Electric Boilers in District Heating Systems: A Comparative Study of the Scandinavian market conditions

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1 Introduction

A successful integration of large shares of variable renewable energy (VRE), e.g. wind energy and solar photo voltaic, in the electricity system requires an increasing amount of flexibility in supply and demand. In countries with extended use of district heating (DH) flexibility from the electricity supply side has since long been offered by combined heat and power (CHP) generation. In the future the need for demand side flexibility options in the electricity system is expected to increase, and through power-to-heat technologies, for instance electric boilers and heat pumps, DH has the potential to offer such flexibility.

Electric boilers in the DH systems are specifically interesting from a flexibility point of view, as recent research indicate that electric boilers can help reduce price variations in the spot market. However, in Denmark, Sweden and Norway, the use of electric boilers in the DH systems is still rather limited.

The aim of this paper is to assess the potentials for electric boilers as flexibility provider in the Scandinavian DH systems given the current market conditions and regulatory frameworks. By reviewing the market conditions of electric boilers in the DH system, including the different components of its marginal costs of the operation such as taxation, grid tariffs and wholesale power prices, barriers affecting the utilization of electric boilers are identified, analysed and compared across countries.

The research presented in this paper is conducted under the Nordic Energy Research's flagship project, Flex4RES, as a part of the analysis on framework conditions for flexibility in the district heating sector.

1.1 District Heating in Scandinavia

The use of DH varies greatly between the three countries. DH is common in Denmark and Sweden, covering 50% and 32% of the respective countries' heat demand. In Norway, on the contrary, less than 5% of the heat demand is supplied by DH (Skytte & Olsen 2016). The theoretical potential for electric boilers defined as the aggregated DH demand (Böttger et al. 2013) is therefore much greater in Denmark and Sweden than in Norway. However, in all three countries the share of DH supplied by electric boilers is fairly small, ranging between less than 1% in Denmark and Sweden (Danish District Heating Association 2015; The Swedish District Heating Association 2015) and 13% in Norway (Statistics Norway 2015).

1.2 Problem Formulation

Electric boilers in the DH system can offer demand side flexibility - they can be turned on when a lot of electric power is available, e.g. during days with strong wind, and be turned off when the electricity supply is limited, e.g. during days with no wind. However, in order to utilize the flexibility potential of electric boilers, two basic conditions needs to be fulfilled: 1) there are incentives for DH companies to invest in electric boiler capacity, and 2) the electric boilers are the optimal dispatch choice when power prices are low, and suboptimal when the power prices are high. While the first condition requires that the *long* term marginal cost of heat from the electric boiler are low compared to competing technologies, the

second condition indicates that the *short* term marginal costs needs to be sufficiently low for low power prices. Thus the two conditions are related: the short term marginal cost determines the potential number of operating hours, which in turn determines the size of the fixed costs allocated to each hour of operation which is included in the long term marginal costs.

In this study, we estimate the short term marginal cost of operation (from here on *marginal costs*) of both electric boilers and the technologies that compete for being the optimal dispatch choice, in order to identify the number of hours in which it is optimal to run the electric boiler. The analysis includes Denmark, Norway and Sweden, and has specific emphasis on tax and tariff structures in each country. The identified number of operation hours is then used for explaining the general market conditions for electric boilers in DH systems, and the potential for using them as a flexibility option under the current regulatory framework.

2 Electric boilers and competitive technologies

A DH area is typically supplied by a number of heat producing plants, often at least one co-generation plant (CHP) and a heat only boiler (HO). The number of hours it is feasible to run the electric boiler, i.e. the number of hours in which electric boilers are the optimal dispatch choice, depends on the short term marginal cost of heat production. When the electric boiler can produce heat at a lower marginal cost than competitive technologies, it will start operating. While the marginal cost of heat-only boilers are independent of the electricity prices, the heat cost of CHP and electric boilers depend on these prices, as these technologies need to sell and buy electricity on the market.

In this study, the considered alternatives to electric boilers are wood chip fired CHP and heat-only boilers, and small-scale natural gas CHP and boilers. Table 1 presents some basic information on the technologies together with the technical data used for calculation of heat price. The data is taken from the technology catalogue 'Technology Data for Energy Plants' published by the Danish Energy Agency (2015).

The technology choice is based on typical decentral DH plants in Denmark. While natural gas fired boilers and CHP plants are common in Denmark, they constitute a minor share of the DH production in Sweden (natural gas is only available in a small part of the country), and in Norway natural gas is not important for district heating at all. Therefore, the natural gas fired technologies are not considered as competitive technologies in Norway.

