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Developments to an existing city-wide district energy network – Part I: Identification of potential expansions using heat mapping

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ABSTRACT

District heating can provide cost-effective and low-carbon energy to local populations, such as space heating in winter and year-round hot/cold water; this is also associated with electricity generation in combined-heat-and-power systems. Although this is currently rare in the UK, many legislative policies, including the Renewable Heat Incentive, aim to increase the amount of energy from such sources; including new installations, as well as extending/upgrading existing distributed energy schemes. Sheffield already has an award-winning district energy network, incorporating city-wide heat distribution. This paper aimed to demonstrate the opportunities for expansions to this through geographical information systems software modelling for an in-depth analysis of the heat demands in the city. 'Heat maps' were produced, locating existing and emerging heat sources and sinks. Heat loads (industrial, commercial, educational, health care, council and leisure facilities/complex) total 53 MW, with existing residential areas accounting for ~1500 MW and new housing developments potentially adding a further 35 MW in the future. A number of current and emerging heat sources were also discovered – potential suppliers of thermal energy to the above-defined heat sinks. From these, six 'heat zones' where an expansion to the existing network could be possible were identified and the infrastructure planned for each development.

1. Introduction

Combined-heat-and-power-based (CHP) district/community heating schemes can have a range of benefits. Firstly, the co-/tri-generation technologies utilised make use of 'waste' process heat, meaning they operate at higher efficiencies so more energy is recovered; this decreases both fuel consumption and pollutant generation for the same energy output and consequently helps achieve CO_2 emission-reduction targets and also aids resource conservation. This is particularly true if low-carbon, renewable/sustainable fuels, like biomass or wastes are used. Secondly, these systems are able to provide cost-effective energy to local populations, in terms of electricity, space heating/cooling and hot/cold water. Due to the higher efficiencies, often lower environmental impacts and customer benefits, increasing the amount of heat generated through distributed energy, namely district heating, can be both a sustainable and secure means of meeting the local heat demand. Historical evidence shows that both energy and heat demands increase with propensity and development. More housing stock using better insulation and other energy efficiency measures however will start to reverse this trend; the implementation of new European legislation concerning energy performance in buildings will also mean heat demands will eventually decrease.

There are also disadvantages to such schemes. The main issue is that a heat distribution network is needed to dispense the energy from the plant to the end-users. Not only can this be expensive, but can also be difficult to retrofit into existing buildings.

1.1. District heating legislation

There are vast amounts of legislation and policies that govern energy generation, especially sustainable/renewable energy targets; related to these are climate change regulations, detailing CO_2 reductions. These often have similar goals, or at least the same means of achieving their outcomes. District heating, one form of decentralised energy, is regulated by several policies: many European Community and UK Energy White Papers, the 2008 Community Energy Saving Programme (CESP), Renewable Energy Strategy (RES), Renewable Heat Incentive (RHI) and the forthcoming Heat and Energy Saving Strategy (HESS). In general, these aim to support

Abbreviations: CESP, Community Energy Saving Programme; CHP, combined heat and power; GIS, geographical information systems; HESS, Heat and Energy Saving Strategy; RES, Renewable Energy Strategy; RHI, Renewable Heat Incentive.

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district heating networks and their development, through specific government authorities; often providing financial incentives.

There have been a series of Energy White Papers [1–3], which state that district heating needs to be promoted, particularly when fuelled by low-carbon local resources, like biomass and waste, that can promote the use of renewable fuels. Using fewer carbon-intensive generation techniques and district heating technologies that increase energy efficiency can help to significantly decarbonise heat generation. It is important to capitalise on such schemes, especially where they have financial benefits. CESP aims to lower energy/fuel bills for those in areas of low income, specifically by improving energy efficiency [4,5]. In some cases, this may result in the implementation of, connection to, upgrading and/or improvement of a district heating scheme. One of the four primary measures in the 2009 UK RES is the introduction of a 'clean energy cash-back' for those generating renewable heat and/or small-scale, clean electricity; this aims to support distributed and community-based power [6]. The recently implemented RHI offers financial support for the installation of renewable heat technologies, such as district heating [7,8]. Different monetary support levels are offered for different scales of heat production and also for different heat generating technologies. A key policy proposal for HESS, to be introduced within the next few years, is the focus on district heating in suitable communities [9]. This aims to identify areas where district heating can be economically-viable – namely where the heat density is great enough (>3000 kW/km^2, designated areas of high heat density). In these, it is thought that a 6% return on investment could be achieved. In the UK, if district heating was utilised in all areas with a high heat density, this would account for 5.5 m properties and contribute 20% of the overall heat demand. Large, high-efficiency natural gas-fired cogeneration district heating schemes would result in CO_2 savings of 9.8 m t/a; replacing gas with biomass could further minimise CO_2 emissions (~19.3 m t/a).

