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Industrial excess heat for district heating in Denmark

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HIGHLIGHTS

- Method for utilisation potential of industrial excess heat for district heating.
- Industrial excess heat from thermal processes is quantified at single production units.
- Linking of industrial excess heat sources and district heating demands done in GIS.
- Excess heat recovery using direct heat transfer and heat pumps.
- 5.1% of the Danish district heating demand could be supplied by industrial excess heat.

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ABSTRACT

Excess heat is available from various sources and its utilisation could reduce the primary energy use. The accessibility of this heat is however dependent amongst others on the source and sink temperature, amount and potential users in its vicinity. In this work a new method is developed which analyses excess heat sources from the industrial sector and how they could be used for district heating. This method first allocates excess heat to single production units by introducing and validating a new approach. Spatial analysis of the heat sources and consumers are then performed to evaluate the potential for using them for district heating. In this way the theoretical potential of using the excess heat for covering the heating demand of buildings is determined. Through the use of industry specific temperature profiles the heat usable directly or via heat pumps is further found. A sensitivity analysis investigates the impact of future energy efficiency measures in the industry, buildings and the district heating grid on the national potential. The results show that for the case study of Denmark, 1.36 TWh of district heat could be provided annually with industrial excess heat from thermal processes which equals 5.1% of the current demand. More than half of this heat was found to be usable directly, without the need for a heat pump.

1. Introduction

District heating has played an important role in the Danish energy past and it can be expected that it will be important in the future as well. After the First Oil Crisis in 1973, district heating based on Combined Heat and Power (CHP) plants was one of the instant measures to fight the crisis and increase the overall system efficiency. Over the last four decades, the share of District Heating (DH) for domestic heating in the country grew from 28% in 1972 to 54% in 2015, thus becoming the dominant means of supply. In the same period the share of CHP plants in the district heating production increased from 28% to 67%, while the share of renewable energy in DH grew from close to 0% to up to 48%. The share of excess heat utilised for the supply of DH in 2015 was 2% [1]. Seen from the EU perspective, Denmark has the second highest share of citizens supplied by DH and the highest trench length of DH pipeline system in the EU [2]. The long term goal in the Danish society is to become 100% renewable in all sectors of the energy system before 2050 [3,4]. Several studies agreed that district heating should be one of the main elements of the future Danish energy system. The potential role of industrial excess heat for DH production is either not analysed or it is not emphasised in these studies.

Münster et al. [5] analysed three scenarios for the Danish energy system in 2025 and concluded that district heating should be expanded to cover between 55% and 57% of the heating demand. Different mixes of fuels and technologies are found to be optimal in different scenarios, but industrial excess heat was not a part of the mix in any of the scenarios. Lund et al. [6] analysed a future 100% renewable Danish energy system. Their analysis shows that it would be optimal to expand district

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Nomenclature

T	temperature, °C
ΔT	temperature difference, K
η	efficiency, –

Abbreviations

CHP	combined heat and power
COP	coefficient of performance
CVR	central company register
DH	district heat
DKE	Denmark East
DKW	Denmark West
EH	excess heat
EPRTR	European Pollutant Release and Transfer Register
ETS	Emission Trading Scheme
GIS	Geographic information system
HD	Heating Demand
HP	heat pump
yr	year

Subscripts

DH	district heat
DIR	direct
EH	excess heat
HP	heat pump
min	minimum
notDH	not district heating