In case the technology catalogue provides a range for efficiencies, the lowest value is used in the calculation. For other values that are given as a range, the mean is used. Furthermore, it is assumed that all fuel-based plants are included in the European Emission Trading System (EU ETS). For the natural gas CHP only the total Operation and Maintenance (O&M) is given in the technology catalogue. In this case an estimate of the variable part has been estimated according to the ratio between fixed and variable O&M costs in similar technologies with the same fuel input.

All taxes, tariffs and fuel costs presented in the marginal cost calculations in Section 3, are given in 2015-prices unless otherwise stated. Regional tax reductions and local variations in grid tariffs are not considered in the study.

Table 1 Basic data on the district heating technologies considered in this study.

	Electric boiler	Biomass CHP	Biomass HO	Natural gas CHP	Natural gas HO
Type	Electric boiler, 10 kV	Wood chip fired medium steam turbine	Wood chip fired district heating boiler	Gas turbine, combined cycle (back-pressure)	Gas fired district heating boiler
Capacity (MW heat)	1 - 25	20 – 100	1 – 12	10 – 100	0.5 - 10
Total efficiency	99%	93%	108%	82%	97%
Heat efficiency		29%		41%	
Electric efficiency		64%		41%	
Variable O&M (€/MWh heat)	0.50	1.77	2.22	0.29	0.07
Nominal investment (EUR/MW heat)	0.06-0.09	1.2	0.5-1.1	1.1-1.6	0.07-0.13
SO2 (g per GJ fuel)	-	1.9	1.9	0	0
NOx (g per GJ fuel)	-	81	81	48	13
CH4 (g per GJ fuel)	-	6.1	6.1	1.5	<3
N2O (g per GJ fuel)	-	0.8	0.8	1	1

3 Marginal Cost of Heat

3.1 Marginal Cost of Electric boilers

This section presents the marginal cost operation of electric boilers in the district heating system. Taxes and tariffs applied to the electricity consumption of electric boilers in the district heating system are country specific, thus a short introduction to the rules applied in each country is given here.

3.1.1 Denmark

Electricity tax: In Denmark all electricity consumption is taxed - when used for heating the tax is 51 EUR per MWh (Skatteministeriet 2011a). However, the Electric Boiler Scheme prescribes special rules for electric boilers when installed at the same location as a CHP unit (Sørensen et al. 2013). With this law, electric boilers are taxed 28.42 EUR per MWh heat, instead of according to the electricity input.

Electricity certificates / PSO: Denmark finances support for renewable energy and energy savings by a Public Service Obligation (PSO), which is levied on the electricity consumption. The Danish TSO, Energinet.dk, administrates the PSO and determines its size 4 times per year. In the first quarter of 2015, it was set to 28.28 EUR per MWh. If the electric boiler is taxed according to the Electric Boiler Scheme, it is in some cases also possible to avoid the PSO. In this analysis it is assumed that the requirements for PSO exemption are fulfilled. Finally, in the spring of 2016 a decision was taken to abolish the PSO system, thus from January 1, 2017 it is no longer relevant.

Grid costs: Energinet.dk owns the Danish transmission grid, charges a system tariff and grid tariff of 3.88 and 5.63 EUR per MWh, respectively, for the use of the grid (Energinet.dk 2014). Furthermore, electricity consumers pay a distribution grid tariff, which varies according to location. The tariffs usually consist of a fixed part and a variable part dependent on energy consumption. Tariff data from the Danish

association of DSOs, Dansk Energi, includes a calculation of a country average tariff of a 10 kV connection. Only the variable part is included.

3.1.2 Norway

Electricity tax: Norway's base tax for electricity consumption was 17.9 EUR per MWh in 2015 (Finansdepartementet 2015), however, under certain conditions electric boilers in the district heating system can achieve a reduced tax (0.537 EUR per MWh). This study assumes that these conditions are fulfilled.

Electricity certificates / PSO: Norway and Sweden have a common system for electricity certificates. The certificates are awarded for renewable electricity. Electricity suppliers and large consumers have a 'quota obligation' which means, they need to hold a certain quantity of certificates in relation to the sale or use of electricity. In 2015, the quota obligation was 8.6% in Norway (Energimyndigheten 2013). In the cost calculation, we used the quota price 16.27 EUR per MWh, calculated as an unweighted average of the prices in 2015 (SKM n.d.).

Grid costs: Grid tariffs in Norway consist of subscription, an effect part based on installed capacity, and an energy part based on consumed MWh. The energy part varies greatly in size between the different grid companies - from 0.56 EUR per MWh to 45.8 EUR per MWh. Based on data collected from Norwegian grid companies, we have calculated an unweighted average of 10.22 EUR per MWh including both prioritised and non-prioritised grid connections.

