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Possibilities and consequences of deregulation of the European electricity market for connection of heat sparse areas to district heating systems

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Abstract

The objective of the study is to analyse the conditions for connection of residential buildings in heat sparse areas to district heating systems in order to increase electricity production in municipal combined heat and power plants. The European electricity market has been assumed to be fully deregulated. The relation between connection of heat sparse areas, increased electricity and heat production as well as electricity prices, fuel prices and emissions rights is investigated. The results of the study show that there is potential to expand the district heating market to areas with lower heat concentrations in the cities of Gävle, Sandviken and Borlänge in Sweden, with both economic and environmental benefits. The expansion provides a substantial heat demand of approximately 181 GWh/year, which results in an electricity power production of approximately 43 GWh/year. Since the detached and stand-alone houses in the studied heat sparse areas have been heated either by oil boiler or by direct electricity, connection to district heating also provides a substantial reduction in emissions of CO_2. The largest reductions in CO_2 emissions are found to be 211,0 ktonnes/year assuming coal-fired condensing power as marginal electricity production. Connection of heat sparse areas to district heating decrease the system costs and provide a profitability by approximately 22 million EURO/year for the studied municipalities if the price of electricity is at a European level, i.e. 110 EURO/MWh. Sensitivity analysis shows, among other things, that a strong relation exists between the price of electricity and the profitability of connecting heat sparse areas to district heating systems.

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Keywords: Combined heat and power, Heat sparse areas, CO_2 emissions, District heating, Deregulated electricity market.

Nomenclature

BEAB	Borlänge Energi AB
CFCP	Coal-fired condensing power
CHP	Combined heat and power
GEAB	Gävle Energi AB
KEAB	Karskär Energi AB
IPCC	Intergovernmental panel on climate change
LPG	Liquefied petroleum gas
MODEST	Model for optimisation of dynamic energy systems with time-dependent components and boundary conditions
NGCC	natural gas combined cycle
SAEM	Swedish average electricity production mix
SEAB	Sandviken Energi AB

1. Introduction

The European Commission has presented a strategy to support and promote cogeneration or so-called Combined Heat and Power (CHP) plant [1]. At present, the EU objectives are to increase the share of CHP of total electricity production in the EU area from 9% to 18% by the year 2010. For Sweden’s part this means an increase from the current 5% to 14% of electricity production. According to the Swedish District Heating Association, electricity production from Swedish CHP plants can increase from today´s low level of 5 TWh/year to 20 TWh/year, based on the existing district heating grids in Sweden [2].

Cogeneration is still at a modest level in Sweden compared to other European countries. Comparatively, the CHP in Finland is 34% of electricity and in Denmark the proportion is 43% and the EU average is around 10% [3]. CHP plants are almost always connected to a district heating network, which functions as a heat sink for the plant instead of the heat from a condensing power plant being cooled by air-cooling towers or water. In this way, more than 90% of the input fuel energy can be converted to useful energy. Since heat and electricity demand often coincide in the Nordic countries, cogeneration plants thus also have the largest electricity generation when the heat load is greatest.

In order to increase the heat and electricity production in the existing CHP plants, the existing heat loads must be used in more effective ways and new heat loads must be identified. These measures will increase the operating time for the existing CHP facilities. However, this is expected to happen in any case in the future because the price of electricity will increase with the deregulation of the European electricity market. Moreover, new CHP plants must be built.

Presently, Sweden has achieved a fairly high degree of connectivity in areas with high heat density. Approximately 80% of all multi-family buildings and 65% of service and commercial buildings are connected to district heating, and the potential for increased connectivity in the heat density areas is limited [4]. Thus areas with low heat and line density are an important segment for further expansion of district heating. Today heat sparse areas, i.e. different groups of detached and stand-alone buildings, have the greatest possibility for expansion to the district heating network and thereby increased heat load bases, see [5-6]. However, viable technologies need to be developed to keep connection costs per house at a reasonable level. According to study presented in [7], it could be expected that the heat sparse areas with a line density of less than 1 MWh/m and perhaps down to about 0.3 MWh/m can be connected. This line density corresponds to a heat density of 10-15 kWh/m^2, depending on the effective width.

The hypothesis of this study is that it should be both environmentally and economically beneficial to connect heat sparse areas to district heating system operating by CHP plant. This beneficial should be more pronounced if one assumes that coal-fired condensed power plant is the marginal electricity production plant and the electricity market is fully deregulated. it is viable to extend the operation of existing CHP plants and construct new CHPs in Sweden. The CHP plant is assumed to use either waste or bio-fuels.

The approach used in this study is that coal-fired condensed power plants are the marginal producer of the electricity in Europe. The local electricity production e.g. by bio-fuel CHP power plants will replace the electricity produced by coal-fired condensed power plants. This means that CO_2 emissions can be credited for the local electricity production. Since the heat demand in new heat sparse areas increases the amount of power production in a CHP plant, the use of coal condensing power plants in Europe will be reduced and thereby this measure can decrease the global emissions of CO_2.

2. Energy System Structure

This section describes the structure of existing energy systems in the cities of Gävle, Sandviken and Borlänge in Sweden, which are the cases for the present study. An overall view of electricity and district heating production in the respective cities is shown in Figures 1, 2 and 3 as well as Table 1.

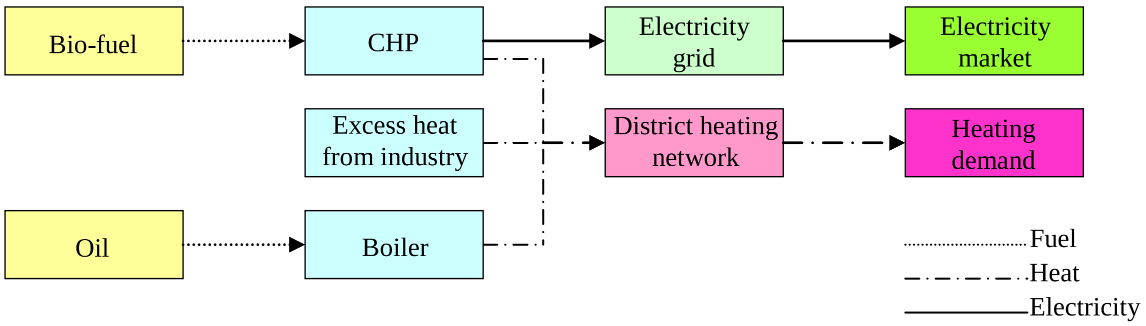

Fig.1. Simplified view of electricity and district heating production in the city of Gävle.

