for shorter buildings within the urban structure, while taller buildings maintain maximum solar potential due to limited shading on roof surfaces. This effect can, however, be minimized if building heights are kept relatively consistent.

4.6.3 District energy
The feasibility of district energy systems relies in part on the total energy demand for the area to be serviced – the general approach being to maximize the total energy demand. This total is calculated by multiplying energy intensity factors for different types of building use (expressed as GJ/m²/yr) by the total floor area of that use (a function of building or development density). It follows therefore that maximizing total energy use involves maximizing the energy intensity factor, the density, or both. What is important about this research is an understanding that changes in density (and building characteristics) create changes in intensity factors.

In general, as density increases (and building characteristics improve), energy intensity factors improve (i.e. decrease), which counteracts the intent to establish a maximized total energy demand. While a certain level of total energy demand is required to make district energy feasible, development should be conducted on the principle that as little energy as possible is needed and used by buildings (or per capita), and then to apply this demand at a higher density, or over a larger area. As a crude example, a building with a high energy intensity factor at a lower density (such as a hospital), which also has very low envelope performance, could provide the same total energy demand as a very high density residential building with high envelope performance. While the total energy demand is the same in both cases, the energy intensity factors and overall energy use per capita are significantly different.

Focus should be first placed on making buildings as energy efficient as possible, before applying the associated density required to make district energy feasible.
4.7 Future buildings

The introduction of new policy measures to increase the energy efficiency of buildings as well as the adoption of voluntary standards such as PassivHaus will likely result in significantly lower energy density, and indeed major efficiency gains will be required to limit a global temperature increase to 2 degrees, which the United Nations indicates will prevent dangerous levels of climate change (Figure 5).

As of 2020 in Europe, “nearly zero-energy buildings” are assumed to be the norm due to the Energy Performance of Buildings Directive (Vandevyvere & Stremke, 2012b) and an IEA report documents low carbon or zero emissions building policies in ten countries, with targets between 2020 and 2050 (OECD/IEA, 2013).

In response to a saturation of district energy in countries where district energy already connects the buildings with higher heat density, a major study (Zinko et al., 2008) identified a wide range of strategies to reduce the cost of district heating to increase the feasibility of low heat density areas. These strategies sought to reduce investment and heat losses, for example, by reducing the pipe dimensions, increasing insulation with new piping systems, decreasing the size of the trench, integrating the install with other infrastructure projects, identifying new energy services such as absorption chillers, washing machines, dishwashers and dryers; the notion of ‘branching out’ (Späth, 2005). There is also an opportunity for individual buildings to become energy generators and traders as part of a district energy network (Nystedt, Shemeikka, & Klobut, 2006).

District energy systems can create perverse incentives that result in the avoidance of successful energy savings strategies, as well as legal requirements that can inhibit more efficient dwellings or buildings – another form of path dependence. One option is to design a tariff structure that reflects ecological impact, analogous to a
carbon tax so that low-energy dwellings are not penalized (Späth, 2005). The development of highly efficient buildings increases the focus on urban planning to maximize the viability of district energy.

Finally, in addition to the decreased heating and cooling demand due to design efficiencies, there is also the impact of climate change on heating degree days and cooling degree days, both of which drive energy consumption (Aebischer, Catenazzi, & Jakob, 2007; Christenson, Manz, & Gyalistras, 2006).
5 Archetypes
An archetype is defined as “a very typical example of a certain person or thing”, almost but not quite one of the repeating components contained in a pattern, or a pattern itself (Eisenack, Luedeke, & Kropp, 2006). An archetype can equally be spatial, referring to a tangible, physical space or intangible as in circumstances, reactions or relations. It may or may not refer to the idealized generalization of a particularity, but it certainly captures dimensions which can be generally encountered in a similar context – themes, as Jung called them (Cicchetti, 2006). Archetypes are used in a variety of fields ranging from literature to design, from psychology to ecology, as a way of simplifying complexity without forfeiting the ability to provide meaningful insights.

5.1 Archetypes and the built environment

Archetypes in architecture and planning are used to categorize typical types of development and help guide best practices and design decisions. For example, in “Transit-Oriented Communities: A Blueprint for Washington State,” planners, architects, and community organizers worked together to identify and categorize five station area development types in order to develop a comparative framework for measuring the performance of transit-oriented communities around station areas relative to policy goals (GGLO, Futurewise, and the Transportation Choices Coalition, 2009). Each station area type was categorized by its location relative to a station hub, zoning attributes (jobs and housing capacity), and infrastructure conditions (bicycle and pedestrian, and transit connectivity), which provided a way to measure how well each type performed from a connectivity, density, and mix-of-uses standpoint -- the higher the performance, the better the type in creating a high-performing districts. Using archetypes, like these, planners and policy makers can better guide design and policy decisions, such as where to increase zoned capacity or make infrastructure investments.

As described in section 1, urban planning is the domain of what are termed “wicked” problems – challenges to which there are no easy solutions. Archetypes are thus a useful tool to identify the essential characteristics of a particular aspect or pattern of the built environment and then to add, take away or substitute this pattern in other places. The attributes of an archetype can describe quantitative dimensions such as energy use, impermeable space, building types and others. When these archetypes are employed to revise the landscape, conclusions can then be drawn by analyzing the attributes associated with each archetype.