3.1.3 Sweden:

Electricity tax: The consumption tax on electricity in Sweden depends on the end-usage. Consumption for non-industry purposes is taxed by 34.4 EUR per MWh while certain regions are eligible for a reduced electricity tax. For industries the electricity tax is at minimum EU level that is 0.53 EUR per MWh. Generally, the temperature of district heating is too low for it to be used in industrial processes, thus district heating mainly serves residential users (Werner 2012). For this reason we assume non-industry consumption tax, and, for simplicity, regional reductions are not considered.

Electricity certificates / PSO: Sweden and Norway has a common certificate system. In 2015 the quota obligation was 14.3% in Sweden (Energimyndigheten 2013) and the average quota cost 16.27 EUR per MWh.

Grid costs: Transmission cost are included in the distribution grid tariffs, which consists of a fixed part (subscription, depending on load) and a variable part, depending on energy transmission. Compared to Denmark and Norway, the energy part of the grid cost is very small. In this study the variable grid tariff is calculated on the basis of data of Swedish Energy Inspection data as mean of variable, energy-based tariffs for 1 MW and 20 MW installations (Energimarknadsinspektionen n.d.).

3.2 Comparison between countries

Table 2 gives an overview of taxes and grid costs, which results in a country specific total cost of operation.

Despite special tax rules for electricity tax of electric boilers, Denmark has by the highest overall marginal cost (excluding cost of electricity), followed by Sweden. While the Swedish electricity tax is slightly higher than the Danish, the variable part of the grid tariff is significantly lower. The grid cost estimate includes only the energy part of the cost, which is generally low in Sweden compared to the

other countries. The Norwegian electricity tax is much lower than both in Denmark and Sweden, resulting in a significant difference in total costs.

Table 2 Marginal cost of heat production of electric boilers in the DH system. The cost excludes electricity purchases, which depends on the electricity market prices.

EUR/MWh heat, excluding electricity purchase	Electric boiler		
	Denmark	**Norway**	**Sweden**
Electricity tax	28.42	0.54	31.73
Electricity certificates	0	1.45	2.35
Grid costs	22.65	10.33	4.33
Maintenance	0.5	0.5	0.5
In total	51.58	12.82	38.91

3.3 Marginal cost of alternatives

3.3.1 CHP

3.3.1.1 Denmark

Energy tax: Consumption of natural gas is subjected to an energy tax of approx. 7.6 EUR per GJ. Energy taxes on fossil fuel consumption are applied for heat production, but not on the fuel used for electricity production. In order to allocate fuel to heat and electricity production two formulas exist, the E and the V formula. In order to minimize taxation, the producer chooses the formula which allocates the highest fuel share to electricity. The V formula is optimal for the natural gas CHP. Biomass products are not subjected to the fuel tax.

CO2 tax and quotas: When the CHP plant is inside the EU ETS, only the fuel allocated to heat is taxed. If outside, then the entire fuel consumption is taxed. The CO2 tax for natural gas amounted to 1.18 EUR per GJ in 2015 (Skatteministeriet 2011b). CO2 quotas needs to be purchased for the CO2 emissions, when the plant is inside the EU ETS. For natural gas we have used the CO2 emission factor of 57.1 tons pr MJ and an average quota price of 8.02 EUR per ton (Investing.com n.d.). Biomass, including wood chips, has an emission factor of 0.

Other emission taxes: In Denmark taxes are applied on NOx and sulphur emissions. In 2015 the tax was 1.54 EUR and 3.53 DKK per emitted kg, respectively (Skatteministeriet 2015; Skatteministeriet 2011c).

Electricity sales and support: Finally, there is an energy-based support for biomass based electricity production, 20.1 EUR per MWh (Energistyrelsen n.d.). Grid cost is set by the Danish TSO as 0.40 EUR per MWh (Energinet.dk 2014).

3.3.1.2 Norway

Energy tax, CO2 tax and quotas: In the Norwegian case, this study only considers biomass based CHP for which neither energy nor CO2 taxes are charged. Biomass, including woodchips, has an emission factor of 0, implying no cost for the EU ETS quotas.

Other emission taxes: Norway taxes NOx emissions by 2.84 EUR per kg (Finansdepartementet 2015).

Electricity sales and support: The marginal cost of the grid tariff is determined according to grid-loss, and can therefore either be positive or negative depending on location. Based on tariff statistics from 2013, an unweighted average of the marginal costs for feeding into the distribution net was estimated to be 0.51 EUR per MWh. Electricity produced with biomass based CHP is eligible for green certificates.

3.3.1.3 Sweden

Energy tax: Like in Denmark fuel taxes are paid for fuel used for heat generation but not for electricity generation. When heat and electricity are co-generated fuel is allocated proportionately to the respective energy output. Even for the fuel allocated to heat, a reduction in the fuel tax is offered. For natural gas the reduced energy tax is 0.76 EUR per GJ for the part of the fuel used for heat (Finansdepartementet S2 1994).

