Energy xxx (2016) 1–10

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Mapping of potential heat sources for heat pumps for district heating in Denmark

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ARTICLE INFO

Article history:
Received 1 October 2015
Received in revised form
14 December 2015
Accepted 20 December 2015
Available online xxx

Keywords:
Heat pumps
District heating
Heat sources
Waste heat
Mapping
Geographic information system

ABSTRACT

The ambitious policy in Denmark on having a 100% renewable energy supply in 2050 requires radical changes to the energy systems to avoid an extensive and unsustainable use of biomass resources. Currently, wind power is being expanded and the increasing supply of electricity is slowly pushing the CHP (combined heat and power) plants out of operation, reducing the energy efficiency of the DH (district heating) supply. Here, large heat pumps for district heating is a frequently mentioned solution as a flexible demand for electricity and an energy efficient heat producer. The idea is to make heat pump use a low temperature waste or ambient heat source, but it has so far been very unclear which heat sources are actually available for this purpose.

In this study eight categories of heat sources are analysed for the case of Denmark and included in a detailed spatial analysis where the identified heat sources are put in relation to the district heating areas and the corresponding demands. The analysis shows that potential heat sources are present near almost all district heating areas and that sea water most likely will have to play a substantial role as a heat source in future energy systems in Denmark.

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1. Introduction

Large-scale introduction of RE (renewable energy) sources for electricity production, such as wind or solar power, increases fluctuation in the supply and reduces the general price level of electricity because of the low marginal production costs of these producers [1]. In Denmark, the development of the electricity prices means that CHP (combined heat and power) plants has fewer operating hours than earlier. In Fig. 1 it can be seen how wind power is increasing and the production from small-scale CHP is decreasing to about one third in ten years. The production on large-scale CHP units is relatively constant even though its production capacity is decreasing in the same period [2].

The decreasing electricity production from CHP units also gives a lower heat production for the district heating (DH) supply and this deficit in heat production needs to be produced from other sources [3]. In the short term, fuel boiler units increase their production, which is an inefficient use of energy resources. In the longer term, other sources, such as solar thermal, geothermal and heat pumps, are predicted to play a larger role in the DH supply, and these have been increasing over the last years [4].

1.1. Heat pumps as a solution

Large-scale compression heat pumps in particular have several benefits for DH production in the future; they can consume electricity when the wind and solar production is high and they produce heat, which can replace the production by fuel boilers. Heat pumps as integrated production units in DH systems can provide a stable and efficient heat supply [5], but it is dependent on a heat source. Compression heat pumps contain a refrigeration cycle that enables cooling of a low-temperature heat source to deliver heating at a higher temperature level using electricity in a compressor to drive the system. The temperature, flow, volume and other parameters of the heat source will determine the possible efficiency. The required supply temperature from the heat pump will depend on the temperature level of the DH network to where the heat pump will be supplying. The higher supply temperature needed from the heat pump, the lower efficiency. Therefore, reducing the

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http://dx.doi.org/10.1016/j.energy.2015.12.127
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Please cite this article in press as: Lund R, Persson U, Mapping of potential heat sources for heat pumps for district heating in Denmark, Energy (2016), http://dx.doi.org/10.1016/j.energy.2015.12.127

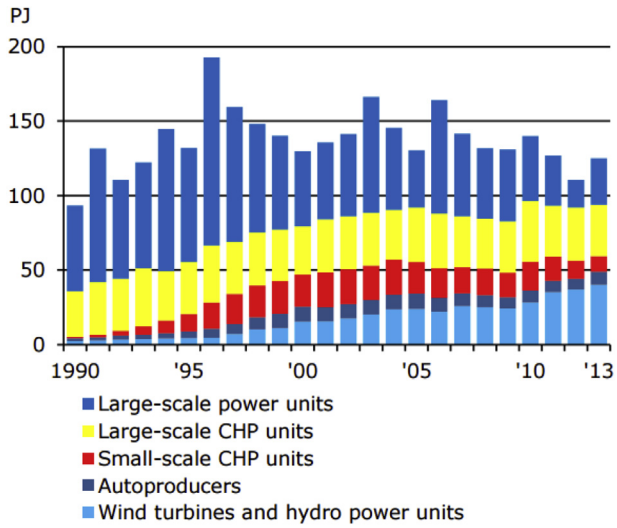

Fig. 1. Electricity production by type of producer. From the Danish annual energy statistics 2013 [2].

temperature levels of DH networks will increase the efficiency of using low-temperature heat sources via heat pumps. 4th generation district heating (4DH) is a concept that highlights the need to reduce the temperature levels of DH networks to adapt them to future energy systems with high shares of RE where large-scale heat pumps play an important role [6].