In planning, archetypes can often be organized by scale, with corresponding prototypical land-use mixes, form and structure, and identities. Some examples of different types of energy-efficient and district energy projects in the United States, at a variety of scales and land use intensities include:
Figure 6. Organization of archetypes for energy-efficient and district energy projects at different scales and land use intensities.

It is important to recognize that energy performance is often measured and benchmarked at the building scale relative to building use, such as commercial office, retail, industrial, residential, or institutional.
5.2 Using archetypes to characterize land-use and energy consumption

Archetypes are commonly used to describe energy characteristics of the built environment. Van der Laan (2011, p. 9) identifies nine recent studies in the academic literature that have used archetypes to describe energy consumption. In the Urban Archetypes Project, a multi-year initiative funded by Natural Resources Canada, Canadian researchers led a project (2004–2010) studying energy consumption of typical households in different neighbourhoods across Canada, “linking energy consumption with neighbourhood urban form and demographics” (Webster, 2007).

Archetypes are frequently used in energy modelling, in particular to construct bottom-up models in which each archetype represents a dwelling, generalized to its basic shape with standard spatial and energy characteristics (Marique & Reiter, 2014; Medina, 2011; Natarajan, Padget, & Elliott, 2011). This approach enables a model to function at the level of individual buildings without relying on actual data for each of the buildings and to explore the implications of urban form characteristics (Sattrup & Strømann-Andersen, 2013). As illustrated above, archetypes can also be defined at the neighbourhood level, in one case as a tool to explore retrofitting suburbia (Barton, Grant, Rice, & Horswell, 2011). The District Energy Concept Advisor relies on archetypes derived from real cases to illustrate the potential for district energy in different configurations (Erhorn-kluttig, Erhorn, Weber, Wössner, & Budde, 2013).

One project, in considering energy reduction opportunities, identified a typology of cities, in which eight categories of cities were identified according to particular characteristics, a similar approach to the archetypes. This particular bundle of characteristics gives rise to specific opportunities that can be generally applied to all cities in that category (Creutzig et al., 2014).

5.3 Archetypes and district energy

Very few studies were identified that employed archetypes to help inform land-use that would support district energy or that would inform the development of district energy systems. One Swedish study developed a series of building archetypes to model how solar energy and load shifting could be employed to reduce the peak load for district energy systems (Molander & Olofsson, 2012) and another evaluated the heating and cooling load of seventeen neighbourhood typologies (Maïzia et al., 2009).
6 CO-BENEFITS
Co-benefits refer to ancillary outcomes that occur as a consequence of an action or actions designed to achieve a different outcome. As this section illustrates, the goal of optimizing land-use decisions for district energy simultaneously achieves other goals.

6.1 Affordable municipal infrastructure and services

The capital cost of urban infrastructure is influenced by the amount of materials needed and the construction effort to install these materials. This is often expressed as a cost per linear metre or foot. The amount and type of materials are influenced by the demand the system is required to meet, and the distance between this demand and the supply point. As demand increases, costs increase due to increase in system size or capacity. Also, costs increase as distance between supply and demand increase. However, this is not a simple linear relationship. For example, in a water supply system, pipe size increases as water demand increases. But if that increase in demand occurs over a shorter incremental distance (i.e. increased water demand from increased building density in a small area, as opposed to increased water demand from low-density sprawl), the increase in cost for bigger pipes outweighs the increase in cost for longer distances of pipe. In general, denser built environments benefit from economies of scale where demands are higher, and distances between supply and demand is shorter. In a study for the US Environmental Protection Agency (EPA), two specific examples are analyzed, highlighting the infrastructure cost benefits of compact development, with additional benefits for green space and stormwater management (Ford, 2009).

Another major impact on costs is determined by the construction efforts to install infrastructure. As site conditions become more challenging, the cost per linear metre increases. It is much easier and cheaper to install a pipe system on a flat greenfield site with good ground conditions, compared to a site where multiple existing utilities are located in contaminated soil under an existing and heavily used roadway. In the majority of urban areas, utilities and piping systems are located below ground in road right-of-ways. That is to say, the pattern of underground pipes generally follows the same pattern as the roads above, as the utilities serve the same above-ground properties as the road. Grid-like block or street patterns result in grid-like utility patterns. Therefore, the linear distances of underground infrastructure are often closely correlated with the distances of road above. It follows, then, that the above-ground street pattern has an impact on the total distance of underground infrastructure, and therefore on cost. A comparison of the percentage of area for streets of different patterns is shown in the figure below (Tasker-Brown & Pogharian, 2002).
Figure 7. Comparison of area used for streets

<table>
<thead>
<tr>
<th></th>
<th>Square grid (Atlanta, Houston, Portland, etc.)</th>
<th>Oblong grid (most cities with a grid)</th>
<th>Oblong grid 2 (some cities or in certain areas)</th>
<th>Loops (Subdivisions - 1950 to now)</th>
<th>Cul-de-sac (1930 to now)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of area for streets</td>
<td>36.0%</td>
<td>35.0%</td>
<td>31.4%</td>
<td>27.4%</td>
<td>23.7%</td>
</tr>
<tr>
<td>Percentage of buildable area</td>
<td>64.0%</td>
<td>65.0%</td>
<td>68.6%</td>
<td>72.6%</td>
<td>76.3%</td>
</tr>
</tbody>
</table>

Traditional grid patterns are generally associated with higher-density areas, particularly in existing cities. Grid patterns generally result in longer distances of road and utilities per area, but these are associated with much higher densities, resulting in much larger benefits from economies of scale, and significantly lower costs per linear metre, if calculated on a per capita basis.

