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Solar heating systems in renewable-based district heating

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Abstract

In this study, we explored cost-optimal renewable-based district heat production systems and potentials to integrate solar heating systems in such systems under different contexts. We investigated under what conditions a solar heating system become cost-efficient to integrate in district heat production systems and the consequences of this integration. We considered a small-scale district heat production system in the south of Sweden where district-heat production cost is higher and hence it is more cost efficient to integrate solar heating in such a district heat production systems. The cost-efficiency of integrating solar heating in a minimum-cost renewable-based district heat production system depends on future fuel prices and investment costs of solar heating systems. In any case, integrating solar heating will help to reduce the use of other primary energy resources as biomass.

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Keywords: District heating; minimum cost; environmental tax; solar heating

1. Introduction

Electricity and district heat (DH) production based on renewable resources is normally given priority in many European member states, especially the Nordic countries [1]. In fact, the goals of primary energy use and CO_2 emission reduction in Europe can be achieved at a lower cost with district heating [2]. The technologies to deploy renewable energy resources in DH production can be fuel-based system such as heat-only boilers, combined heat and power (CHP) plants and electric heat pump (EHP) as well as non-fuel solar water heating (SWH) technology, although solar irradiation is not uniformly distributed throughout the year. Nevertheless, DH production systems are normally designed to minimize DH production cost. Therefore, those renewable energy technologies must be cost-competitive to be used in a minimum-cost DH production system.

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In this study, we explored cost-optimal renewable-based DH production systems and potentials to integrate solar heating systems in such systems under different contexts of wood fuel price. We investigated under what conditions a solar heating system become cost-efficient to integrate and the consequences of this integration in a small-scale DH production system in the south of Sweden.

2. Method and assumptions

Our analysis was based on the data of the existing district heating system in Ronneby, Sweden (Fig. 1). DH production from this system reached 107 GWh per year at the peak heat load demand of 34 MW in 2011.

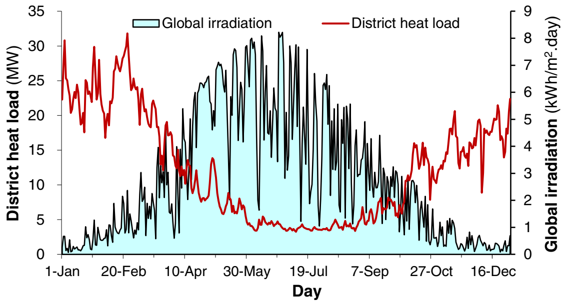

Fig. 1. DH load and daily global irradiation in 2011 in Ronneby (56.21N; 15.276E)

We designed renewable-based DH production options that comprise different DH production units and meet the DH load at the minimum DH production cost. The DH production cost was calculated using equation derived from [3]. The value of cogenerated or used electricity was assumed to equal to that from a reference standalone power plant, including biomass-based steam turbine (BST), biomass integrated gasification combined cycle (BIGCC) and large-scale wind farm (Table 1).

Table 1. Technologies for heat and electricity production

Technology	Size	Specific investment costs	Fixed O&M costs	Variable O&M costs	Production efficiency (%)		Scale factor
					Heat	Electricity	
Heat-only production	*(MW_{heat})*	*(€/kW_{heat})*	*(€/kW_{heat}.year)*	*(€/MWh_{fuel})*			
- EHP	10	520	3.7	0.2	280[a]	-	0.8
- Wood chips	12	500	10.0	2.2	108.0	-	0.8
- Wood powder	12	375	5.6	2.2	93.0	-	0.8
- Large SWH	8000[b]	227[c]	-	0.14[d]	500[e]	-3.3[e]	0.8
CHP plants							
- BIGCC	26	2800	63.5	4.4	51.0	39.0	0.9
- BIGGE	15	2570	55.1	4.4	53.5	35.5	1.0
- BORC	12	840	28.0	3.3	89.0	15.0	0.9
- BST	17	1850	41.0	2.4	81.0	24.0	0.8
Standalone power plant							
- BIGCC	500	1620	70.0[f]	-	-	50.0	-
- BST, Pulverized	400	1630	-	3.54[g]	-	45.0	-
- Wind, large-sea based	375	2770	-	22.2	-	3100[h]	-

[a] coefficient of performance (COP); [b] in m^2 of solar collector; [c] in €/m^2; [d] per MWh of produced heat; [e] in kWh/m^2/year; [f] including *Variable O&M costs*; [g] including *Fixed O&M costs*; [h] yearly utilization time.

We considered commercial/conventional DH production units which suits to be used in a renewable-based energy system including DH production of the considered scale. Also, pre-commercial CHP technologies, such as BIGCC, biomass integrated gasification with gas engine combined cycle (BIGGE) and biomass-based organic rankine cycle (BORC), are considered (Table 1). The global solar irradiation on a horizontal plane in Ronneby, which was about 1030 kWh/m^2 in 2011, was used. We estimated the deliverable energy from SWH based on the function of solar irradiation and the temperature different between ambient and the fluid entering the collector. In 2011, the price of wood fuel was of €22.2/MWh. However, wood fuel price could increase by 45% to €32.1/MWh if wood fuel price is driven by minimum-cost fossil-based condensing power plants [4]. We used these price levels as the scenarios namely *reference wood fuel price* and *increased wood fuel price*, respectively, to elaborate the renewable-base DH production system. For all the considered production units, we assumed an economic plant life of 25 years and a maximum operating period of 7200 hours per year. In our calculations, we used 2011-average exchange rates of €/SEK = 9.0 and $/SEK= 6.5 and a discount rate of 6% for all the investment. All the presented data were based on the lower heating value (LHV) of fuels.

