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An analysis of heating energy scenarios of a Finnish case district

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ABSTRACT

District heating is widely used in heating buildings in Finland. Due to new European legislation, increasing adaption of renewables, and new stakeholders in the heating business, Finnish district heating needs to evolve. This paper analyzes energy and emissions impacts of different heating energy scenarios in a typical Finnish district heated area. A period of 20 years (2015–2035) was studied assuming the future development of the building stock.

The conservative, extensive and extreme scenarios assumed different amounts of solar energy and ground source heat pumps to be implemented as decentralized systems. In addition, two heat prosumer scenarios were analyzed, namely an industrial waste heat scenario and a modest solar heat prosumer scenario.

Despite the increase of the buildings' total floor area by about a third, the combined heating and domestic hot water consumption per floor area was estimated to decrease by about 36%. The extreme scenario with ground source heat pumps and a solar thermal system decreased the annual centralized heat production by 34% and the industrial waste heat scenario by 32%. The waste heat scenario decreased the emissions the most.

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1. Introduction

According to the Energy Year 2014 (data retrieved by Statistics Finland (2015)), 33.3 TWh of district heat was consumed in Finland, of which 55% was consumed in residential buildings, 10% in industrial buildings and 35% in other buildings. Approximately 69% of the net production was produced in combined heat and power (CHP) and 31% in district heating plants. Nearly a third (32%) of district heat was produced from wood residues and forest chips, 21% from coal, 19% from natural gas, and 16% from peat (Statistics Finland, 2015).

In Finland, every building connected to a district heating system has an individual substation (Sipilä, Nuorkivi, & Pietiläinen, 2016). This includes at least two heat exchangers, circulation pumps, automatic control and metering systems and other equipment. The heat exchangers are used for space heating and for domestic hot water. Sometimes, there may be third heat exchanger, for ventilation system (Sipilä et al., 2016). The domestic hot water (DHW) must be supplied at a minimum of 55 °C (Ministry of the Environment, 2007).

In Finland, the number of clients connected to district heating has been increasing steadily since the 1970s. Still, the specific annual heat consumption in district heated buildings has been continuously decreasing and it was about 130 kWh/m^2, a on average in 2015 (Energiateollisuus ry, 2016). Considering the Finnish building stock as of 31.12.2015 (Statistics Finland, 2016b), 78% of the apartment buildings, 45% of the attached houses, and 6% of the detached houses were connected to district heating. In 2015, 45% of the total buildings gross floor area and 39% of all the residential gross floor area was heated with district heating.

Internationally, district heating is heavily evolving and it is boosted by the adoption of renewable systems (H. Lund, Werner et al., 2014). Denmark has a political goal that all electricity and heat supply shall be based on renewable energy by 2035 (Danish Energy Agency, n.d.). This has encouraged both research (e.g., (Alberg Østergaard, Mathiesen, Möller, & Lund, 2010; Bach et al., 2016; R. Lund, Ilic, & Trygg, 2016; Tol & Svendsen, 2015)) as well as real experiments and pilots (e.g., (Čulig-Tokić et al., 2015; Olsthoorn,

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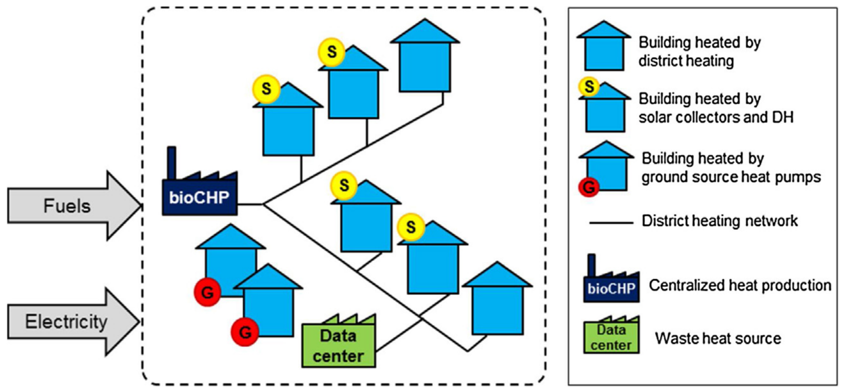

Fig. 1. The system boundaries.

Table 1
The CO_2 equivalent and particulate emission factors for the different heating alternatives (IINAS, 2016).