Beyond hard infrastructure, municipalities also provide services such as fire protection, policing, recreation, schools and transit, all of which are significantly impacted by the spatial distribution of buildings in a city. The City of Calgary found in an analysis of alternative growth scenarios that savings of 33% or $11 billion over 60 years could be achieved in operations and maintenance through compact growth (IBI Group, 2009).

6.2 Attractor for increased density

Many municipalities are focused on revitalizing or strengthening their downtowns (Wolman, Ford, & Hill, 1994). Theodore Roosevelt said of the Panama Canal, “If you build it they will come”. Can a district energy system attract high-density developments? The answer is yes, in several ways. First, all developers recognize the economic value of avoiding the capital cost of a conventional boiler system and utility space, as well as the potential to produce additional revenues by reprogramming utility space for revenue generation. Second, developers interested in sustainable building design will be attracted by the low-carbon attributes of a district energy system, along with the associated LEED credits. Finally, if the developer also owns and operates the new building, then the lifecycle savings and price certainty of district energy versus conventional options.
will be attractive. If the development is to be sold or rented to others, the stable price of district energy can become a marketing feature.

6.3 Reduced Energy Sprawl

The term energy sprawl was coined by The Nature Conservancy to describe the consumption of land by new energy generating facilities and new energy distribution infrastructure (e.g. land used for fossil fuel exploration, extraction and processing; pipelines for natural gas and oil; electricity generating facilities including hydroelectric dams; electricity transmission networks) (Bronin, 2010). The Nature Conservancy estimates that approximately 206,000 square kilometres of land in the United States will be affected by energy infrastructure over the next twenty years, based on a business-as-usual approach (Palmquist, 2019). Energy sprawl may be less evident than urban sprawl to urban planners, and in fact reducing urban sprawl (for example by increasing density) can lead to increased energy sprawl if conventional energy channels alone are used. It’s also important to note that land is consumed by some alternative energy systems such as large wind farms and solar parks. District energy reduces energy sprawl by localizing heating, cooling and electricity generation, reducing the need for additional external generation capacity and distribution systems (Bronin, 2010).

6.4 Reduced Embodied energy

Embodied energy in the built environment relates to the energy used or consumed in the pre-use stage of a building, that is, the energy required to build a building. This initial embodied energy can be further divided into three categories, namely, material manufacturing (including raw material acquisition, transportation and manufacturing), transportation to site and on-site construction. It follows that as building density increases and more square footage is constructed, more building materials are used, and the total embodied energy increases. As building density increases, area per person tends to decrease, and embodied energy of built area decreases per capita (Norman, MacLean, & Kennedy, 2006). It could similarly be argued that construction of a denser built environment could result in lower transportation and on-site construction energy per capita, as time and materials are focused at a centralized site over a shorter period of time, in comparison to decentralized low-density construction.

Another point to consider is the lifetime or durability of a building. Initial embodied energy accounts for only the beginning of a building’s life. The longer the building stands, the higher the benefit of that embodied energy over time.
6.5 Health benefits

Many, but not all, of the compact urban forms that enable district energy also contribute to improved health outcomes. In the past five to ten years there has been an explosion of literature on this relationship. Higher density is associated with higher levels of active transportation (Sallis, Floyd, Rodríguez, & Saelens, 2012), which in turn translates into improved health outcomes with respect to heart disease, type 2 diabetes, colon cancer, breast cancer, and mortality (Hankey, Marshall, & Brauer, 2012).
7 Modelling
“A model is not a piece of absolute and universal science but the expression of a point of view that will take place in a social context where it will more or less be relevant” (Bouleau, 1999, p.340).

There are two streams of modelling of interest to this project: urban energy modelling and district energy modelling. Within these two streams there is overlap as those who are interested in district energy seek to characterize the heating and/or cooling demand of the built environment to investigate the feasibility of district energy, and those who are interested in energy flows within the built environment also seek to understand heating within buildings. For this reason, both streams are investigated, but greater attention is paid to specific approaches within the umbrella of district energy modelling.

