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Future power market and sustainable energy solutions – The treatment of uncertainties in the daily operation of combined heat and power plants

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HIGHLIGHTS

- Increasing renewables make electricity system balancing increasingly important.
- Small-scale combined heat and power plants can provide electricity system balancing.
- Plants are experiencing decreasing feasibility of combined heat and power units.
- We simulate a small-scale district heating plant with solar collector fields.
- Providing electricity system balance can increase feasibility of small-scale plants.

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ABSTRACT

Intermittent renewable energy sources (RES) are increasingly used in many energy systems. The higher capacity of intermittent RES increases the importance of introducing flexible generation units into the electricity system balancing. Distributed district heating plants with combined heat and power (CHP) can provide this flexibility. However, in electricity systems with a high penetration of intermittent RES, CHP units are currently experiencing decreasing hours of operation, making it likely that existing CHP capacity will be phased out from the energy system. Furthermore, when the plants provide balancing for the electricity system, the complexity of their daily operation planning is increased. This article analyses and discusses how these units can improve their economic feasibility by providing balancing services to the electricity system, benefitting both each individual plant and the system as a whole. This is done by using the case of the Danish district heating plant, Ringkøbing District Heating, which has a relatively high capacity of solar heating installed and is located in an area with a high penetration of wind power. It is found that the plant can increase the economic feasibility of the CHP unit by participating in the electricity balancing tasks; however, it is uncertain whether the benefits are substantial enough to keep the distributed CHP capacity in operation.

1. Introduction

The transformation of the existing energy system into a future sustainable energy system imposes new challenges to the energy system. The increased capacity of intermittent renewable energy sources (RES) increases the need for flexibility in the energy system [1,2]. Lund et al. [3] found that district heating (DH) should have an increased interaction with the electricity system in future sustainable energy systems, as DH can help integrate flexible solutions and improve the energy efficiency of the system. This is supported by studies of different countries energy system. Connolly and Mathiesen [4] present a pathway to a 100% renewable energy system, using Ireland as a case. In the pathway DH is utilized with a high degree of interaction with the electricity system. The Danish governmental appointed Commission on Climate Change [5], The Danish Society of Engineers [6], Lund et al. [7] and Münster et al. [8] all investigate the role of DH in future sustainable energy system in Denmark. They all find that DH should play an active role and have an increased interaction with the electricity system. Liu et al. [9] investigate the ability of the Chinese energy system to

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integrate wind power, and finds that an increased interaction between DH and the electricity system can greatly increase the ability to integrate wind power. DH is a system which allows the distribution of heat produced centrally through a network to end consumers in larger areas. DH enables the use of a wider variety of heat sources and an increased flexibility in heat production. Production units such as combined heat and power (CHP) units and heat pumps enable DH interaction with the electricity system, thus providing flexibility in the electricity system. These production units are found to be of increasing importance to the energy system and can also be useful in other connections than DH, such as desalination [10].

An increasing capacity of intermittent RES will increase the need for balancing the electricity system [11,12], and it becomes increasingly important to have flexible generation units participate in this balancing [13,14]. Sorknæs et al. [15] show that wind power can provide some balancing through a balancing market; however, this is expected only to be relevant in relatively few cases. Balancing has traditionally been provided by large production units, such as hydro power and steam turbines based on fossil fuels and nuclear power. As many of the large production units are inflexible by design, it is expected that these will become unfeasible with a high penetration of intermittent RES in the energy system [16]. As these large units leave the system, flexible distributed generation units will be needed to provide a larger share of the balancing. Here, the distributed DH plants can play an important role. However, it is also expected that buildings will become increasingly energy efficient [17,18], resulting in lower heat demands. This in turn will reduce the hours of operation of the DH production units [19]. It will still be possible to have a stable or increasing DH demand in areas, where the DH demand can feasibly be increased by connecting new buildings to the DH system, to an extend where it makes up for the heat demand reduction from improved energy efficiency of buildings. However, this will not be possible in all areas [20]. As the hours of operation are reduced, it will become even more important for DH plants to increase the value of each hour of operation to cover the long-term marginal costs. This can be done by, for example, increasing the value of traded electricity by selling or purchasing electricity at times when the electricity system needs it the most. A practice already utilized by many DH plants. Likewise, the DH plants can participate in the balancing of the electricity system to increase their income. Thus, providing electricity system balancing does not only benefit the electricity system as a whole, but can also benefit the individual DH plants.