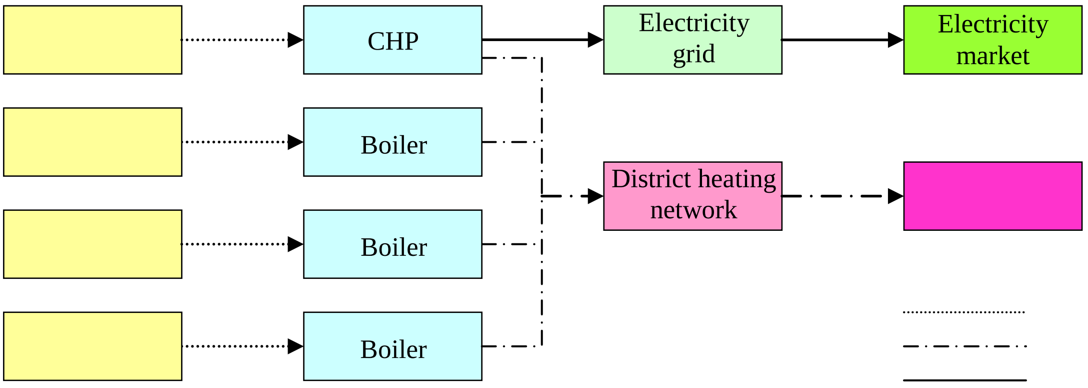

Fig.2. Simplified view of electricity and district heating production in the city of Sandviken.

2.1 Energy system structure in Gävle municipality

The city of Gävle is situated on the east coast of Sweden, 170 km north of Stockholm, and has about 92,000 inhabitants. The district heating system is run by the municipal-owned energy company *Gävle Energi AB*, hereinafter called "*GEAB*". The total district heating demand is around 785 GWh/year. The base supplier of heat is the bio-fuel CHP plant, Johannesverket, with a total capacity of 55 MW heat, 22 MW electricity and 20 MW flue gas condensing. The nearby companies *Karskär Energi AB* (hereinafter called "*KEAB*") and "*Korsnäs*" deliver heat to the district heating system in the town of Gävle. *Korsnäs mill* produces paper from pulp, e.g. liquid packaging board, white top kraft liner, folding carton board, kraft and sack paper and fluff pulp. *KEAB* is an energy company owned by *Korsnäs* that produces electricity, process steam and heat for *Korsnäs'* needs. The heat delivery from *KEAB* includes heat from oil, flue gas condensing, steam from bio-fueled CHP plant and heat pumps. *KEAB* guarantees to deliver in effect up to 70 MW to the district heating system. The excess heat from *Korsnäs mill* includes heat from evaporators that are unconventional in the sense that they are built to supply heat to *GEAB*. This excess heat is limited to a maximum of 285,000 MWh/year to the district heating network. There is also an oil-fired boiler to cover peak loads in the district heating system. The energy system is further described in [8].The energy system structure and the plant data is shown in Fig. 1 and Table 1, respectively.

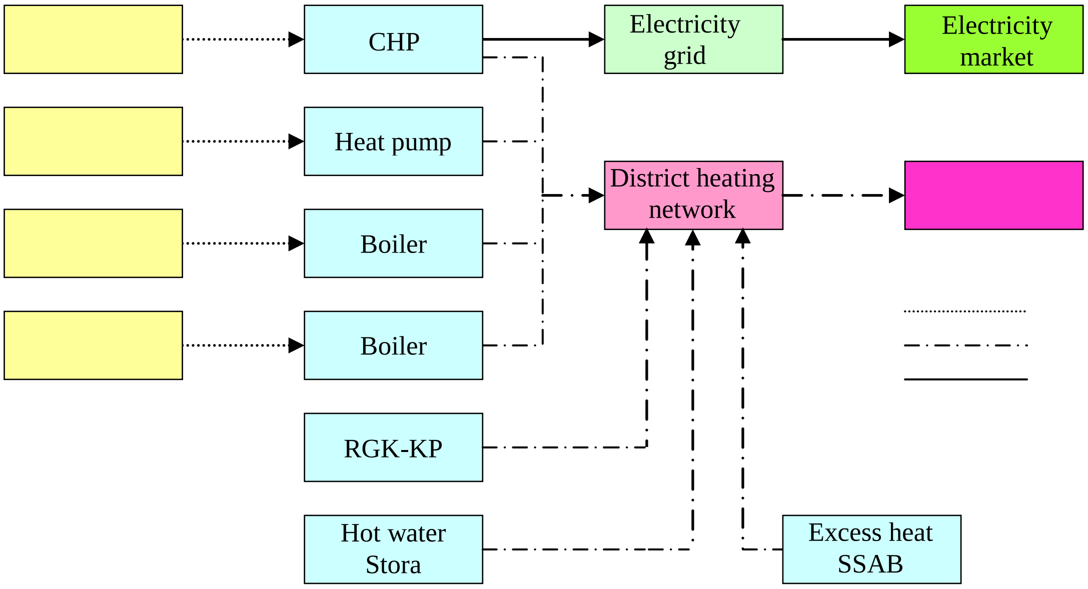

Fig.3. Simplified view of electricity and district heating production in the city of Borlänge.

2.2 Energy system structure in Sandviken municipality

The city of Sandviken is situated on the east coast of Sweden, 190 km north of Stockholm, and has about 37,000 inhabitants. *Sandviken Energi AB*, hereinafter called "*SEAB*", owns the local energy utility in the municipality. A CHP plant is used to produce heat for district heating and electricity with an 8 MW flue gas condensing unit. The CHP plant uses a bio-fuel mix (peat and wood chips) as a supply fuel. The total district heating demand is around 230 GWh/year. A wood powder boiler covers peak loads and also summer loads of the district heating demand when the

CHP is closed in summer for maintenance work. There are also LPG and oil boilers to cover peak loads in the district heating demand. The energy system is further described in [8]. The energy system structure and the plant data is shown in Fig. 2 and Table 1, respectively.

Table 1
The energy systems of GEAB, SEAB and BEAB.

System	Plant type	Heat (electricity) output (MW)	Efficiency (%)	Fuel type
GEAB				
	CHP	75[a] (22)	88[b] (0.4[c])	Bark/wood chip
	Boiler	170	85	Oil
	Boiler	120	85	Bio-gas
	Heat supply from KEAB	70	100	
	Heat supply from Korsnäs	38	100	
SEAB				
	CHP	26[a] (5.2)	90[b] (0.28[c])	Peat/wood chip
	Boiler	20	85	Wood powder
	Boiler	40	90	LPG
	Boiler	20	90	Oil
BEAB				
	CHP	23 (7)	90 (0.3[c])	Waste
	Excess heat[d] from SSAB mill	2.7-10[d]	100	
	Heat from Stora Kvarnsvede mill	30[e], 75[f]	100	
	Boiler	125	82	Oil
	Boiler	20	82	Oil
	Boiler	22[a]	93[b]	Bio-fuel

[a] Including flue gas condensing.
[b] Excluding flue gas condensing.
[c] Electricity-to-heat output ratio (without flue gas condensing heat).
[d] Time dependent power, maximum delivered energy 285,000 MWh/year.
[e] Heat from flue gas condensing at Stora Kvarnsvede mill.
[f] Heat from hot water boiler at Stora Kvarnsvede mill.