A workshop under the auspices of the Organisation for Economic Co-operation and Development (OECD) that explored the development and state of urban models globally, identified motivations for using models as: exploring and discussing policy scenario development and alternative futures, informing policy decisions, convincing professionals, checking that the ex-ante reasoning makes sense, testing theory and method and exploring design alternatives and design decisions (Devisme, Bosse, Dumont, & Ouvrard, 2011).
### 7.1 Structure of models

A model is defined as a conceptual abstraction of an existing or proposed real system that captures characteristics of interest, consisting at its essence of inputs, calculations and outputs. One description of an ideal model of urban systems included the following criteria (Waddell, 2005, p. 5):

- **Agent-level representation**: individual households and jobs;
- **Dynamic representation of time**, usually in annual steps, with path-dependence;
- **Representation of highly disaggregate geographies**, such as small grid-cells or parcels;
- **Representation of individual choice processes**: moving, locating;
- **Use of a discrete-choice modelling framework** to represent choice behaviour;
- **Representation of interactions of households, firms and developers in real estate markets**, and the role of prices; and
- **Representation of scenarios of public policies** for land use, transportation and the environment.

A parallel discussion relates to standard model ontologies, but the ontology refers to the programming language describing the model (Keirstead & Dam, 2010; Métral, Falquet, & Vonlanthen, 2007). In this vein, a standard open-source energy systems optimization model, OSeMOSYS, provides standardized code for model development (Charlie Heaps, Howells, & Clark, 2012; Warren, 2011). The most critical question in terms of model structure is the question of what is generated within the model (endogenous) and what the inputs from other sources (exogenous) are. Any agent or process whose attributes and/or behaviour are determined within the model is considered endogenous to the model, and factors which affect system performance but whose values are provided as inputs are called exogenous factors. The boundary of the model determines which variables are inputs and which variables are the subject of evaluation in the model. Keirstead et al. (2012, p.}
5) noted three different boundaries of urban energy systems, each with significant implications for the type of model employed:

- Pure geographic, i.e. the urban energy system consists only of those technologies that lie within a city’s administrative boundaries;
- Geographic-plus, i.e. everything within the administrative boundaries plus easily traceable upstream flows, like electricity consumption;
- Pure consumption, i.e. the energy system encompasses all energy activities of a city’s occupants wherever they occur. For example, attributing a resort’s energy consumption and emissions to the home cities of the visiting tourists.

### 7.2 Modelling approaches

Modelling of urban systems has been evolving rapidly, driven by urban theory and computing abilities, but the history of their use is relatively short, spanning fifty to sixty years (Oryani & Harris, 1997). The earliest land-use models attracted significant interest and effort as a strategy to understand and manage the rapid growth in automobile use. Douglass Lee (1973) published a watershed paper in 1973 titled “Requiem for large-scale models” in which he identified major weaknesses. Following this paper, interest waned and the focus shifted to short-term problem solving for more than a decade (Pinto & Antunes, 2007). The emergence of GIS in the 1980s increased computer power, and increased data availability reinvigorated the relevance of models as significant tools for urban policy decision-making (L. Li, Sato, & Zhu, 2003).

Of the urban systems that can be modelled, transportation has attracted the most interest, evolving from the classic four-stage model which used a sequential analysis of trip generation, trip distribution, modal split and trip assignment to generate traffic flows to cellular automata, which simulate individual or household behaviour (Kane & Behrens, 2002) and employs complexity theory to generate unpredictable outcomes. In addition to these resource-intensive models, a new generation of sketch-planning-type models has been developed which range from full-scale simulation to diagnostic-indicator-like approaches (Batty, 2004). The overall result of the various streams of urban systems model development over the past forty years is a very diverse ecosystem of different approaches that are difficult to categorize or standardize.
One framework evaluated nineteen models against three axes representing temporal, spatial and human decision-making complexity (Agarwal, Green, & Grove, 2002). The authors indicate that the relationship between human and environmental systems contains many nonlinearities and spatial and temporal lags which are not captured by statistical techniques, creating a significant challenge for modelling. Nonlinear dynamic models respond to this challenge, using stock variables (for example, capital stock in an economy), flow variables (annual investment in capital) and parameters to create a model that is not dependent on historical data and that generates emergent, unpredictable outcomes. It is, however, still difficult to tune these models to local contexts (Batty, 2004). In another approach, Table 4 identifies nine different families of characteristics of energy models (Beeck, 1999, p. 7).

Table 4. Characteristics of energy models

<table>
<thead>
<tr>
<th>Approach</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specific: energy demand, energy supply, impacts, appraisal, integrated</td>
</tr>
<tr>
<td></td>
<td>approach, modular build-up</td>
</tr>
<tr>
<td>2. The Model Structure: Internal</td>
<td>Degree of endogenization, description of non-energy sectors,</td>
</tr>
<tr>
<td>Assumptions &amp; External</td>
<td>description of end-uses, description of supply technologies (how many</td>
</tr>
<tr>
<td>Assumptions</td>
<td>variables are generated within the model vs. captured from other</td>
</tr>
<tr>
<td></td>
<td>sources)</td>
</tr>
<tr>
<td>3. The Analytical Approach</td>
<td>Top-down (i.e. deconstructs the economy to understand households) or</td>
</tr>
<tr>
<td></td>
<td>bottom-up (i.e. constructs a city transportation system based on</td>
</tr>
<tr>
<td></td>
<td>household behaviour)</td>
</tr>
<tr>
<td>4. The Underlying Methodology</td>
<td>Econometric, macro-economic, economic equilibrium, optimization, simulation,</td>
</tr>
<tr>
<td></td>
<td>spreadsheet/toolbox, backcasting, multi-criteria.</td>
</tr>
<tr>
<td>5. The Mathematical Approach</td>
<td>Linear programming, mixed-integer programming, non-linear</td>
</tr>
<tr>
<td></td>
<td>programming.</td>
</tr>
<tr>
<td>6. Geographical Coverage</td>
<td>Global, regional, national, local, or project</td>
</tr>
<tr>
<td>7. Sectoral Coverage</td>
<td>Energy sectors or overall economy.</td>
</tr>
</tbody>
</table>
A 2011 review which narrowed in specifically on energy system models identified five key areas of modelling practice including technology design, building design, urban climate, systems design and policy assessment (James Keirstead et al., 2012).

