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A greenhouse gas abatement framework for investment in district heating

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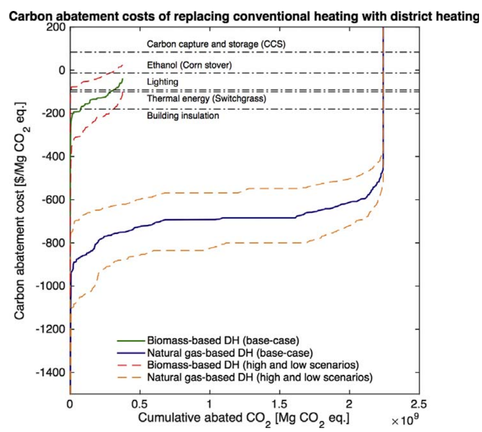
HIGHLIGHTS

- Method developed for categorizing the cost-effectiveness of district heating.
- Biomass and natural gas district heating effectively mitigate GHG emissions.
- District heating is competitive with other energy-saving building strategies.
- Performance of natural gas is highest due to efficiency in electricity generation.

GRAPHICAL ABSTRACT



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ABSTRACT

Biomass resources could be used in the Northeastern U.S. in centralized district heating networks supplied by combined heat and power (CHP) plants to reduce consumption of petroleum resources (fuel oil), generate renewable electricity, and cost-effectively reduce greenhouse gas (GHG) emissions when supplying buildings with space and water heating. Alternatively, the CHP plants could be powered by natural gas, which would reduce GHG emissions relative to conventional, individual heating solutions owing to the improved efficiency of co-generation. To assess the potential for investment in these technologies, hourly heat load demand in residential and commercial buildings in all New England and New York state towns (populations > 5000) was estimated and used to optimize the energy efficiency of district heating networks using MODEST software. All of the 116 studied locations without access to natural gas distribution infrastructure showed negative carbon abatement costs, the majority between −$250 and −$38 per Mg CO_2 equivalents (eq.), when biomass-fed district heating was implemented due to significantly reduced operational costs and life cycle GHG emissions. Similarly, almost all (465 out of 467) locations connected to the natural gas grid were found to have negative GHG abatement costs, ranging from −$4500 to −$400 per Mg CO_2 eq., demonstrating strong economic feasibility for district heating. Natural has an economic advantage over biomass in district heating due to its combined cycle CHP plants being able to generate more electricity per heat unit compared to biomass CHP plants and its lower O&M costs. District heating in all locations could abate 2.6 billion Mg of CO_2 eq. at an economic surplus over 30 ears of continuous operation. Using a framework that integrated spatial tools, optimization, LCA, and cost evaluation, this study uniquely identified promising locations in the U.S. where district heating could be both environmentally and economically beneficial. This framework can be applied to other global regions that have significant space heating needs, for CHP implementation, and as a tool for identifying alternative building

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energy investments, such as improved insulation or individual space heating solutions, which in some cases could yield higher GHG reductions per dollar.

1. Introduction

Many areas of the northeastern United States lack connectivity to natural gas distribution infrastructure, and thus rely on fuel oil or biomass to fulfill household space-heating needs. Large scale centralized heating is typically more efficient than household (small) scale heating and can potentially reduce the cost and environmental impact of space heating [1]. While many European countries have invested in centralized heating, the benefits of the technology have not been fully realized in North America, even in climates with high year-round space heating needs. However, in recent years select small-scale district heating (DH) projects that use locally available biomass have emerged in small towns in New England [2,3]. Biomass-fed DH systems could be a sustainable solution for reducing greenhouse gas (GHG) emissions and for diversifying energy supply in remote areas of the United States that are largely liquid fuel dependent. Natural gas CHP plants enable efficiently producing heat and electricity simultaneously. DH is a long-term investment for space-heating that can use multiple fuel sources and hence can be altered as technologies evolve [1]. Examples of this include gasification of biomass [4] and the possibility of connecting solar thermal energy plants to an existing DH grid [1].

Whereas most DH systems in Europe use new hot water-based systems, the majority of existing DH systems in older US cities such as New York and Boston are steam-based [5]. An exception is St Paul, MN, which invested in a wood residue-fed 25 MW_e CHP plant that heats 80% of commercial, residential, and industrial buildings in central parts of the city [6]. Overall expansion of DH in the US has been slow since the 1950s, with total supply of DH and cooling systems making up less than 5% of the total heating and cooling load [7]. In spite of this, in recent years some DH projects have been launched, for example in Montpelier, VT where one DH project led to many inner city buildings being connected to a DH system based on wood-fired boilers [2]. However, in Greenfield, MA, several proposed biomass-based DH projects were not competitive with current oil prices [3]. None of the proposed projects considered designing a CHP plant able to generate and sell electricity to the grid.