2.3 Energy system structure in Borlänge municipality

The city of Borlänge is situated on the east coast of Sweden, 220 km north of Stockholm, and has about 47,000 inhabitants**.** The total district heating demand is around 450 GWh/year and heat generation is carried through energy utilities which belong to *Borlänge Energi AB*, hereinafter called "*BEAB"*, the municipal energy utility for the city of Borlänge. The base supplier of heat is the new waste bio-fuel CHP plant with flue gas condensing unit. There is a bio-fuel-fired boiler with flue gas condensing (22 MW) and a heat pump (24 MW heat). *BEAB* also utilises limited excess heat from the *SSAB* company (max 60,000 GWh/year) and *Stora Kvarnsveden mill*. The heat from *Stora Kvarnsveden mill* consists of heat from flue gas condensing the so-called RGK-KP (30 MW) and hot water (75 MW), which covers the remaining load in the district heating demand. The heat pump is not included in the present analysis because it has gone out of production. There are also oil-fired boilers (145 MW heat) to cover peak loads in the district heating demand. The energy system is further described in [8]. The energy system structure and the plant data is shown in Fig. 3 and Table 1, respectively.

3. Method

3.1 Model used to analyse the district heating system

For analysis of district heating systems an optimisation model known as MODEST (Model for Optimisation of Dynamic Energy Systems with Time-dependent components and boundary conditions) is used [9, 10]. In the MODEST code the whole system is represented as a network of energy chains. The network of the described energy system starts from the primary energy supply and ends in the end-user sectors. MODEST is a bottom-up model and is driven by an exogenous demand for useful or final energy in the end-user sectors. The MODEST model includes descriptions of other activities due to national characteristics and also detailed sub-systems for e.g. domestic fuel supply and combined heat and power production. The system is optimised by linear programming using the total present value costs of the entire system over the whole study period, i.e. 10 years for the present study, as the objective function which is to be minimised. Present and potential installations and energy flows should be considered and their best combination can be obtained through optimisation. Several alternatives with regard to energy supply and conservation measures may be included in the analysis. The model has flexible time steps, which can reflect demand peaks and diurnal, weekly and seasonal variations in energy demand and other parameters. The MODEST code has been applied to the electricity and district heating supply for more than 50 Swedish municipalities [11-15]. The model can be used among other things as support in decision-making to find an optimal investment. In this paper, MODEST has been applied to the electricity and district heating supply for the cities of Gävle, Sandviken and Borlänge.

3.2 System cost and input data

The system cost, which is the operational cost for providing heat to the district heating grid during a ten-year period, is calculated in the model. The investment cost for connection of heat sparse areas to district heating systems is included. The investment cost is applied on new distribution pipes. Operating and maintenance costs, costs related to emission allowance trading, and carbon dioxide and energy taxes are also included. Various predictions of future costs for emission allowance trading exist; the one assumed in this study is 15 EURO/ton emitted CO_2. The green electricity certificate price is also included in the model and is assumed to be 25 EURO/MWh.

Fuel costs and CO_2 emissions used in this paper are shown in Tables 2 and 3. Energy and CO_2-taxes are included in the fuel costs. Bio-fuel is assumed to be Carbon dioxide neutral, according to the IPCC guidelines for national greenhouse gas accounting [16]. The local electricity production replaced electricity produced by different emission-accounting models to explore the differences depending on the extent CO_2 emissions can be treated. Three different alternatives for electricity production have been assumed in the present study, see Table 4. Coal-fired condensing power (CFCP) plants have been assumed to be the short-term marginal power plant in the European electricity system. But for a longer-term perspective, natural gas combined cycle (NGCC) plants represent the marginal power plant. Finally, the Swedish average electricity production mix (SAEM) has been used to calculate the CO_2 emissions in order to reflect the traditional accounting method used in Sweden.

Table 2
Fuel costs including taxes that are used in the model for the base case.

Fuel	Waste	Oil	Bio-fuel	LPG
Cost [EURO/MWh], *GEAB*	-	75[1]	13 (Mixed bio-fuel)	
Cost [EURO/MWh], *SEAB*	-	75[1]	19 (wood-powder) 18 (Mixed bio-fuel, including peat)	54[1]
Cost [EURO/MWh], *BEAB*	-40	75[1]	21	

[1] Non-industrial use

Electricity prices are assumed to be 34 EURO/MWh average price [20]. In the model, electricity sales are considered as income, and the model chooses to produce electricity when it is profitable. The estimated number of the detached and stand-alone houses in heat sparse areas, the predicted heat demand, investment cost for new distribution pipes, installation fee, annual subscription as well as variable fee in the cities of Gävle, Sandviken and Borlänge are presented in Table 5.

Table 3
CO_2 emissions from different fuels [17].

Fuel	CO_2 emissions (kg CO_2/MWh of fuel)
Bio-fuel	0
Waste[1]	90
Oil	267
LPG	234
Peat	386

Table 4
Different accounting models for CO_2 emissions for electricity production.

Accounting model	CO_2 emissions (kg CO_2/MWh of electricity)
Short term marginal electricity production (CFCP)	974[a]
Long term marginal electricity production (NGCC)	337[a]
Swedish average electricity production mix (SAEM)	11[b]

[a] Calculated from [18].
[b] [19].

Table 5
Overview of the number of the detached and stand-alone houses, heat demand, investment cost for new distribution pipes, installation fee, annual subscription as well as variable fee to district heating systems in the cities of Gävle, Sandviken and Borlänge [8, 21].

Municipality	Gävle	Sandviken	Borlänge
Number of houses	6 047	360	651
Heat Demand [GWh/year]	158	10	13
Investment cost for new distribution pipes [MEURO]	15 400	1 147	1 265
Installation fee [EURO/house]	5 914	1 462	1 608
Annual subscription fee [EURO/house and year]	761	300	83
Variable fee [EURO/MWh]	38	43	59

4. Results

This section contains the optimisation results of the present systems with and without heat sparse areas in Gävle, Sandviken and Borlänge, respectively. The optimisation calculations for each case provide system costs, the amount of heat and electricity produced and the amount of emissions of CO_2 using different accounting models.

4.1 Optimisation of existing energy systems with and without heat sparse areas

The Gävle, Sandviken and Borlänge energy systems have been simulated with and without the connection of detached and stand-alone houses in heat sparse areas to assess the effects of the new heat load in the district heating systems on the energy system utility and environment. An overview of the simulated cases is presented in Table 6.