heating to between 63% and 70% of the future heating demand. Even though excess heat is mentioned as a way to reduce fuel input and district heating is emphasised as a crucial medium for utilisation of excess heat, the role of excess heat was not analysed in more details. Möller and Lund [7] investigated the expansion of district heating into natural gas areas and recommended to expand district heating to cover between 50% and 70% of the future heating demand. They have assumed that excess heat can cover between 83 GWh and 153 GWh of the net heating demand each year; this assumption is not elaborated further. Mathiesen et al. [8] proposed a vision of a 100% renewable Danish energy system in 2050 including a description of intermediate scenarios for 2015 and 2030. The proposed solution includes a drastic expansion of district heating networks until 2030. As a result, heat supply from district heating remains constant until 2050 despite significant heat savings. District heating is produced from biomass, solar heating, electric boilers and large-scale heat pumps, while industrial excess heat was not considered as an alternative. The limitation of biomass use for heating in a 100% renewable energy system was analysed by Mathiesen et al. [9]. Industrial surplus heat of 2.65 TWh/yr was included in the study and the results showed that it is economically feasible. It is also stated that district heating is important in 100% renewable energy systems as it allows the utilisation of, for instance, large-scale solar thermal plants, large-scale heat pumps and industrial surplus heat. To find the optimal heat supply for a housing community from the energy system perspective, Karlsson et al. [10] used the TIMES-DK model. District heating proved to be optimal from the system perspective in all analysed scenarios. In the scenario leading to a 100% renewable energy system before 2050, surplus heat from biorefineries contributed to district heating production in central[1] areas of East Denmark with around 4.2 TWh/yr after 2035. These biorefineries represent investments calculated by the model and do not currently exist in Denmark. In the analysis of energy scenarios up to 2020, 2035 and 2050 published by the Danish Energy Agency [12] industrial excess heat contributed to the production of DH with annually 0.89 TWh and 0.42 TWh in central and decentral DH areas, respectively. Despite the existing and possible future potential of excess heat contributing to the supply of district heat, only a few works have thoroughly studied it. From the studies [6,7,9,10,12] it can be further concluded that industrial excess heat brings socio-economic benefits, improves energy system efficiency and reduces primary energy demands. Since these benefits are generally desired, utilisation of EH for DH could also be interesting in countries and regions outside of Denmark.

Several studies aimed at quantifying industrial Excess Heat (EH), also referred to as waste heat, and their theoretical utilisation potential, as well as the appropriate technologies. The study by Miró et al. [13] quantified the excess heat for different countries and regions. On the European level, Naegler et al. [14] quantified the industrial heat demand by branch and temperature level. This work provides useful information for further analyses of EH in Europe. The methods used to estimate the excess heat potential of regions, were categorised and reviewed by Brückner et al. [15]. The geographical locations of the heat sources were not specifically taken into account, however size parameters for companies (e.g. number of employees) were used in the classification. Brückner et al. [16] further investigated the utilisation of EH for residential heating in an urban neighbourhood. The authors concluded that the heating demand of the area cannot be covered by EH sources within its border. Excess heat should however still be accounted for when refurbishing buildings.

For Sweden, Broberg et al. [17] estimated the industrial excess heat potential for district heating networks and showed how EH investments could become profitable. Viklund and Johansson [18] reviewed the technologies for the utilisation of EH and estimated their potential for a region in Sweden. The results showed that a high potential was found for DH, considering only heat sources above 95 °C and no heat pumps. An analysis by Hammond and Norman [19] showed the heat recovery opportunities in the UK industry. The authors estimated the potential of excess heat from 11 industrial sectors and, based on the excess heat temperatures, showed the utilisation potential for different technologies. In addition, an analysis of heat transportation between sites with surplus heat and heating demand was performed. Another study for the UK [20] investigated the potential of using industrial excess heat for district heating. An assessment of the potential based on transmission distances was performed and it was found that approximately one third of the UK excess heat could be used for DH. A relevant study for the present work was performed by McKenna and Norman [21], where a spatial model of industrial heat loads and technical recovery potentials in the UK were presented. This study analysed heat loads and EH, grouping them into different temperature bands and estimating the recovery potential. The distribution of the heat was done mainly by site allocation based on the EU Emission Trading Scheme (ETS). The results show the geographical distribution of needed and rejected heat by industrial sector and temperature interval.

Persson et al. [22] presented a methodology to assess annual excess heat volumes from fuel combustion activities in energy and industrial facilities based on CO_2 emission data from the European Pollutant Release and Transfer Register (E-PRTR). This study was performed on the EU level. Their results show that the theoretical excess heat from industrial facilities in Denmark amounts to 3.4 TWh per year. This

[1] In the Energy Producers Count by the Danish Energy Agency [11] district heating producers are grouped into central and decentral. Central and decentral plants supply central and decentral DH areas, respectively. The central DH areas have higher heating demands, installed capacities and transmission efficiencies compared to decentral DH areas.