CO2 tax and quotas: In Sweden CHP plants inside the EU ETS scheme does not have to pay CO2 tax. Instead quotas have to be purchased – for natural gas CHP we have used the CO2 emission factor of 57.1 tons per MJ and an average quota price of 8.02 EUR per MWh. Biomass CHP has an emission factor of 0, thus no quotas has to be purchased for biomass fired CHP.

Other emission taxes: Sweden taxes sulphur emission by 3.21 EUR per kg SO2 in the fuel.

Electricity sales and support: Electricity produced with biomass based CHP is eligible for green certificates. The variable part of the grid cost is assumed to be zero in Sweden, as research indicate that a variable part of the grid tariff is rarely used in Sweden (Sweco 2012).

Summary

Table 3 below summarises the cost of heat production for biomass fired CHP, excluding the potential electricity sales. It also shows the marginal cost of heat from natural gas CHP in Denmark and Sweden.

Table 3 Marginal cost of heat production from biomass and natural gas fired CHP. The cost excludes the sales of electricity at market price, however, it includes the electricity grid cost and the support obtained for the electricity production.

EUR/MWh heat, excluding electricity purchase	Biomass CHP			Natural gas CHP	
	Denmark	**Norway**	**Sweden**	**Denmark**	**Sweden**
Fuel cost	36.95	38.25	32.89	64.36	84.29
Fuel tax / energy tax	0.00	0.00	0.00	22.81	3.34
CO2 tax and quotas	0.00	0.00	0.00	7.55	4.02
Other emission taxes	1.63	1.08	0.03	1.49	0.00
Grid cost an electricity support	-8.93	-7.35	-7.37	0.40	0.00
Maintenance	1.77	1.77	1.77	0.29	0.29
In total	**31.42**	**33.75**	**27.32**	**96.90**	**91.94**

In all three countries the costs for biomass CHP are close to 30 EUR per MWh, and the minor differences can be explained by differences in the cost of fuel and emission taxes. Furthermore, while Denmark

awards a fixed feed-in premium (FIP) for electricity produced by biomass-installation, Norway and Sweden awards green certificates, whose value is slightly lower than the Danish FIP.

Despite variations in fuel cost, fuel tax, CO2 tax and other emission taxes, the total cost level for natural gas CHP is similar in Denmark and Sweden. The marginal cost of heat from natural gas fired CHP is significantly greater than the case of biomass fired CHP in both countries.

3.3.2 Heat-only boilers

3.3.2.1 Denmark

Energy tax: Consumption of natural gas is subjected to an energy tax of approx. 7.6 EUR per GJ. Biomass consumption is not taxed.

CO2 tax and quotas: The CO2 tax for natural gas amounted to 1.18 EUR per GJ in 2015 (Skatteministeriet 2011b). CO2 quotas have to be purchased for the CO2 emissions, when the plant is inside the EU ETS. For natural gas we have used the CO2 emission factor of 57.1 tons per MJ and an average quota price of 8.02 EUR per ton (Investing.com n.d.). Biomass, including wood chips, has an emission factor of 0.

Other emission taxes: In Denmark taxes are applied on NOx and sulphur emissions. In 2015 the tax was 1.54 EUR and 3.53 DKK per emitted kg, respectively.

3.3.2.2 Norway

Energy tax, CO2 tax and quotas: Biomass in Norway is subjected to neither energy tax nor CO2 tax. Despite assuming the HO boilers are inside the EU ETS, no quotas are needed given biomass has an emission factor of 0.

Other emission taxes: Norway taxes NOx emissions by 2.84 EUR per kg (Finansdepartementet 2015).

3.3.2.3 Sweden

Energy tax: In Sweden HO boilers pay full energy tax, which is 2.53 EUR per GJ for natural gas (Finansdepartementet S2 1994). Biomass consumption is not subjected to energy tax.

CO2 tax and quotas: HO boilers fuel with natural gas pay for CO2 emissions both through CO2 tax of 5.2 EUR per GJ and through EU ETS quotas. For natural gas CHP we have used the CO2 emission factor of 57.1 tons per MJ and an average quota price of 8.02 EUR per MWh. Biomass HO has an emission factor of 0, thus no quotas has to be purchased for biomass fired HO.

Other emission taxes: Sweden taxes sulphur emission by 3.21 EUR per kg SO2 in the fuel (Finansdepartementet 1990).

Table 4 Marginal cost of heat production from biomass and natural gas fired HO boilers.