Table 6
Overview of the simulated cases in Gävle, Sandviken and Borlänge.

Description	Case	Municipality, Heat demand [GWh/year]		
		Gävle	Sandviken	Borlänge
Simulation of the existing energy system without heat sparse areas	Present	785	231	450
Simulation of the existing energy system with heat sparse areas	Base	943	241	463

4.2 Heat and electricity production for the present and base case in Gävle

The optimal heat production according to the optimisation is shown in Fig. 4. Fig. 4 shows heat supply to the district heating system of Gävle, for the present and base case provided by different utility plants.

As shown in Fig. 4, the bio-fuel CHP plants, together with heat waste from *KEAB* and *Korsnäs*, generate the major part of the district heating. The oil-fired boilers cover the peak loads. In the base case, the bio-fuel CHP plant increases its energy production due to increasing the amount of bio-fuel in order to not only cover the extra heat demand but also to enable increased electricity generation. This increases electricity production considerably, from 88 GWh/year (present case) to 125 GWh/year (base case), which also reduces the system costs due to more revenue from both electricity sales and electricity certificate trading. The bio-fuel supply increases from 349 GWh/year to 500 GWh/year. The oil fuel supply increases from 10 GWh/year to 22 GWh/year.

The result of optimisations shows that the connection of heat sparse areas to the district heating grid for *GEAB* means that the system cost would decrease by 5 MEURO/year including the investment cost for the new distribution pipes.

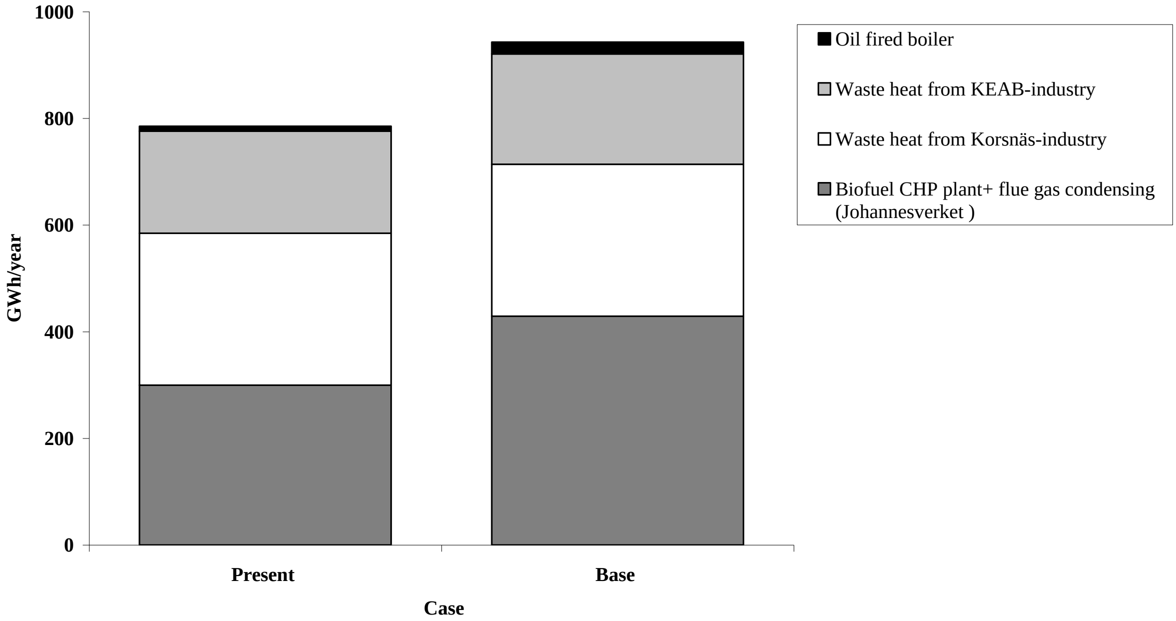

Fig. 4. Case analysis result: heat production in Gävle

4.3 Heat and electricity production for the present and base case in Sandviken

The optimal heat and electricity production according to the optimisation is shown in Fig. 5. Fig. 5 explores which plants are going to be used in order to provide the heat supply to the district heating system of Sandviken, for the present and base case.

Fig. 5 shows that the bio-fuel CHP plant covers the base load throughout the year. The bio-fuel boiler supplies additional heat during the year. LPG boiler will be used to cover the remainder of the heat demand during the winter. After implementation of the new extra heat load in the base case, both the bio-fuel boilers and the CHP plant increase their energy production in order to cover the extra heat demand. This means that the electricity generation will increase from 32 GWh/year to 34 GWh/year, which also reduces the system costs due to more revenue from both electricity sales and electricity certificate trading.

For *SEAB* in Sandviken the system cost decreases by just over 214,300 EURO/year if the heat demand load increases from today's 231 GWh/year to 241 GWh/year, and if the investment concentrates only on new distribution pipes.

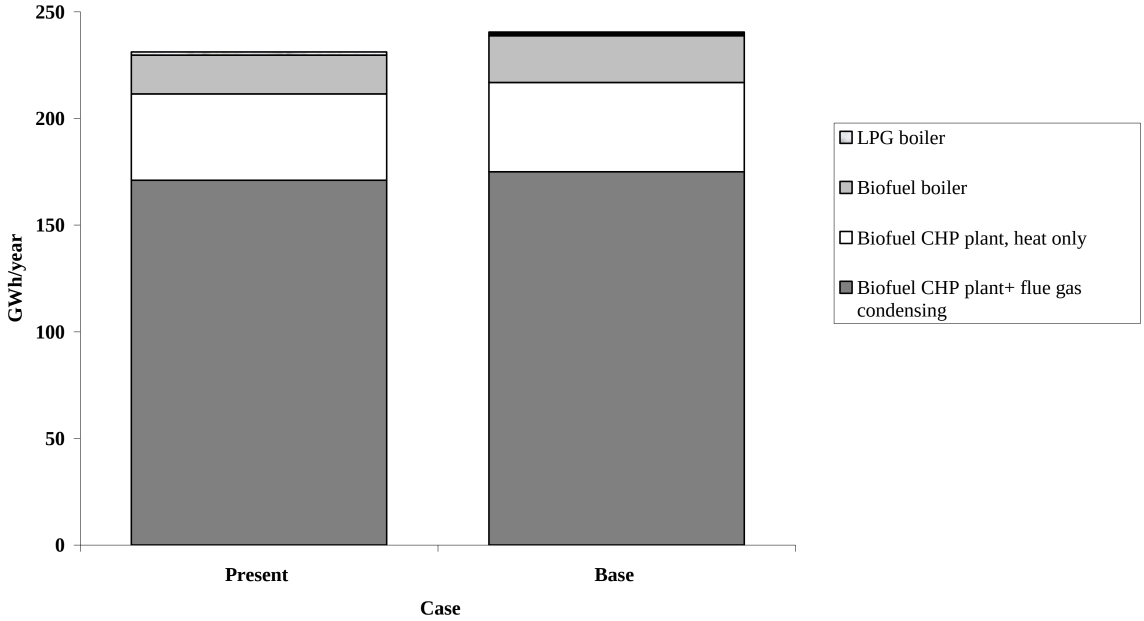

Fig. 5. Case analysis result: heat production in Sandviken.