A review of models for analyzing the GHG impacts of land-use decisions classified eleven models by scope, methodology, scale and support for policy making (Condon, Cavens, & Miller, n.d.). Methodological categories included spatial/nonspatial, top-down/bottom-up, simulation/end-state and observation-based/process-based. Of these options for GHG modelling, the authors indicated that a spatial dimension is advantageous as it interprets the physical organization of a city and more effectively communicates the implications of decisions. Simulation models generate outcomes based on a series of rules, whereas the end-state method describes a future condition and works backwards. Finally, a workshop coordinated through the OECD investigated the state of urban modelling and profiled a number of leading models (Devisme et al., 2011). The OECD workshop report includes a detailed review of the state of urban models and the current issues, challenges and debates under way.
7.3 Urban Energy models

Urban energy models seek to track the spatial and temporal variation in urban energy demand. In general these models are developed for a particular location or set of circumstances, although there are more generic approaches emerging such as SynCity (J. Keirstead, Samsatli, & Shah, 2010). One substream of this broader category seeks to quantify GHG emissions associated with urban areas in order to guide local governments in their mitigation efforts (Devisme et al., 2011). The techniques and strategies employed to quantify energy vary widely. One approach, seeking to assess urban heating demand, employs LiDAR (airborne laser scanning) to identify three-dimensional profiles of the buildings. A transmission heat-loss method is then used to identify heat demand (Strzalka, Bogdahn, & Eicker, 2010). Another approach divides a city into typologies of relatively homogeneous built environment characteristics, assigns resource consumption to each typology and calculates energy and other resources used – a top-down approach (Sarralde, Quinn, & Wiesmann, 2011). Similarly, but more precisely, both the Energy and Environmental Protection Model (Cf, 2001) and the Urban Archetypes Project (Webster, 2008) classify buildings into one of twenty types and attach them to a particular spatial location to enable calculation of building and transportation energy consumption. Common to all of these approaches is the use of GIS, essentially a manipulable database of spatial information. But the rise of big data gives rise to a whole new range of as yet untapped sources of data (Martino et al., n.d.). For example, Google’s NEST, a ‘learning’ thermostat, not only tracks energy consumption online but also the behaviour of residents over time (Barker, Mishra, Irwin, & Cecchet, 2012).

One notable stream of effort within the urban energy modelling world is that of urban metabolism. The urban metabolism method seeks to track the flux of energy or carbon, and/or other resources through the urban system including changes in storage (Sahely, Dudding, & Kennedy, 2003), a complex but systematic approach that includes embodied as well as operational energy. In their literature review on the subject, Holmes and Pincetl (2012), note that urban metabolism provides a complete picture of actual and embedded energy use over short- and long-term time scales.

New strategies for validating models include actual measurements of carbon fluxes, although there are challenges extrapolating the accounting framework against actual location-based emissions (Christen et al., 1990).
7.4 District energy models

Typically, all the studied models used for analyzing the feasibility of district energy projects include the following elements for the analyzed area:

- Calculation of consumption of heating or cooling for all customers.
- Technical and economic calculations for individual cooling and heating.
- Technical and economic calculations for district energy cooling and heating, including network costs.
- Comparison of base case (individual heating or cooling) with district energy.

This approach is shown in the figure below.

Figure 8. Modelling of district energy.
7.4.1 Assumptions and theory behind the modelling approaches

The most common methodology used for comparing different individual solutions for heating and cooling with district energy systems is to make a calculation of the net present value of the costs for the different scenarios over a planning period (typically twenty years) and compare the individual solution with district energy (F. Li, 2013).

An overview of typical assumptions is shown in the figure below.

**Figure 9. Assumptions in district energy models.**

- Inputs on general framework
  - Fuel prices, power prices, taxes and subsidies
  - Lifetime and interest rate for investments

- Specific inputs for district energy area
  - Number, size and types of buildings => energy density, installation costs
  - Consumption profile (seasonal, diurnal load variations)
  - Network costs and losses
  - Local sources for cooling or heating: Sea water, ground water, geothermal energy, industrial surplus heat etc.