Energy form	CO_2e emissions [$kgCO_2$/MWh]	Particulate emissions [kg/MWh]
District heat	49	0.024
Electricity	345	0.05

Haghighat, & Mirzaei, 2016)) on Danish district heating. Even if every country is different, some of the Danish experiences can be adapted also elsewhere. In Germany, there are several districts where solar assisted district heating is used (e.g., (Bauer et al., 2010; Dan Bauer, Marx, & Drück, 2014)), typically in combination to seasonal thermal storage. In Sweden and in Canada, there are also district heating systems connected to solar heat production (e.g., (Lundh & Dalenbäck, 2008; Sibbitt et al., 2012)). All of these experiments exist in climatic conditions relevant to the Finnish ones.

Similarly, Finnish district heating is facing important challenges, since new European regulations are coming in to play affecting both energy generation methods and building energy efficiency (Paiho & Reda, 2016). It is expected that utilization of renewable energy will increase in Finland. According to a forecast made by Laitinen et al. (2014), the amount of installed heat pumps will increase by 140% by 2020 compared to the situation in 2010. The number of ground source heat pumps is expected to increase the most; by 320% compared to the situation in 2010. In 2014, only about 16 GWh of solar heat was produced in Finland (Statistics Finland, 2015). However, from the year 2004 the production was increased by 68%.

Perhaps one of the most unused resource in district heating is the utilization of industrial or commercial excess or waste heat. In 2014, only 0.6% of district heat in Finland was produced from industrial waste heat (Statistics Finland, 2015). Miró, Brückner, and Cabeza (2015) estimate that yearly industrial waste heat potential is 82 PJ (nearly 23 TWh) in Finland. According to a Swedish study (Ivner & Broberg Viklund, 2015), industrial excess heat in district heating can often be beneficial.

There is also a new stakeholder coming into the district heating business, called a "prosumer". The prosumer is a customer that both uses and supplies energy, such as electricity or district heat (Brange, Englund, & Lauenburg, 2016). In Sweden, the Stockholm city has opened its district heating network for all heat suppliers (Fortum, 2015). In addition, evaluations on the potential for district heating contribution from small scale prosumers, based on excess heat, in Malmö have been made (Brange et al., 2016). In Finland as well, first experimental tests on open district heating have started (Fortum, 2016). Other stakeholders of future energy systems as well as more information about Finnish building stock and heating can be found from a project publication (Paiho et al., 2016).

This study was motivated by a review of prospects of Finnish district heating (Paiho & Reda, 2016). It seemed evident that further analysis is needed especially regarding renewable technologies and prosumer options. This article aims to analyze different heating energy scenarios in a typical existing Finnish district heated area by means of energy and emission impacts. The focus is on increased share of ground source heat pumps (GSHP), solar thermal collectors (STC) and different heat prosumers within the district heated area. The intention is to resolve impacts of potential, realistic and industry-identified scenarios to develop heating of an existing Finnish district. The focus is on possible alternatives, which could be replicated elsewhere, to evolve a typical existing district heating network towards an open heating market.

2. Material and methods

A typical existing Finnish area heated with district heating was selected for the study. The study was made by simulating selected scenarios. Scenarios for the future development of the case area's district heating system were selected in order to examine different possible development pathways and to compare their technical performance and environmental impacts. In the scenarios, the focus was on the demand side of the district heating network and the actions and choices made by the end users of energy.

The scenarios were simulated using the APROS software (Fortum & VTT, n.d.), which is a dynamic simulation software developed by Fortum and VTT. More details on APROS thermal hydraulic flow models are available at (VTT Technical Research Centre of Finland, n.d.). APROS is a wide software, which enables investigation of the system operation under varying process conditions. For example Suojanen, Hakkarainen, Tähtinen, and Sihvonen (2017) present modelling with APROS. The number of consumer types (heat load types by profile) were three: buildings of types: residential, office and public. There were 25 connection points of consumption. The simulations provided a deeper understanding about the physical energy system behavior. The simulation model comprised a district heating network in the case area and the buildings connected to it as points of aggregated consumption. In addition to district heating, the model also provided the opportunity to use either ground-source heat pumps or solar thermal collectors to cover the building's heat demand. The simulations provided data, describing the energy consumption in the area and the energy technologies used to cover the heat demand. Each building's demand was also simulated and depended on outdoor air temperature, internal heat gains (different by building type) and properties of building envelope, which were set in scenarios. Orientations of buildings of the same type were the same.

A period of 20 years (2015–2035) was studied. The simulation results were used to compare the scenarios against each other and

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