EUR/MWh heat	Biomass HO boilers			Natural gas HO boilers	
	Denmark	**Norway**	**Sweden**	**Denmark**	**Sweden**
Fuel cost	21.90	22.67	19.49	27.20	35.63
Fuel tax / energy tax	0.00	0.00	0.00	28.22	11.80
CO2 tax and quotas	0.00	0.00	0.00	6.07	21.00

Other emission taxes	0.97	0.64	0.02	0.17	0.02
Maintenance	2.22	2.22	2.22	0.07	0.07
In total	22.86	23.31	19.51	61.73	68.52

Summery

Table 4 shows the marginal cost of heat production in biomass HO boilers in the three countries and natural gas HO boilers in Denmark and Sweden.

For biomass none of the countries apply fuel or CO2 tax, however, small variation in the fuel input cost result in small differences in the total marginal costs. Overall, the level is similar across all three countries.

While the total taxation level for natural gas HO is similar in Denmark and Sweden, Denmark emphasizes on fuel tax, while Sweden on CO2 tax. In total the cost level in Denmark and Sweden is similar, though slightly higher in Sweden.

3.4 Comparison between technologies

Denmark

Figure 1 shows the marginal cost of operation for electric boilers and competing technologies for a range of possible electricity prices. For all positive electricity prices, electric boilers have higher marginal cost of operation than biomass CHP and HO. Compared to natural gas CHP, electric boilers is the optimal dispatch choice for electricity prices lower than 22.66 EUR per MWh, while compared to natural gas HO boilers it is only optimal for prices below 10.15 EUR per MWh.

The figure also reveals that only for very high electricity prices it is profitable to use the natural gas CHP compared to the natural gas HO boiler. Natural gas HO boilers are often installed for peak-load operation in connection to a CHP plant, however, it operates throughout the majority of the time despite the intention of using the boiler for peak-load only.

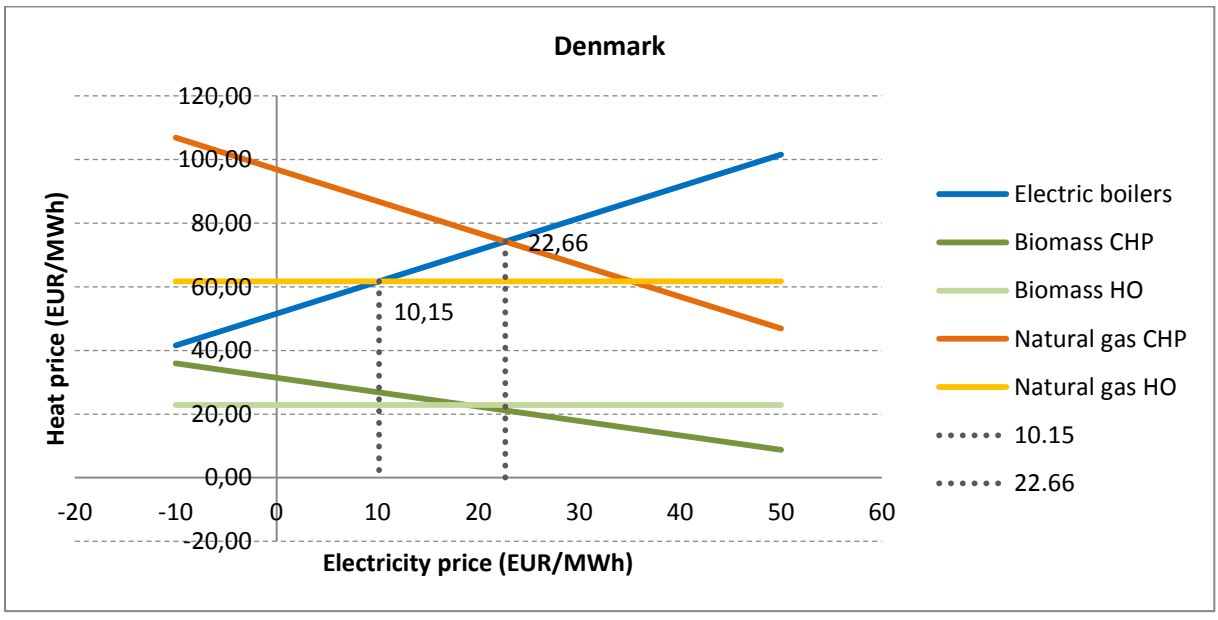


Figure 1 Denmark: Short term marginal cost of heat as a function of electricity price. The blue line indicates the cost of electric boilers. The electricity prices at which the marginal heat cost of electric boilers are equal to that of natural gas HO and CHP are marked with a dashed line.

Norway

Figure 2 shows the marginal cost of heat as a function of the electricity prices. In Norway the electric boiler has lower marginal cost of operation than biomass fired HO boilers for electricity prices up to 10.49 EUR/MW and for biomass CHP up to 14.40 EUR per MWh. This means that electric boilers are the optimal dispatch choice for operation up until these electricity prices. Compared to the Danish case, the intercept is shifted significantly towards higher prices, which can be explained by the low tax on electricity when consumed by the electric boiler.