4.4 Heat and electricity production for the present and base case in Borlänge

As shown in Fig. 6, the new waste CHP plant together with the bio-fuel boiler generates the major part of the heat for the district heating system. The excess heat from *Stora Kvarnsveden* and *SSAB* supplies additional heat during the year. After implementation of new extra heat load in the base case, the new waste CHP plant increases its energy production in order to cover the extra heat demand. This means that generation of electricity will increase from 51 GWh/year to 55 GWh/year, which also reduces the system costs due to more revenue from electricity sales.

For *BEAB* in Borlänge the system costs would decrease by 321,500 EURO/year if the heat load demand increases from today's 450 GWh/year to 463 GWh/year, and investment is concentrated only on new distribution pipes.

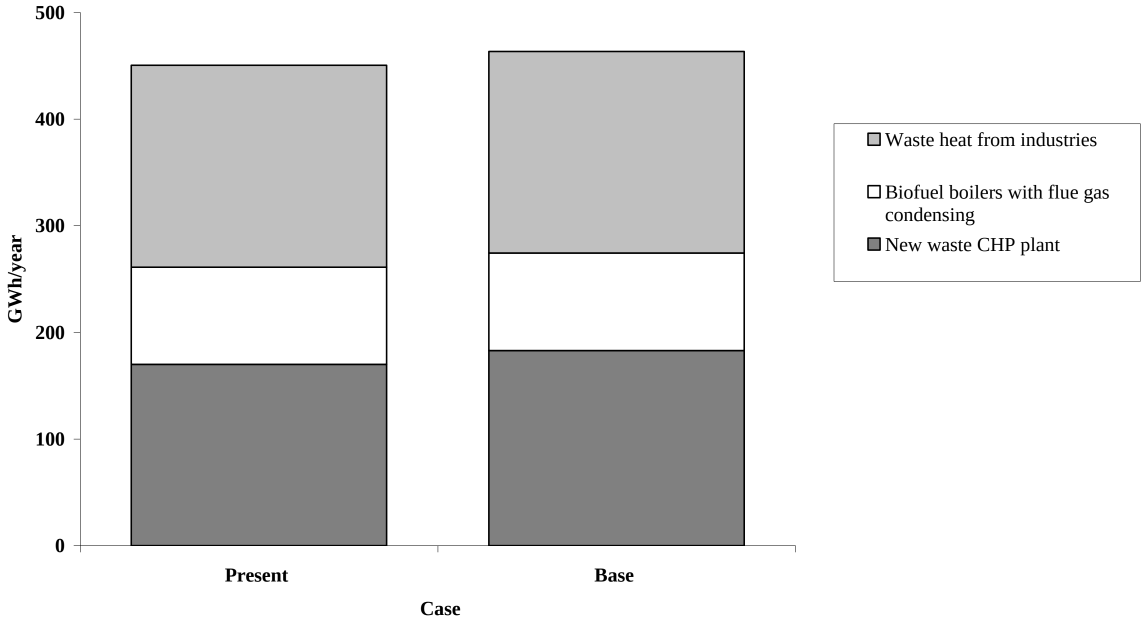

Fig. 6. Case analysis result: heat production in Borlänge.

4.5 CO_2 emissions for the present and base case

The annual reduction in CO_2 emissions for the studied municipalities and for the different accounting models, compared to the present case, is shown in Table 7. The accounting models for CO_2 emissions are presented in Table 4. In order to estimate the CO_2 emissions from the houses in the heat sparse areas before connection to the district heating network, two different heating systems have been considered. The detached and stand-alone houses in the heat sparse areas have been heated either by an oil boiler with an efficiency of 90% or by a radiator system using direct electricity. As shown in Table 7 there is possibility to reduce CO_2 emissions for all accounting models and for both heating systems, except for the case with Swedish average electricity production mix (SAEM) and houses heated by direct electricity.

The largest reductions of CO_2 emissions are found by accounting for short-term electricity production using a CFCP plant and long-term electricity production using an NGCC plant. It is worth mentioning that even though the average Swedish electricity production mix is used to account for the CO_2 emissions, there are modest possibilities to reduce CO_2 emissions by connecting the houses heated by oil to the district heating network.

Table 7
The annual reduction (- sign)/increment (+ sign) CO_2 emissions in ktonnes for the studied municipalities for the different accounting models and different heating systems compared to the present case.

Description	Houses heated by direct electricity			Houses heated by oil		
	CFCP	NGCC	SAEM	CFCP	NGCC	SAEM
City of Gävle	-186,0	-61,8	+1,8	-79,0	-55,4	-43,3
City of Sandviken	-9,8	-2,1	+1,8	-30,0	-1,7	-1,1
City of Borlänge	-14,9	-4,0	+1,5	-6,0	-3,5	-2,2

5. Sensitivity Analysis

A sensitivity analysis has been conducted to examine the effect of varying several parameters on the base case assumptions. Table 8 shows the cases that have been studied and compared with the Base case for each city. The electricity price is 34 EURO/MWh, cost of emission allowance trading is 15 EURO/tonne CO_2 and the bio-fuel price is based on Table 2 for the Base case. Results of the sensitivity analyses are provided in the following sections.

Table 8
Variables changed in sensitivity analysis

Variable	Sensitivity analysis cases		
Electricity price [EURO/MWh]	50	70	110
Cost of emission allowance trading [EURO/tonne CO_2]	10	20	30
Bio-fuel price in Table 2 increased by	10%	20%	30%

5.1 Sensitivity analysis for GEAB

Table 9 shows the profitability of connecting small houses in heat sparse areas to district heating systems at base price for bio-fuel but with an increasing price of electricity to European levels in the municipality of Gävle [22]. Fig. 7 shows the profitability of connecting small houses in heat sparse areas to district heating systems with different bio-fuel and electricity prices for *GEAB*.

Electricity price

An increase in the price of electricity from today's level to European prices of electricity (110 EURO/MWh, 70 EURO/MWh, 50 EURO/MWh), with the base price of bio-fuel, see Table 2, does not change the structure of the energy system in the base case. The system cost decreases from 3.8 MEURO/year (present case) to approximately -11 M EURO/year with the electricity price of 110 EURO/MWh, -6 MEURO/year with the electricity price of 70 EURO/MWh, and -3.4 MEURO/year with the electricity price of 50 EURO/MWh; these are a result of an increase in the price of electricity price. Table 9 shows how the profitability varies with an increase in the electricity price to the European level.