As argued by Lund and Andersen [21], in the EU, distributed DH plants with CHP have undergone a change in the interaction with the electricity system. Lund and Andersen [21] define this change as a four-stage development; going from the first stage with electricity being settled by a fixed price and subsidy, to the last stage with electricity being settled on international electricity markets where fluctuating renewable energy has a major influence on the market price. This development also highlights the development of an increasing amount of uncertainties in the daily operation of a DH plant. This is especially the case of distributed DH plants with several production units or a thermal storage system, as these plants are flexible in terms of how and when the required heat is produced. In the earlier stages with a fixed price and subsidy, the electricity price was known weeks or months in advance. In the later stages, the electricity price is only known after the electricity trading has occurred, and then often for only the following 12–36 h on day-ahead wholesale markets. On intraday wholesale markets and balancing markets, the period can be even shorter. The participation on balancing markets introduces further uncertainty, as the dispatch on balancing markets is often not guaranteed and only known once the dispatch of the units has taken place. Further, the price on a balancing market is for some price structures settled after dispatch. Besides these uncertainties, the participation on different markets will often result in different gate closures for bidding, and an offer on one market could partly be based on the forecasts of prices on markets with later gate closure, which further complicates the daily operation. For distributed DH plants, these challenges are especially prominent, as these rarely have the manpower to analyse this on a daily basis.

These challenges are already visible in Denmark. Denmark has an extensive use of DH. In 2012, about 62% of all households were connected to DH. Likewise, the implementation of distributed CHP units in DH plants is relatively high. In 2012, 541 distributed CHP units accounted for about 13% of the total installed electric capacity in Denmark [22]. Danish CHP plants with a capacity larger than 5 MW_e have since 2007 been required to trade on market terms, and most of the distributed CHP plants in Denmark trade under market conditions [23]. Prior to being forced to assign to market conditions, the distributed CHP plants were managed according to the so-called triple tariff, where three different tariff rates are set according to Danish regulations [24]. Units smaller than 5 MW_e can choose to stay on the triple tariff until 2015 [23]. The triple tariff operates with low payments for electricity in the weekend, and this originally incentivised the plants to acquire thermal storage systems that could store heat from the CHP through the weekend. Therefore, the distributed CHP plants in Denmark have for the most part installed thermal storage systems. More detailed overviews of the Danish incentive policies for CHP in DH and RES can be found in Sovacool [25], Hvelplund [26] and Chittum and Østergaard [27].

Besides the development of the distributed CHP plants, a large share of RES in the form of wind turbines is installed in the Danish electricity system. In 2013, wind power production accounted for 33.8% of the total electricity production in Denmark [28]. Like the distributed CHP plants, a large share of the Danish wind turbines trade under market conditions and their production directly affects the market price. Thus, increased wind power penetration has proven to decrease the market price [29]. Denmark is an integral part of the power exchange Nord Pool Spot. The Nord Pool Spot area covers Denmark, Estonia, Finland, Latvia, Lithuania, Norway and Sweden. The Nord Pool Spot area is geographically divided into smaller bidding zones, where prices are settled separately when bottlenecks occur between the bidding zones. The Danish electricity system is divided into two bidding zones, Western Denmark (DK1) and Eastern Denmark (DK2). These are interconnected to Continental Europe and the Scandinavian Peninsula, respectively [30]. Most of the Danish wind power is produced in DK1. In the last couple of years, the average wholesale electricity price in DK1 has decreased from a peak of about 48 EUR/MW h in 2011 to about 39 EUR/MW h in 2013. Likewise, the number of hours with high electricity prices has also decreased. In 2011, the price was above 45 EUR/MW h in 5309 h, while in 2013, this had decreased to 1826 h [31]. Danish distributed CHP plants will for the most part sell electricity during hours with high electricity prices. Due to the decreasing number of these hours, the electricity production from distributed CHP plants in Denmark went from 6.18 TWh in 2011 to 4.48 TWh in 2013 [28]. The DH not produced by CHP units is to a large extent instead produced on fuel boilers producing only heat, which for many Danish distributed CHP plants is natural gas fired boilers. As the advantage of a DH network is among other the ability to utilize otherwise discarded heat [3], e.g. using CHP units, this development is problematic as it reduces the advantages of DH, as heat production using natural gas boilers can occur more fuel efficiently at each individual building, when taking into account heat loss in DH grids. The Danish distributed CHP plants are already now experiencing the challenge of covering their long-term marginal cost with decreasing hours of operation. As the CHP units' hours of operation are decreasing, many distributed