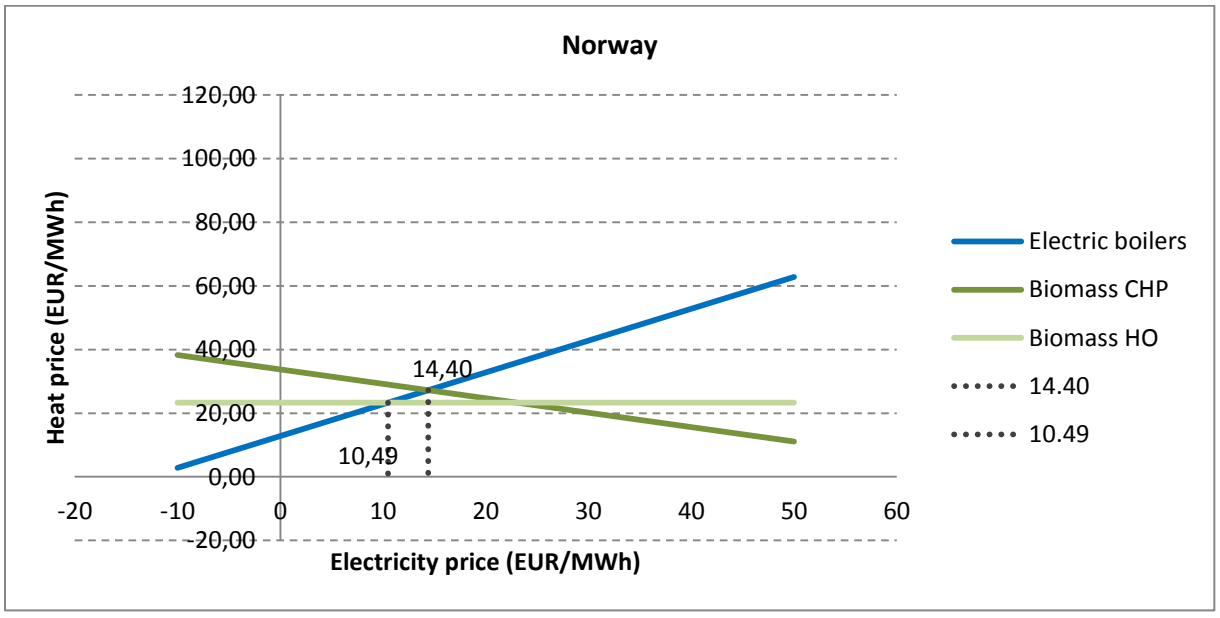


Figure 2 Sweden: Short term marginal cost of heat as a function of electricity price. The blue line indicates the cost of electric boilers. The electricity prices at which the marginal heat cost of electric boilers are equal to that of biomass HO and CHP are marked with a dashed line.