Table 9
The profitability (MEURO/year) with an increase in the electricity price.

Description	Electricity price			
	34 EURO/MWh	50 EURO/MWh	70 EURO/MWh	110 EURO/MWh
City of Gävle	5.0	7.2	9.8	14.8
City of Sandviken	0.2	0.75	1.5	2.9
City of Borlänge	0.3	1.2	2.3	4.6

If the price of electricity increases from today's level to European prices of electricity (50 EURO/MWh, 70 EURO/MWh and 110 EURO/MWh), with the base price of biomass fuel, the profit becomes: 7.2 MEURO/year, 9.8 MEURO/year and 14.8 MEURO/year compared to the present case.

Bio-fuel price

An increase in the price of bio-fuel by 10, 20 and 30% and an increase in the price of electricity from today's levels to European prices of electricity (110 EURO/MWh, 70 EURO/MWh, 50 EURO/MWh), does not change the structure of the energy system in the base case but the profitability will vary. Fig. 7 shows the profitability for base cases compared with the present case at different electricity and bio-fuel prices.

5.2 Sensitivity analysis for SEAB

Table 9 shows the profitability of connecting small houses in heat sparse areas to district heating systems at base price for bio-fuel but with an increasing price of electricity to European levels in the municipality of Sandviken [22]. Fig. 8 shows the profitability of connecting small houses in heat sparse areas to district heating systems at different bio-fuel prices and electricity prices for *SEAB*. Fig. 9 shows the profitability of connecting small houses in heat sparse areas to district heating systems at various values with regards to cost for emission allowance trading.

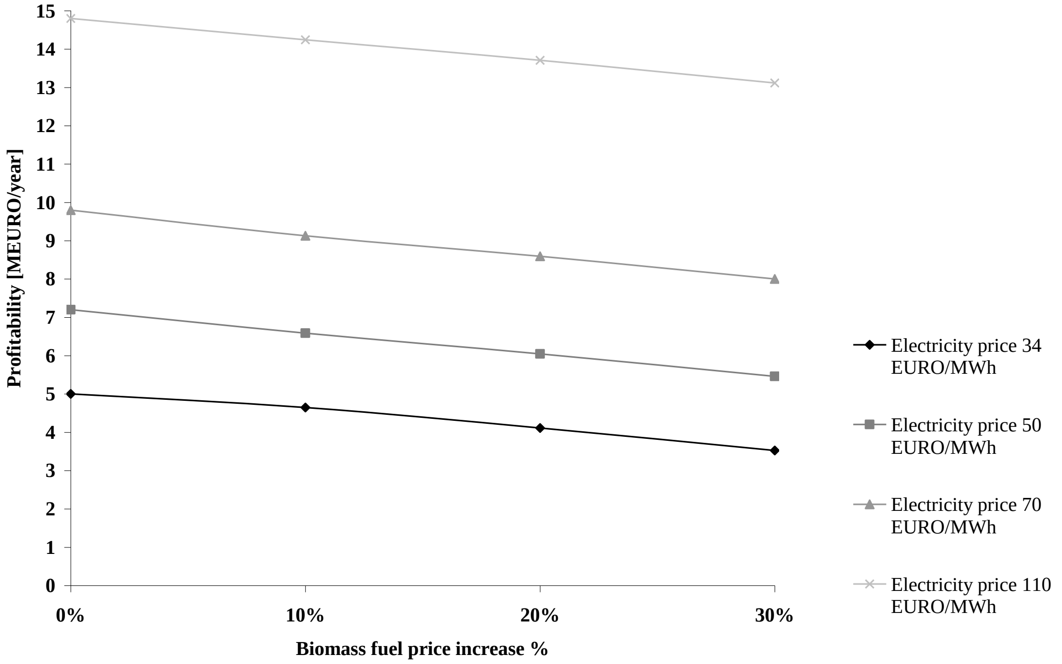

Fig. 7. Profitability at different electricity prices relative to biomass fuel prices, Gävle

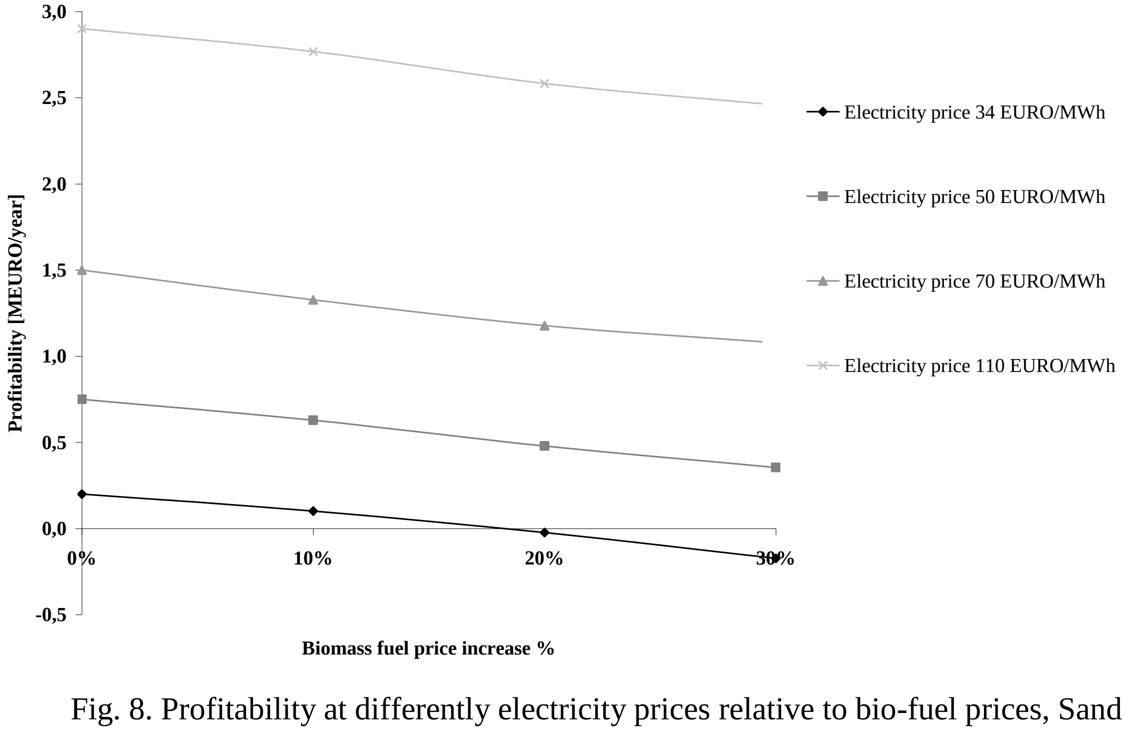

Fig. 8. Profitability at differently electricity prices relative to bio-fuel prices, Sandviken.