1.2. The national picture: district heating in the UK

The UK has one of the most developed and liberalised electricity markets but the amount of decentralised energy is low. Toke and Fragaki [10] stated that the use of cogeneration and district heating is negligible, even though the potential is vast and there are specific government targets, considered above. Although in the long-term district heating can be competitive with other energy supplies, in the short-/medium-term, the economic risks, regulatory uncertainties and 'lock-in' of existing technologies can, and have, considerably restrained such developments [11].

1.3. A city focus: district heating in Sheffield

Despite the limited amounts of decentralised energy in the UK, the north of England has several distributed systems. Sheffield has an extensive, award-winning district energy network, incorporating electricity generation and community heating; this is operated by Veolia Environmental Services in conjunction with Sheffield City Council. The primary energy facility for the network combusts ~225,000 t/a of local residual/non-recyclable municipal waste to cogenerate 60 MW of thermal energy for district heating and 21 MW of electrical energy, which is fed into the National Grid [12]. There are over 140 buildings served by this, including shops, hospitals, hotels, commercial/council offices, leisure facilities and the majority of both universities in the city; additionally, almost 3000 residential environments are connected [12]. In total, 120,000 MWh/a of heat is delivered to these buildings, which prevents the release of ~21,000 t/a of CO_2 to the atmosphere, when compared to conventional heat generation. Established in 1988, this district energy network is not only the largest in the UK, but also the most successful [12].

This system clearly provides a number of environmental and economic benefits, through the generation of low-carbon, low-cost energy for local populations. There are however a number of reasons to expand this network. The rationale for this investigation, and thus also for the expansions, is to:

- supply sustainable and secure energy to the city,
- provide reasonably-priced heat, critical to the fuel poverty agenda,
- reduce carbon emissions, helping Sheffield become a low-carbon city,
- help meet national/international legislation regarding renewable/sustainable energy and carbon emission reductions (e.g. RES, UK Low Carbon Transition Plan and Carbon Reduction Framework among others),
- generate heat in proximity to where it can be used,
- be a 'landmark' city to encourage further decentralised energy deployment in the UK.

1.4. Recent developments in district heating

Several recent papers [13–19] have outlined various developments in the field of district heating. Lund et al. [13] contemplated its role in future renewable energy systems, in terms of fuel demand, carbon emissions and costs. Currently, ~46% of the net heat demand in Denmark is met by district heating. They determined the best solution here was gradual expansions of district schemes (to 63–70%), with small-scale heat pumps for homes in more remote areas – this would be valid for both fossil- and renewably-fuelled systems.

Many have investigated changing the fuel and/or process used for district heating. Egeskog et al. [14], for example, assessed the possibility of biomass-gasification-based cogeneration of biofuels for both transportation and district heating in the EU. Kalina [15] examined the technical and economic benefits of retrofitting a municipal coal-fired heating plant with integrated biomass steam-gasification cogeneration. This would result in reductions of both emissions and fossil fuel consumption, with significant energy savings. The economic feasibility was evaluated and showed that such projects can be financially-attractive with monetary support. The integration of cooling cycles into CHP systems (trigeneration), via absorption chillers/heat exchanges have also been investigated to enhance efficiency, economics and primary energy savings [16,17].

Cakembergh-Mas et al. [18] and Knutsson et al. [19] used simulation-based approaches to model such systems. The former used a mixed integer linear programming optimisation model for an economic assessment of a Kraft mill, whilst the latter developed a new model (HEATSPOT) for the analysis of district heating at an aggregated national level. The use of other modelling/simulation techniques and tools, such as geographical information systems (GIS), is now starting to be used within this field, to aid decentralised energy developments, as considered in Section 2.1.

1.5. Research objectives

This research has been divided into two main areas. The first was to investigate potential expansions of Sheffield's existing district energy network via heat mapping, detailed herein (Part I). The primary objectives were: (i) to produce heat maps for thermal energy sources and sinks in the city; (ii) to link these heat sources and sinks, thus identifying 'heat zones' – areas where an extension to the network may be possible; and (iii) to outline/plan the infrastructure for each development. Secondly, the economic and