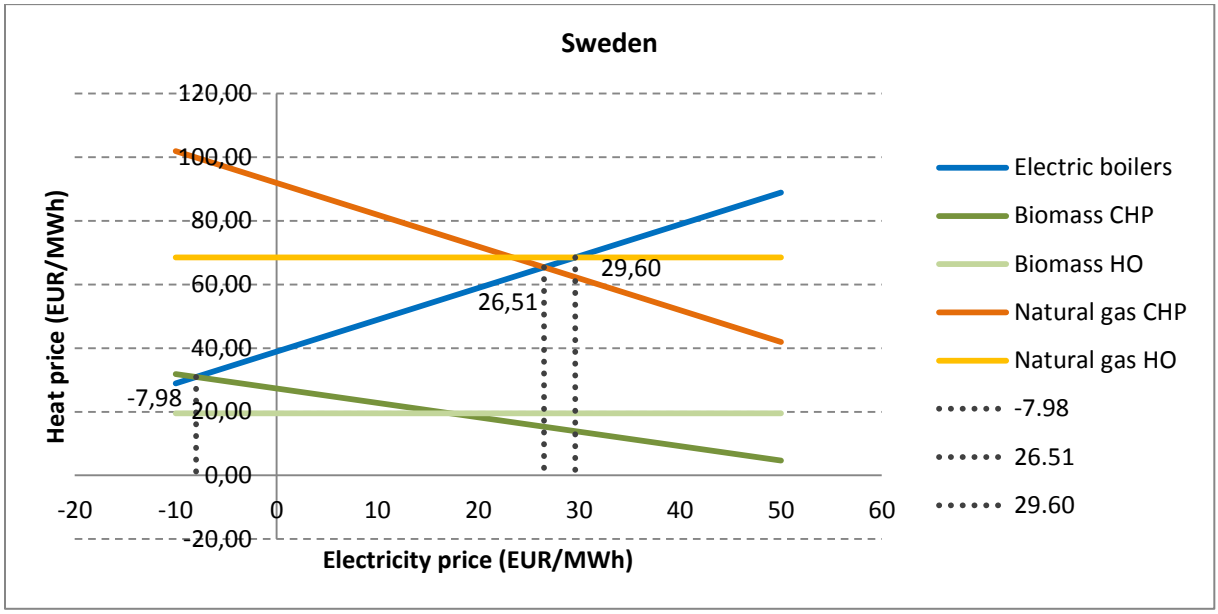


Figure 3 Sweden: Short term marginal cost of heat as a function of electricity price. The blue line indicates the cost of electric boilers. The electricity prices at which the marginal heat cost of electric boilers are equal to that of natural gas HO and CHP, and biomass CHP are all marked with a dashed line.

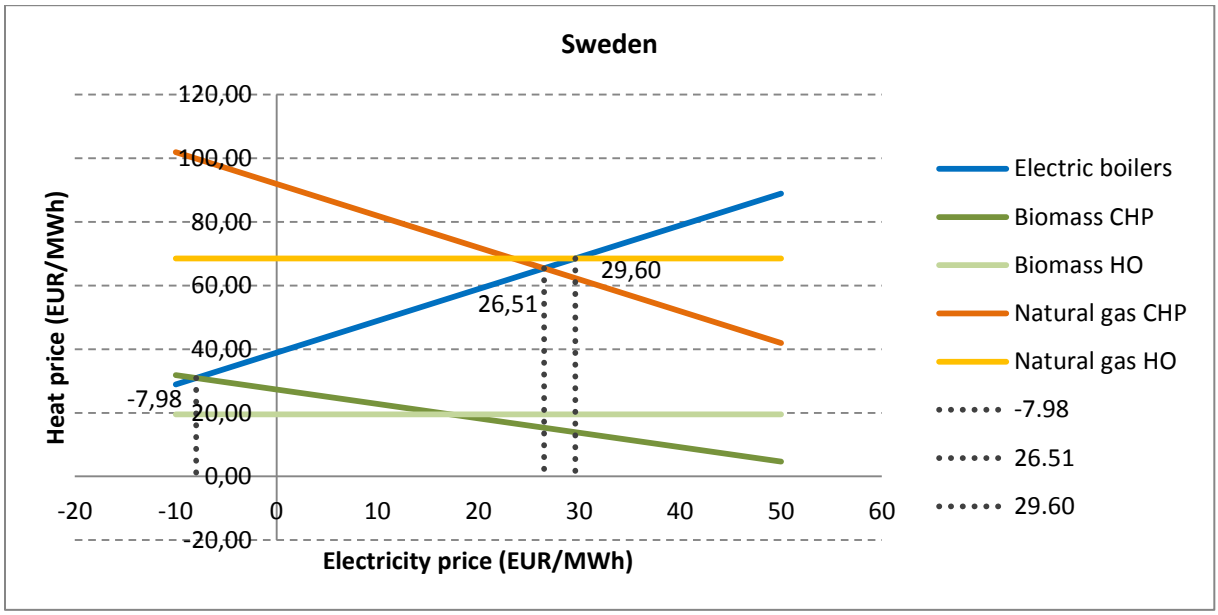


Figure 3

Sweden

Figure 3 show the marginal cost of heat according to electricity price in the Swedish case. According to the figure, electric boilers can only compete with biomass CHP for electricity prices below -7.98 EUR per MWh. When compared to natural gas plants the electricity price should be below 26.51 EUR per MWh and 29.60 EUR per MWh for the electric boiler to be competitive with CHP and HO boilers, respectively.

The figure reveals the interesting phaenomenon that the marginal cost of the electric boiler intercepts with the marginal cost of natural gas CHP before the natural gas HO. This means that in a DH area consisting of an electric boiler, a natural gas HO boiler and a natural gas CHP unit, the HO boiler will never be the

optimal dispatch option. This is in clear contrast to the Danish case, where the natural gas HO is the optimal choice for a wide range of electricity prices.

Summary

The differences in marginal cost of operation result in very different optimal dispatch curves and thereby different electricity prices below which electric boilers are competitive. Table 5 The electricity price in EUR per MWh below which electric boilers is the optimal dispatch choice in comparison to the competing technologies.Table 5 summarizes the results in the Danish, Norwegian and Swedish case.

Table 5 The electricity price in EUR per MWh below which electric boilers is the optimal dispatch choice in comparison to the competing technologies.