Electricity price

An increase in the price of electricity from today’s levels to European prices of electricity (110 EURO/MWh, 70 EURO/MWh, 50 EURO/MWh), with the base price for biomass fuel, does not change the structure of the energy system much. The bio-fuel CHP plant with its FB boilers accounts for the majority of energy production. With an increased price of electricity to 50 EURO/MWh the production of heat from the FB boilers increases in order to produce more electricity. Thereby, the production of direct heat from the FB boilers will be somewhat decreased. After that, the energy system structure becomes exactly the same when the price of electricity increases from 50 EURO/MWh and up to 110 EURO/MWh. The system cost will decrease, partly because of the increased production of electricity, partly because of increased prices of electricity that provide increased revenues. The system cost decreases from approximately 2.7 MEURO/year to approximately -0.2 MEURO/year with the price of electricity at 110 EURO/MWh, 1.17 MEURO/year at 70 EURO/MWh and 1.9 MEURO/year at 50 EURO/MWh as the result of increasing prices of electricity.

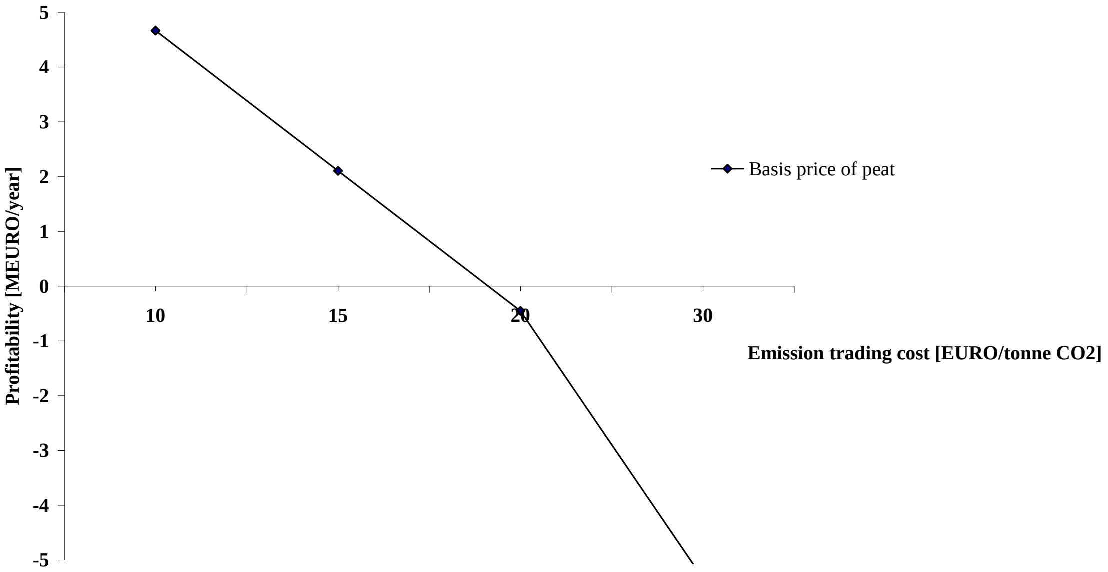

Fig. 9. Profitability at various values on costs for emission allowance trading, Sandviken.

If the price of electricity increases from today’s levels to European prices of electricity (50 EURO/MWh, 70 EURO/MWh and 110 EURO/MWh), with the base price of bio-fuel, the profit becomes 0.8 MEURO/year, 1.5 MEURO/year and 2.9 MEURO/year compared to the present case, see Table 9.

Bio-fuel price

An increase in the price of bio-fuel by 10, 20 and 30% with today’s price of electricity does not change the structure of the energy system compared with the base case. The system cost increases with increased bio-fuel prices. An increase in the price of electricity from today’s level to 50 EURO/MWh with the basic price of bio-fuel results in increased production in CHP plants with FB boilers in order to produce more electricity. Thereby, the production of direct heat coming from the FB boilers decreases somewhat. The energy system structure becomes exactly the same when the price of electricity is increased from 50 EURO/MWh up to European prices of electricity up to 110 EURO/MWh. An increase in bio-fuel price by 10, 20 and 30% at different European prices of electricity (50 EURO/MWh, 70 EURO/MWh, 110 EURO/MWh) does not change the structure of the energy system but, on the other hand, the profitability will be changed. Fig. 8 shows the profitability for the base case compared with the present cases of different electricity prices relative to bio-fuel prices. With electricity price of 34 EURO/MWh and an increase in bio-fuel price of 20% and up, profitability becomes negative.

Costs for emission allowance trading

An increase in the costs for emission allowance trading from 15 EURO/tonne CO_2 to 10 EURO/tonne CO_2, 20 EURO/tonne CO_2 and 30 EURO/tonne CO_2 does not change the structure of the energy system compared with the base case. The system cost, on the other hand, is changed due to increased costs for peat because of increasing the costs for emission allowance trading. This in turn means that profitability will decrease with increased costs for emission allowance trading, see Fig. 9.

5.3 Sensitivity analysis for BEAB

Table 9 shows the profitability of connecting heat sparse areas to district heating systems at different bio-fuel prices with an increasing price of electricity to European levels for *BEAB* [22].

Electricity price

An increase in the price of electricity from today's level to European prices of electricity (110 EURO/MWh, 70 EURO/MWh, 50 EURO/MWh), with the basic price of bio-fuel, does not change the structure of the energy system. The system cost decreases from approximately 2 MEURO/year to approximately -2.6 MEURO/year with the price of electricity at 110 EURO/MWh, -0.3 MEURO/year at 70 EURO/MWh and 0.8 MEURO/year at 50 EURO/MWh as the result of increased prices of electricity.

If the price of electricity increases from today's level to European prices of electricity (50 EURO/MWh, 70 EURO/MWh and 110 EURO/MWh), with the base price of bio-fuel, the profit becomes: 1.2 MEURO/year, 2.3 MEURO/year and 4.6 MEURO/year compared to the present case, see Table 9.

Bio-fuel price

An increase in the price of bio-fuel by 10, 20 and 30% with an increase in the price of electricity from today's level to European prices of electricity (110 EURO/MWh, 70 EURO/MWh, 50 EURO/MWh) does not alter the structure of the energy system. The *BEAB* system is not sensitive to changes with respect to increases in bio-fuel prices by 10, 20 and 30%, because the waste-based CHP plant is responsible to a great extent for the energy production. If the bio-fuel price is increased by 10, 20 and 30% the bio-fuel boiler then withdraws from the system and is replaced by excess heat, delivered from the industry. The profitability will slightly decrease compared with the present case when the price of bio-fuel increases by 10%, while with increases of 20 and 30% the profitability becomes the same as the case with a 10% bio-fuel price increase.