- Data for relevant energy production units – individual and district energy solutions
  - Size
  - Technical and economic data: efficiencies, variable and fixed O&M costs, investments etc.
  - Emission data
  - Technical constraints
  - Political constraints

7.4.2 Spatial and non-spatial dimensions in the models

None of the models studied has a focus on the spatial dimensions of the community area in the analysis. It is typically up to the user to specify the number of buildings, the area of the buildings, the length of the needed pipes in the district energy network, as well as other related infrastructure. This approach requires that the user have detailed knowledge of district energy systems and the related technology and cost data. However, in two of the models discussed below (the COWI Heat Atlas and the study using Balmorel) a GIS database has been used as input for the district energy model to calculate energy density and the rough layout of the district heating network. A further model, the District Energy Concept Advisor provides guidance to urban planners and developers at an early stage of the development of the built environment, but it is not grounded in a specific community (Erhorn-kluttig et al., 2013).
7.4.3 Level of decision-making that the models are designed to influence

The studied models are all designed to influence decision-making on the level of politicians or planners. However, most of the models require the insight of technical staff to set up the necessary inputs and interpret the calculations and results.

7.4.4 Methods used for modelling

Four of the five studied models use spreadsheets as the model platform. The mathematical model structure is fairly simple and is based on basic theory for energy balances and financial calculations. One model is based on linear programming, using the model language GAMS. But this is only necessary if a number of district energy areas need to be optimized at the same time, taking into account the dynamics of the regional power system.

7.4.5 Graphical user interface

Four of the five studied models use spreadsheets as the model platform. The mathematical model structure is fairly simple and is based on basic theory for energy balances and financial calculations. One model is based on linear programming, using the model language GAMS. But this model is only necessary if a number of district energy areas need to be optimized at the same time, taking into account the dynamics of the regional power system.
7.5 Existing models

There are a large number of quantitative models used for different aspects of the district energy lifecycle. The models can be divided into different types that serve different purposes, as illustrated in Table 5.

*Table 5. Model characteristics*

<table>
<thead>
<tr>
<th>Model type</th>
<th>Description</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic models</td>
<td>Models of district heating networks, pressure losses, flows, pumping</td>
<td>Systemrørnet, Termis.</td>
</tr>
<tr>
<td>Energy System models</td>
<td>The role of district heating in the energy system. Simple representation of district heating networks (demand, production, fuel use).</td>
<td>Balmorel, EnergyPlan, Times, SUNTool</td>
</tr>
<tr>
<td>Models of load dispatch in single district heating system</td>
<td>Hour by hour dispatch of production units, heat storages etc</td>
<td>EnergyPRO.</td>
</tr>
<tr>
<td>Costing models</td>
<td>Models for calculating costs of district energy systems, dimensioning and lay out of pipes. Sometimes includes GIS applications</td>
<td>RETScreen</td>
</tr>
<tr>
<td></td>
<td>Calculating production costs for different technologies for individual and district energy systems</td>
<td></td>
</tr>
<tr>
<td>Decision models for district energy projects</td>
<td>Feasibility of district energy taking into account investments in district heating network, heat/cooling production price, energy density. Some models use GIS tools.</td>
<td>Rambøll model developed for the Danish Energy Agency, COWI Heat Atlas (combination of models), RETScreen, DEEM, Balmorel. Includes elements from models 3, 4, 5 and 6 above.</td>
</tr>
<tr>
<td></td>
<td>Models for determining energy consumption and density in an area with different types of buildings.</td>
<td></td>
</tr>
<tr>
<td>Urban planning models</td>
<td>Decision models for district energy also including planning of urban structure to fit with District Energy Systems.</td>
<td>None identified.</td>
</tr>
</tbody>
</table>
7.6 Review of models

Models used to evaluate the feasibility of district energy are used by most consultants and some industrial companies working in the field of district energy. Many of these are proprietary models, which means that developing an exhaustive list is difficult. The models studied are shown in the box to the right.

One model which was not studied but is notable is the SUNtool, a highly technical simulation model that includes urban planning dimensions and district energy (Robinson et al., 2007). While it is described in the literature, its website is no longer available.

- Rambøll
- COWI Heat Atlas
- RETScreen
- DEEM
- Balmorel
- District Energy Concept Advisor
7.6.1 Rambøll model

In recent years many municipalities in Denmark have started working more systematically with cross-cutting strategic energy planning including energy efficiency measures, heat planning, transportation and other variables. To support this work the Danish Energy Agency has developed guidelines and tools to be used in the planning. One of these tools is an Excel model for evaluating the feasibility of district heating in new developments in towns and cities. The model includes an input sheet, an output sheet and a number of calculation sheets. The inputs from the user include: number and area of different types of buildings (i.e. single family, multi-storey, offices), energy standard of buildings, distance to nearest district heating network, costs and environmental impact of nearest district heating network (choice between 3 levels of costs), and specification of individual heating alternatives.

Based on these inputs the model calculates the costs of the individual and district heating alternatives and makes a comparison of the two. The model includes both a calculation of the consequences for the users (including taxes and subsidies) and a socio-economic calculation.

7.6.2 COWI VarmeAtlas

In 2013–2014, the Danish consultancy companies COWI and Ea Energy Analyses carried out an analysis of the future for district heating in Denmark for the Danish Energy Agency. This task included an analysis of the optimal split between district heating and individual heating in Danish buildings. Today district heating has a share of about 50%, but the analysis showed that it is economically feasible to increase this to about 60%. As part of the project an Excel-based model was developed to analyze the competition between the individual and district heating alternatives. The model includes data for all buildings in Denmark based on the Danish national Building and Houses Database (BBR) and COWI’s existing GIS tools. The buildings were grouped in about 4,000 town areas with data for energy consumption of the buildings, energy density and distance to the nearest existing district heating network.

