Energy xxx (2017) 1–9

Contents lists available at ScienceDirect

Energy

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

The potential of power-to-heat in Swedish district heating systems

Gerald Schweiger [a, c], Jonatan Rantzer [a], Karin Ericsson [a, *], Patrick Lauenburg [b]

[a] *Environmental and Energy Systems Studies, Department of Technology and Society, Lund University, PO Box 118, SE-221 00 Lund, Sweden*
[b] *Department of Energy Sciences, Lund University, PO Box 118, SE-221 00 Lund, Sweden*
[c] *AEE INTEC Institut für Nachhaltige Technologien, Feldgasse 19, 8200 Gleisdorf, Austria*

ARTICLE INFO

Article history:
Received 31 October 2016
Received in revised form
10 February 2017
Accepted 13 February 2017
Available online xxx

Keywords:
Power-to-heat
Flexibility measure
Sweden
District heating systems

ABSTRACT

The main challenge for future electricity systems is to match the available electricity from variable renewable resources with the electricity demand in place, time and quantity. One option for increasing electricity system flexibility is to integrate the electricity system with the district heating systems via the use of power-to-heat technologies such as electric boilers. The overarching objective of this paper is to increase the understanding of what role power-to-heat could have in Sweden and to contribute to the development of methods and tools that can be applied when analysing the potential of power-to-heat. For that purpose we estimate the technical potential of power-to-heat for different power scenarios and assumptions and identify key parameters which have significant impact on the potential. The calculations are based on hourly simulations of electricity production, electricity consumption and district heat load. The power-to-heat potential was estimated to 0.2–8.6 TWh, where the potentials at the higher end pertain to scenarios with high amounts of wind and solar power production (corresponding to 54–64% of electricity consumption). Access to thermal storage increases the potential of power-to-heat while the use of industrial waste heat and heat from waste incineration in the district heat load reduces the potential.

1. Introduction

The installation of wind power and solar power is growing rapidly in many countries around the world [14]. With the expansion of electricity production from variable energy sources such as wind and solar energy, other parts of the energy systems must become more flexible. There are a number of options for increasing electricity system flexibility, including increasing supply and demand flexibility, developing energy storage technologies and systems services and increasing the transmission capacity of the national grid and interconnections to other countries [17]. Demand flexibility may be facilitated by the integration of the electricity system with the heating and gas systems. Such integration offers an opportunity to increase the electricity consumption during hours of very high electricity production from variable electricity sources by producing heat (power-to-heat) or gas (power-to-gas). This paper focuses on power-to-heat, which refers to heat production from electricity through heat pumps or electric boilers, and the application of this technology in the district heating sector. However, power-to-heat could also be applied in buildings and industries with a demand for heat.

Power-to-heat is attracting growing interest in Europe (see for example Refs. [5,7,18,21]), especially in Denmark (see e.g. Refs. [16,20,23] and Germany (see e.g. Refs. [4,12]. The benefit of this technology is that it may reduce the need for curtailment and the hours of very low electricity prices while saving fuel in heat production [22]. Denmark and Germany, both of which feature a high percentage of variable, renewable energy sources in their electricity supply, have seen an increasing number of power-to-heat projects being realised over the past few years. These projects mainly involve investments in the district heating systems, but also some in industry [1]. In other countries with very limited use of district heating, the opportunity for power-to-heat may primarily lie in industry. A study concerning the Netherlands shows that there is a considerable potential for utilising power-to-heat in Dutch industry, but that the potential is limited in the district heating systems [13].

This paper focuses on Sweden, which similar to Denmark, has extensive district heating systems. District heat accounted for 58% of the energy supplied to buildings in Sweden in 2014 [28]. During the past few years there has been a considerable growth in wind

* Corresponding author.
E-mail address: karin.ericsson@miljo.lth.se (K. Ericsson).

http://dx.doi.org/10.1016/j.energy.2017.02.075
0360-5442/© 2017 Published by Elsevier Ltd.

power production in Sweden. In 2015 wind power accounted for 10% of the Swedish electricity production. Solar electricity production is still negligible [31], but has potential for future growth.

Several factors suggest that variable electricity production will expand considerably in Sweden over the coming decades. One important factor is the recent multi-party agreement which introduced a goal of 100% renewable energy sources in electricity production by 2040 [24]. Although the agreement states that the target should not be interpreted as an end date for nuclear power, it adds to the political uncertainty concerning the future of nuclear power which accounted for about 35% of Swedish electricity production in 2014 [31]. Nuclear power is furthermore fraught with high costs. Another factor is the falling costs of solar PVs and the customers' desire to produce their own electricity [15]. Sweden has by international comparison favourable conditions for integration of variable electricity production due to a robust transmission grid and large capacity of storage hydropower [35]. However, the ongoing development that suggests very high proportions of variable electricity production in Sweden and neighbouring countries within a few decades is raising concerns over future supply quality and security. This in turn motivates the analysis and development of flexibility measures [34].