3. Results

Of the considered standalone power plant, BIGCC plant has lowest electricity production cost of €71.6 and €91.4 per MWh in *reference wood fuel price* and in *increased wood fuel price* scenarios, respectively (Table 2). These values are used as the reference values of electricity for each scenario. Electricity from wind power is potentially competitive at the *increased wood fuel price* scenario.

Table 2 Production cost of standalone electricity (€/MWh)

Technology	***Scenario***	
	Reference wood fuel price	*Increased wood fuel price*
- BIGCC	71.6	91.4
- BST	74.8	96.8
- Wind power	92.0	92.0

Performance of each DH production units depends on its utilization time and scenarios (Fig. 2). Under the *reference wood fuel price* scenario, cost of DH production from SWH is about €36.2 per MWh. Therefore, it is not cost efficient to use SWH in minimum-cost system. However, under the *increased wood fuel price* scenario DH production cost from a SWH is lower than the variable cost of the considered DH production units, therefore can supplement heat for the DH production system.

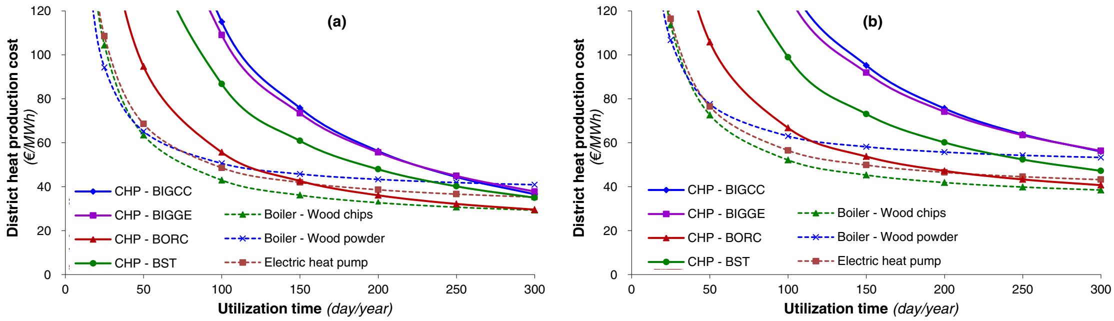

Fig. 2. Performance of DH production units under *Reference wood fuel price* (a) and *Increased wood fuel price* (b) scenarios

Table 3 shows the details of the minimum-cost DH production system under different scenarios and options. At the *reference wood fuel price* scenario, system with heat-only boilers is the most cost-efficient for DH production. If electricity coproduction is desired, primary energy use for DH production reduces by 4.9%, but DH production cost increases by 0.6%. In the *increased wood fuel price* scenario, the coproduction option along with SWH reduces 14.1% and 0.5% of primary energy use and production cost of DH, respectively.

Table 3. Minimum-cost DH production system under different options and scenarios

Parameter		***Reference wood fuel price***		***Increased wood fuel price***	
		Heat-only boilers	*Considering all technologies*	*Heat-only boilers*	*Considering all technologies*
Technology:[a]	○ *Peak load*	WP boiler	WP boiler	WP boiler	WC boiler
	○ *Medium load*	WC boiler	WC boiler	WC boiler	WC boiler
	○ *Base load*	WC boiler	CHP-BORC	WC boiler	CHP-BORC & SWH
Installed capacity *(MW_{heat})*:	○ *Peak load*	9	9	7	7
	○ *Medium load*	4	20	4	24
	○ *Base load*	21	5	23	3 & 27,500[b]
Fuel use at DH production system *(GWh/yr)*		100	107	99.8	92.4
Cogenerated electricity *(GWh/yr)*		0	6.0	0	3.3
Fuel use for DH production *(MWh/MWh_{heat})*		0.93	0.88	0.93	0.80
DH production cost *(€/MWh)*		36.7	36.9	45.9	45.7

[a] Note: WP: Wood powder, WC: Wood chips; [b] In m^2 of solar collector

4. Discussion and conclusions

This study showed that DH production system with integrated production units (than heat-only boilers) reduces primary energy use for DH production. However, at the considered DH production system, there are fewer technical options due to the high specific investment cost of the small-scale non-heat only boilers. Cogeneration options are not very attractive if value of coproduced electricity is equivalent to that from standalone power plants. This is due to the high specific investment of these technologies compared to the heat-only boilers. However, the technology of BORC can potentially be used in minimum-cost renewable-based DH production system.

SWH is generally not cost efficient to be used in DH production systems under the current investment cost and fuel prices, but under the favourable conditions of increased fuel price. SWH system is not sensitive to fuel price changes, but the cost of avoided fuel use may be considered in analysing its effectiveness. With increased market penetration, the investment cost of large-scale SWH systems may reduce [5] whereas prices of conventional fuels may increase [6], it may be cost-efficient to use SWH in DH production systems in the near future.

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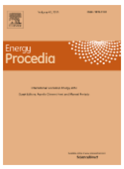

Biography

Nguyen Le Truong is a PhD candidate in Linnaeus University, Sweden. His research focus relates to district heat production technologies and systems.

Leif Gustavsson is a professor in Linnaeus University, Sweden. His main field of research is systems analysis from a bottom-up perspective linked to sustainable development.