Based on assumptions for fuel prices, taxes and subsidies, CO2 prices, power prices and technical and economic data for heating technologies, the costs for individual heating of the buildings were calculated. Costs for the heat production in the district heating networks were computed with the energy market model Balmorel and fed into the Heat Atlas model. However, it was also possible to calculate the district heating costs for alternative land uses and use these results as inputs into the model. Finally, the model also includes inputs and calculations of the costs for connecting buildings to a district heating network depending on the energy density and the distance of the buildings to existing district heating networks.
The results of the model include the costs for individual heating systems and district heating for all existing buildings in Denmark and a comparison between the costs of the two alternatives. Based on these results the optimal split between individual and district heating for a particular jurisdiction can be evaluated depending on the input assumptions.

7.6.3 RETScreen

RETScreen is a software system used to evaluate energy efficiency, renewable energy and cogeneration project feasibility, and ongoing energy performance. The RETScreen software is a unique decision support tool developed with the contribution of numerous international experts from government, industry and academia, and is provided free of charge for worldwide use. RETScreen evaluates energy production and savings, costs, emission reductions, financial viability, and risk for various types of renewable-energy and energy-efficient technologies (RETs). The software (available in multiple languages) also includes product, project, hydrology and climate databases, a detailed user manual, and a case study–based college/university-level training course, including an engineering e-textbook.

The software has quite a broad scope and the analysis of district energy systems is just one of a number of applications of the model. It is a spreadsheet model where the user can choose the type of project analyzed, i.e. energy efficiency, power production, heating, combined heat and power, and others. The possible project types include district energy systems and in this case the user needs to specify inputs including the number, area and energy consumption of buildings, the required temperature, the pipe size and length of the district heating network, as well as detailed technical and economic data for the heat production technologies in the base case and in the district energy case. The outputs from the model include a cost analysis, a financial analysis and an emissions analysis in which the district energy system is compared to the base case.
7.6.4 DEEM
The District Energy Economic Model (DEEM) is a spreadsheet tool designed specifically to help developers, engineers and municipal planners forecast how the benefits of a district energy system translate into revenue, savings and jobs for a specific community. The tool has been developed by Natural Resources Canada’s CanmetENERGY and the focus of the tool is district energy in Canada.

The model includes five input sheets where the user specifies data for the BAU case (individual heating or cooling) and the DE case. The required inputs are detailed and include data for the number and energy consumption of buildings, and economic and technical data for the BAU and DES cases. The model then calculates the costs of the two cases and completes a comparison. The model includes a number of alternative perspectives and calculations to show the range of economic benefits of DE including wages and salary earnings, GDP, taxes, jobs and environmental impacts.

7.6.5 Balmorel
The Balmorel model simulates investment and operations of a combined electricity and CHP system from an international perspective. It permits integrated analyses of demand and supply of electricity and heat while balancing operations against investment, local electricity generation against import/export of electricity, and price elastic demand against generation and investment. It represents demand of electricity and heat in a number of geographical locations, each with individual time variations over the year.

Key inputs are existing electricity and heat generation capacities, electricity transmission capacities and demand. Additional key assumptions relate to fuel prices, CO2 costs, taxes and support schemes. The main outputs are consumption, production, electricity transmission, emissions and other characteristics of the energy system.

The model is formulated as a deterministic linear optimization model in the General Algebraic Modeling System (GAMS) modelling language. This permits changes and adaptations of the model to specific applications that are not presently covered by the standard version of the model. The model’s GAMS code is available at open-source conditions at www.Balmorel.com.
In the study “The role of district heating in the future Danish energy system” (Münster et al., 2012) the Balmorel model was adapted in order to analyze the competition between district heating and individual heating of buildings. In this version of Balmorel, approximately 400 Danish district heating areas were grouped in approximately 25 aggregated areas. For each of these areas the potential for expanding the district heating networks into areas with individual heating and the related costs of the network expansions was calculated using a heat atlas from Aalborg University. Based on this input the Balmorel model was able to optimize the expansion of district heating based on the costs for individual heating and the costs of district heating production and network expansion.

7.6.6 District Energy Concept Advisor

The District Energy Concept Advisor was developed as part of IEA Annex 51 “Energy Efficient Communities.” The program is designed for urban planners, housing companies, developers and local political decision makers in the very early planning stages of the energy supply of neighbourhoods. The tool is populated with national building archetypes with a fixed geometry, a usage profile and U-values of the building envelope (related to the age of the building). The user can explore a wide range of possibilities for building service systems (space heating, hot water generation, ventilation, cooling) and the integration of renewable energy sources (Erhorn-kluttig et al., 2013).
### 7.7 Comparison of the models