1.2. Heat pumps in national scenario analyses

Heat pumps are often included as part of future energy scenario analyses for Denmark, because of their ability in integrate wind power, for example in Ref. [7] where a 100% renewable energy scenario for Denmark is presented or in Ref. [8] where three different scenario for the future energy supply in Denmark is compared. In recent scenario analysis from the DEA (Danish Energy Agency) [9] heat pumps also play a central role. These scenarios suggest different levels of heat pump integration, but in general higher shares of wind power correlates with higher integration of heat pumps. None of these studies have considered which heat sources to use or if there are heat sources available to cover the assumed capacities and production or where these are located compared to the heating demands.

1.3. Studies of heat sources for heat pumps

A literature review shows that a large number of studies analyse the use of heat pumps in concrete cases to utilise waste heat or low-temperature heat sources in connection with DH supply.

In Ref. [10] it is suggested to use a combination of different waste heat sources (sewage water, surface water, ground water and others) for DH supply using distributed heat pumps, and concludes that this will increase the system efficiency significantly. A study on utilisation of low-temperature industrial excess heat [11], compares application of different types of heat pumps for the purpose and concludes that the different types of heat pumps are feasible for different applications. In Ref. [12] it is suggested to utilise the already existing waterborne urban infrastructure, such as sewage and drinking water, to recycle heat in the urban areas. A study has evaluated the operation of an existing DH system in Beijing, where a combination of ground water and sewage water as heat sources for heat pumps are applied, and suggested improvements of the system [13].

A case study has analysed the use of lake water in an open-loop as a heating and cooling source, analysing the coefficient of performance (COP) and the environmental impact on the lake ecosystem, showing that it is generally a feasible application [14]. In a similar study, seawater is analysed as a potential heating and cooling source assessing the environmental and economic impacts of the application, concluding that the application is a feasible alternative [15].

A number of studies have documented other potential heat sources, which may not currently be relevant in the Danish context, but will be in many other countries. Some examples of this are [16]: documents a large excess heat production from hydro power plants. In Ref. [17] it is described how thermal springs can be used as heat sources for heat pumps to provide comfort heating. And in Ref. [18] the potential in utilising the water in closed flooded coal mines are analysed and shown to be profitable and reducing CO_2-emissions.

These studies discussed here show examples of how different heat sources can be used for DH supply in specific cases where the particular heat sources have been identified, but no general resources mapping has been found for any of the heat sources, neither for Denmark nor from any other country. A few studies made by Danish consultancies have analysed the energy potential for certain heat sources relevant for heat pumps in Denmark. One is carried out by PlanEnergi with a focus on large scale thermal storage and heat pump technology for district heating [19]. Another one done by Viegand & Maagøe with a focus on how excess heat in the industry can be utilised more efficiently internally or through DH [20]. None of these cover geographical correlation between heat source and heat demand nor do they make a full resource assessment, but rather an assessment of what is feasible from a business economic point of view on the short term. A thorough mapping and assessment of the heat from large-scale facilities has been made in connection with the Heat Roadmap Europe study [21], but this does not cover other low-temperature or ambient heat sources.

To provide the missing link between the national scenario analysis scale and political ambitions related to heat pumps and the possibilities with different heat sources, this study analyses the geographical relation between the potential heat sources and the demands in the DH networks. This will provide the basis for more qualified system analysis and potential integration of heat pumps in Denmark. The mapping is specific for Denmark, but the methods for the mapping can be used for any country or region. The method can also be used for assessment for sources for district cooling, but in this case it will be necessary to consider other sources than included in this study.

2. Materials and methods

This study is an analysis of the availability of heat sources for heat pumps for application in the DH supply. It includes location of the heat sources relative to the DH networks and rough estimates of the potential energy production from the heat sources. Economic considerations on feasibility of the potential heat pump systems or specific technical or environmental limitations are not included here. A concrete project will always have to rely on a specific assessment of the local conditions.

This section presents the methods, which consists of two main parts; mapping and data collection.

2.1. Mapping methods

The idea of mapping is to find heat sources that are located near DH demand. Heat sources that are far from DH demand may in some cases be relevant to include, but in this study only the heat

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