Electricity price (EUR per MWh) at cost curve interception	Biomass CHP	Biomass HO	Natural gas CHP	Natural gas HO
Denmark	-13.87	-28.71	22.66	10.15
Norway	14.40	10.49	-	-
Sweden	-7.98	-19.40	26.51	29.60

4 Hours of Boiler Operation - Spot market

Table 6 below shows the percentage of hours in which the electric boiler has lower marginal cost of operation than the competitive technologies. In other words, the percentage indicates how often electric boilers is the optimal dispatch choice when compared to the other technologies. A high number means that it is often feasible to run the electric boiler, while a small number means the opposite. The electricity price observations used for estimating the percentage are area spot prices from 2014 and 2015. The country average is calculated as an unweighted average of the percentage in each of the countries' spot area.

In Denmark, electric boilers had lower marginal cost than biomass CHP and HO in, respectively, 0.1% and 0% of the hours, indicating that electric boilers are never the optimal dispatch choice. The same is the case in Sweden - when used in combination with biomass installations electric boilers would simply never be feasible to run. In Norway, on the other hand, electric boilers often have the lowest marginal cost of operation, on average 14.4% and 7.1% of the time compared to biomass CHP and HO, respectively. Within Norway electricity price variations exists, resulting in electric boilers being the optimal dispatch choice in more hours in the southern trading areas than in the northern. The difference in number of operating hours between Norway, Denmark and Sweden, corresponds to the difference in deployment level – the number of operating hours clearly affects the investment incentives.

In Sweden, electric boilers appear feasible to run around half of the time when compared to natural gas installations. However, only a few natural gas fired DH plants exist. Furthermore, despite the higher instalment cost and fixed O&M, new biomass installations are likely to be more attractive than new electric boilers, due to the lower marginal cost of biomass fired heat. This means that Swedish DH companies looking to invest in new capacity would choose biomass plants over electric boilers. In Denmark, this is often not possible due to restrictions in investing in new biomass HO installations (Energistyrelsen n.d.). In Denmark electric boilers' ability to compete with natural gas installations are significantly worse than in Sweden, expressed as a lower percentage of hours in which electric boilers are the optimal dispatch choice compared to natural gas installations.

Table 6 The percentage of hours in which electric boilers is the optimal dispatch choice within each trading area. The percentage is based on historical hourly price observations in 2014 and 2015.

% hours of operation	Spot area	Biomass CHP	Biomass HO	Natural gas CHP	Natural gas HO
Denmark	DK1	0.1%	0.0%	28.6%	7.8%
	DK2	0.1%	0.0%	23.7%	5.9%
	Average	**0.1%**	**0.0%**	**26.2%**	**6.9%**
Norway	Oslo	16.3%	7.3%	-	-
	Kr.sand	16.4%	7.2%	-	-
	Bergen	16.3%	7.3%	-	-
	Molde, Tr.heim	11.1%	6.4%	-	-
	Tromsø	11.7%	7.1%	-	-
	Average	**14.4%**	**7.1%**	-	-
Sweden	SE 1	0%	0%	47%	63%
	SE 2	0%	0%	47%	63%
	SE 3	0%	0%	46%	62%
	SE 4	0%	0%	46%	62%
	Average	**0.0%**	**0.0%**	**46.6%**	**62.7%**

The analysis shows that taxation and tariff structure in combination is a considerable barrier for exploiting the flexibility potential of this technology. The tax on the electricity consumed by the electric boilers increases the marginal cost of operation and at the same time, biomass is not subject to fuel or energy taxes. As a result electric boilers are the optimal dispatch choice only for extremely low electricity prices, in fact so low in Denmark and Sweden that they hardly ever occur. In Norway, the conditions for electric boilers are better, as the tax on electricity consumption for electric boilers is much lower.

It is furthermore problematic that in Denmark and Sweden even in case of negative electricity prices, indicating a large over-generation of electricity, it is more feasible to run biomass HO boilers, than to use the excess electricity for heating. The case where wind turbines cease operation to decrease electricity production, while biomass HO boilers are running on full load is not an unlikely scenario. A much more efficient use of resources would be to use the additional wind power generation for heat production instead of biomass. However, under the current tariff structure this is not economic for the DH company.

5 Conclusion

Electric boilers in the DH system can provide demand side flexibility through the coupling of the power and heat sectors, and thereby assist the integration of large shares of VRE in the energy system. Under the current regulation electric boilers in the DH systems are, however, unable to offer flexibility in a competitive manner. The national regulation of electric boilers in the DH systems varies across the Scandinavian countries but does not correspond to current and future energy system needs. As investors can only expect very few hours of profitable operation they will decline to invest in this technology and the future electricity system will be without a significant source of flexibility. Improving the framework conditions for electric boilers and thereby making them more attractive in the eyes of the investors can be considered a way of supporting VRE deployment goals.

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