<table>
<thead>
<tr>
<th>Model</th>
<th>Characteristics</th>
<th>Complexity</th>
<th>Open source or proprietary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rambøll model</td>
<td>Spreadsheet model. Simple input structure.</td>
<td>Low</td>
<td>Open source</td>
</tr>
<tr>
<td>COWI Varmeatlas</td>
<td>Spreadsheet model. Not very user-friendly. The strength of the model is that it is able to analyze a number of district energy systems at the same time. It is not very detailed on the level of each individual DH system.</td>
<td>Medium</td>
<td>Proprietary</td>
</tr>
<tr>
<td>RETScreen</td>
<td>Spreadsheet model. The model includes the possibility to analyze a number of different renewable-energy and energy-efficient technologies (RETs) and district energy is just one. The many details needed in the input structure set high demands for the technical insight of the user.</td>
<td>Medium</td>
<td>Open source</td>
</tr>
<tr>
<td>DEEM</td>
<td>Spreadsheet model. Many details needed in input. Includes a broader view on the benefits of district energy and includes economic benefits such as GDP, taxes, jobs, etc.</td>
<td>Low</td>
<td>Open source</td>
</tr>
<tr>
<td>Balmorel</td>
<td>GAMS model. Quite complex input and model structure. Not suitable for analyzing district energy in a single area but useful for analyzing the role of district energy in the energy system of a country or region.</td>
<td>High</td>
<td>Open source</td>
</tr>
<tr>
<td>District Energy Concept Advisor</td>
<td>Users can choose from databases of building types and customize the buildings, select technologies and evaluate different options using an interface.</td>
<td>Medium</td>
<td>Proprietary</td>
</tr>
</tbody>
</table>
7.8 Open source

7.8.1 Definition
A number of the models reviewed are open source. Open source referred initially to a way of writing and distributing software in which it was given away for free, in direct contrast to the traditional approach in which software is developed as a trade secret and sold (Healy & Schussman, 2003). The formal definition requires that the source code for the program must be available at little or no charge, redistribution of the program, in source code or other form, must be allowed without fee, distributions of modified software must be allowed without discrimination, and the distributions of those modifications must be permitted on the same terms as the original program (Lerner & Tirole, 2005).

7.8.2 Benefits and challenges
Successful open-source projects rely on a community of users who are willing to innovate and share their innovations so that the software is enhanced based on the users’ direct experiences. Participants in an open-source process may accrue social benefits “in contrast to atomized agents relying on price signals to make decisions, community participants should be well-connected (‘pervasively networked’) and information should flow well between them”, as well as the practical benefits “of having software that works properly, the increase in reputation that comes from being associated with a successful project, and the potential... [for] further commercial opportunities” (Healy & Schussman, 2003, pp. 6–7). In their analysis, Healy & Schussman conclude that the more successful a project, the more professional its core contributors will be, that a strong hierarchy is necessary and that successful projects will have core participants mobilized in a very similar manner to core participants in a social movement.

7.8.3 Examples
Many urban energy models use open-source licenses including UrbanSim (Waddell, 2010), LEAP (C. Heaps, Clark, & Howells, n.d.), SPRAC (York, 2012), Urban Footprint (Calthrope Associates, 2011) and others.
8 Conclusions
District energy is a powerful approach to providing energy to buildings that can deliver increased efficiency and resilience and contribute to significantly reducing or eliminating GHG emissions in the appropriate context. District energy faces many barriers, however, including high capital costs, complex customer arrangements, a pre-existing built environment, often with inadequate heating and cooling density, challenging legal frameworks and a limited understanding amongst professionals, community members and politicians.

Much of the work and effort to date on district energy has been responsive to a pre-existing built environment, primarily in the field of engineering, taking advantage of legacy density in the built environment and/or anchor loads. As the world continues to urbanize, there is an opportunity to ensure that district energy is a key consideration when providing infrastructure to rapidly growing cities. In part, this opportunity can be driven by a global imperative to reduce and/or eliminate fossil fuel combustion. The consideration of district energy can be enhanced if it is presented in the context of additional health, financial, transportation and quality of life benefits that accompany the types of land-use that enable it.

When considering the shape of the built environment to come, planners fill a critical role in ensuring that district energy is included in the toolbox, even if it is not installed as the built environment develops. The longevity of and capital investment in the built environment challenges future course deviations.

Planners are not engineers and their world is a complex world with many shades of grey and no clearly or easily definable solutions to wicked problems. As a result, a tool designed for a planner takes a very different form from a tool designed for engineers, as it must incorporate and embrace the fuzziness of the planning world. There is considerable work underway to illustrate, measure and model energy flows in the context of the built environment and the impact of building morphology, systems and proximity. Planners are uniquely positioned, with their continual focus on the future, to consider the energy implications of the built environment while integrating community growth, social and economic factors into the mix.


Arup. (2011). Climate action in megacities: C40 cities baseline and opportunites. C40 Cities Climate Leadership Group


United States Botanic Garden, the Lady Bird Johnson Wildflower Center at the University of Texas at Austin, and the American Society of Landscape Architects. (2014). Welcome to Sustainable Sites Initiative. Retrieved from http://www.sustainablesites.org/about


Van Dam, K. H., & Keirstead, J. (2010). Re-use of an ontology for modelling urban energy systems. Next


International Energy Agency
Energy Technology Initiative on District Heating and Cooling including Combined Heat and Power