Power-to-heat has so far received little attention in a Swedish context. One exception is Söder [35]; p. 33–38) who has estimated the technical potential of power-to-heat (as a flexibility measure) in the district heating systems to 1.2 TWh per year. That study was based on hourly simulations, the utilisation of electric boilers and a scenario with an annual solar and wind power production of 55 TWh. The heat from waste incineration and industrial waste heat was excluded from the district heat load which was simulated based on the load curve of Stockholm. Another example is Sköldberg et al. [30] who have done a case study on four district heating systems for which they analysed the impact of more variable electricity prices (as a result of high penetration of variable electricity production) on the operation of different heat production units and the choice of heat sources. Their results show that despite low electricity prices, the use of heat pumps and electric boilers increases only marginally due to the current tax on electricity consumption and the availability of low-cost waste heat from waste incineration and industries in the systems studied.

The overarching objective of this paper is to increase the understanding of what role power-to-heat could have in Sweden and to contribute to the development of methods and tools that can be applied when analysing the potential of power-to-heat. For this purpose this paper addresses the following questions:

i) What is the technical potential of power-to-heat in the Swedish district heating systems for different electricity scenarios, conditions and restrictions?
ii) Which conditions and restrictions have considerable impact on the power-to-heat potential?
iii) What is the economic potential of power-to-heat in the Swedish district heating systems for different electricity scenarios?

These questions are addressed by first designing three electricity scenarios and identifying conditions and restrictions to be investigated. Two of the electricity scenarios involve a considerable growth in electricity production from variable renewable energy sources, and thus imply a time perspective some decades ahead (for simplicity we refer to this time to be around 2050). We estimate the technical potential based on hourly simulations of electricity production, electricity consumption and district heat load. This approach was inspired by Böttger et al. [4] who have estimated the technical potential of power-to-heat in Germany. However, our study also involves further development of their methods in order to account for various restrictions and conditions. For example, we have developed a storage model in order to analyse the effects of access to thermal storage on the potential for power-to-heat. We estimate the economic potential based on a straightforward cost model.

This paper contributes to the research field by providing the first detailed study on the power-to-heat potential in Sweden for various conditions and restrictions. Moreover, unlike previous studies, this study is based on hourly simulations of all district heating systems using a GIS (geographical information systems) approach. The resulting GIS database, as well as the models (available as a Python library),[1] are publicly available for further investigation. Another novelty of this paper is that it presents the development and implementation of a storage model and storage strategy to analyse the impact of different storage sizes on the potential of power-to-heat.

2. Methodology

2.1. Technical potential - overall approach

The *theoretical potential* of power-to-heat is the annual district heat load for all district heating systems, since all this heat in theory could be produced from electricity. The current theoretical potential of power-to-heat in the Swedish district heating systems thus amounts to about 57 TWh which was the supply of district heat in 2014 [32].

In contrast, the *technical potential* specifies the amount of "surplus electricity" that can be converted to district heat load. A more appropriate term for "surplus electricity" is negative residual load, which is used onwards in this paper. Negative residual load and other important concepts that are used in this paper are defined in Table 1. The technical potential only includes the negative residual load that is matched in time with the available district heat load, unless there is access to thermal storage.

In order to estimate the technical potential for power-to-heat we have to make a number of simplifications and rough assumptions. Three major simplifications are that we i) disregard the potential development of other flexibility measures than power-to-heat, ii) disregard the export and import of electricity, and iii) neglect bottlenecks in future power transmission and distribution networks. The last simplification implies that the geographical location of electricity production units and district heating systems is not taken into account.

The power-to-heat technology is assumed to be electric boilers which are cheaper, but less efficient than heat pumps. An argument for this choice is that the unit will only be operated at times of very high electricity production from variable renewable sources.

The sections below describe how we calculate the technical potential based on different electricity scenarios, conditions and restrictions. The calculations are carried out by first simulating the hourly district heat load and residual power loads for different scenarios. The district heat load and the negative power residual loads are then matched.

[1] The database (https://github.com/GersHub/P2HSweden) contains information on all Swedish district heating systems (production units, storage size/capacity, share of waste heat etc); data on outdoor temperatures in each county (to calculate the hourly heat load); data on the electricity system (hourly power consumption and power production for different technologies).