Several studies have previously looked at the potential of DH in the US. Ulloa [7] specifically drew a connection to the transfer of learning from European experience with DH through examining the economics of combining waste incineration with DH in the northeastern US, and concluded it was cost-effective in the denser locations considered. Reber et al. [8] looked at geothermal heat and DH, and found it potentially cost-effective in many counties in New York and Pennsylvania, but would require small technological improvements. Gils et al. examined the total potential of DH in the US and concluded it was especially attractive in the northeastern regions [9]. Hendricks et al. concluded that heat-only biomass-based district heating could potentially replace fuel oil-based space heating in 8 out of 10 studied rural villages in New York state, while reducing overall heating expenses [10].

Several studies also show the potential and place of DH in future energy systems, if adapted to include multiple energy sources for cost-effective heat production and distribution [11–14]. More recently, a review of DH case studies by Lake et al. found that DH typically adapts to its surrounding heat supply options and utilzes increasing proportions of renewable energy sources, while optimizing the system's economics [15]. By optimizing DH supply in a Danish city, Amer-Allam et al. concluded that GHG emissions could decline by up to 95% by 2030, while simultaneously reducing costs [16]. Rismanchi argues that next generation DH networks with integrated thermal storage for optimizing heat supply and demand could improve energy efficiency in future growing urban areas [17]. A Swedish case-study by Weinberger et al. argues for optimizing DH systems with process steam needs and industrial waste heat according to which is most cost effective [18]. Directing DH investment effort in order to simultaneously use optimal energy resources and cost effectively mitigate GHG emissions requires tools for integrating these goals into decision making. A challenge to the development of such tools is that many parameters that strongly influence the viability of DH, such as density of development and the heat demand of specific buildings, are inherently small-scale (building-level and block-level characteristics). Detailed small-scale information of this type is increasingly available, but the relevant information is often scattered across different databases. This study develops a framework for pulling together information from diverse sources in order to develop location specific assessments of the viability for DH. The goal is not to replace engineering design studies but rather to cost-effectively screen locations to identify those where the considerable investment in an engineering feasibility study is most likely warranted.

New York State and New England serve as example applications of this framework. Given that space and water heating dominates residential energy use in New York and New England (Fig. 1) [20], and the two regions combined account for 85% of US heating oil consumption [21], there is great potential to both improve the environmental performance and cost of space heating by examining the cost effectiveness of DH investment with fuels available in the region, including biomass resources and the burgeoning natural gas supply in western and southern parts of the region (Fig. 2) [22].

The framework developed by this study evaluates the potential of

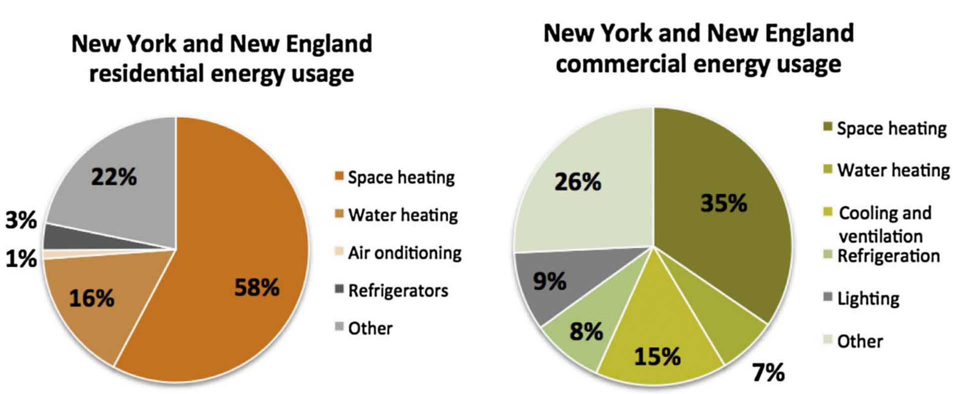

Fig. 1. Residential and commercial energy usage in New York and New England. Space and water heating make up 74% of total energy use and 42% of commercial energy use [19,20].