6. Conclusion

The results of the optimisations show that it is surely worth investing in expansion of district heating in the heat sparse areas in Gävle, Sandviken and Borlänge. Heat demand would increase and the possibility of producing more electricity combined with increased prices of electricity in the future would make the investments even more profitable. For *GEAB*, the possibility exists to increase electricity generation through the increased heat load. This would be through increasing the amount of bio-fuel to the CHP plant from today's 349 GWh/year to 500 GWh/year. For *SEAB*, the possibility exists of increasing the generation of electricity with the increased heat load: 32 GWh/year to 34 GWh/year by increasing the amount of bio-fuel. For *BEAB*, the possibility exists of increasing the generation of electricity with the increased heat load, through increasing the amount of waste fuel to the waste boiler which, in turn, increases the heat production from the boiler from today's level of 170 GWh/year to 183 GWh/year.

The study shows that connection of heat sparse areas to district heating increases electricity generation by approximately 43 GWh/year. The global emissions of CO_2 would decrease by 211,0 ktonnes/year considering the coal-fired condensed power plant as the marginal electricity production plant. For the natural gas condensed power plant the CO_2 reductions will be 68,0 ktonnes/year. The results revealed that even though the SAEM is used to account for the CO_2

emissions, there are modest possibilities to reduce CO_2 emissions by connecting the houses heated by oil to the district heating network.

Connection of heat sparse areas to district heating also means that the system cost decreases by about 5.5 MEURO/year for the municipalities together with today's price of electricity. The profitability increases by approximately 22 MEURO/year for the municipalities combined if the price of electricity is at a European level of 110 EURO/MWh.

Sensitivity analyses show that *GEAB* system is not sensitive to changes with respect to an increase of bio-fuel price of 10, 20 and 30%. The energy system structure does not change, and despite increased prices of bio-fuel, it becomes profitable to increase the heat load. This, in turn, depends not only on increased prices of electricity, but also on the electricity certificate (the electricity which is produced by the bio-fuel based CHP plant is entitled to electricity certificates). Although profitability decreases with increased bio-fuel prices, it would still remain profitable to connect heat sparse areas to district heating even with increased bio-fuel prices up to 30%.

The results of sensitivity analyses show that the *SEAB* system is sensitive to changes regarding to bio-fuel price and price of electricity. With today's price of electricity and an increase of bio-fuel price of 20% or more, the system cost will increase compared with the present case (today's system) and it is no longer profitable to connect heat sparse areas to district heating. With increased prices of bio-fuel prices by 10, 20 and 30%, on the other hand, it still becomes profitable to connect heat sparse areas to district heating, if electricity prices increase from 34 EURO/MWh to European prices of electricity (50 EURO/MWh, 70 EURO/MWh and 110 EURO/MWh); however, the profitability decreases when the price of bio-fuel increases.

Sensitivity analyses also show that the *SEAB* system is sensitive to changes relative to the cost of emission allowance trading for peat. The results of optimisations show that when the cost of emission allowance trading for peat is at today's level, i.e. 15 EURO/tonne CO_2, it will be profitable to connect heat sparse areas to district heating, producing a profit of approximately 2.1 MEURO/year compared with the present case. With decreasing value from 15 EURO/tonne CO_2 (today) to 10 EURO/tonne CO_2, the profitability will increase still more compared with the present case. When the value is changed to 20 EURO/tonne CO_2 and 30 EURO/tonne CO_2, the system cost will increase and it is no longer profitable to connect heat sparse areas to district heating.

The *BEAB* system is not sensitive to changes with respect to increases in bio-fuel prices. This is due to the fact that the waste-based CHP plant is to a great extent responsible for the energy production and the bio-fuel boiler will be replaced by excess heat delivered from the industry.

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References

[1] Directive 2004/8/EC of the European Parliament and of the Council of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending directive 92/42/EEC. Official Journal of the European Union, Feb. 21:2004, L52/50–60, 2004.

[2] Swedish District Heating Association. District heating and combined heat and power in the future (Fjärrvärme och kraftvärme i framtiden, in Swedish) ISSN 1401 1401-9264, 2004.

[3] Eurostat Poketbooks. Energy, transport and environment indicators, ISSN 1725 4566 2009.

[4] Swedish Energy Agency, Energy indicators (Energiläget), ET2009:28, 2009.

[5] C. Reidhav and S. Werner, Profitability of sparse district heating, Applied Energy 85 (2008) 867-877.

[6] S. Forsaeus Nilsson, C. Reidhav, K. Lygnerud and S. Werner, Sparse district-heating in Sweden, Applied Energy 85 (2008) 555-564.

[7] Swedish District Heating Association. District heating to residential buildings – heat losses and distribution costs (Fjärrvärme till småhus - Värmeförluster och distributionskostnader, in Swedish). FVF 1997:11, 1997.

[8] S. Amiri S., F. Nilsson, B. Moshfegh, Possibilities and consequences of deregulation of the European electricity market for connection of heat sparse areas to district heating systems

(Möjligheter och konsekvenser av avreglering av den Europiska elmarknaden för anslutning av värmeglesa områden till fjärrvärmesystem- Värmegles projektet, in Swedish), Department of Technology and Built Environment, Gävle, Sweden. Dnr 15-1034/06, 2007.

[9] D. Henning, Optimisation of local and national energy systems: Development and use of the MODEST model, Dissertation No. 559, Linköping University, Linköping, Sweden, 1999.

[10] A. Gebremedhin, A regional and industrial co-operation in district heating systems, Dissertation No. 849, Linköping Institute of Technology, Linköping, Sweden, 2003.

[11] A. Gebremedhin, B. Moshfegh, Modelling and optimisation of district heating and industrial energy system - An approach to a locally deregulated heat market The International Journal of Energy Research 28 (2004) 411-422.

[12] J. Sjödin, D. Henning, Calculating the marginal costs of a district heating utility. Applied Energy 78 (2004) 1–18.

[13] D. Henning, S. Amiri, K. Holmgren, Modelling and optimization of electricity, steam and district heating production for a local Swedish utility, European Journal of Operational Research 175 (2006) 1224–1247.

[14] S. Amiri, L. Trygg, B. Moshfegh, Assessment of the natural gas potential for heat and power generation in the County of Östergötland in Sweden, Energy Policy 37 (2009) 496-506.

[15] M. Karlsson, A. Gebremedhin, S. Klugman, D. Henning, B. Moshfegh, Regional energy system optimization - Potential for a regional heat market. Applied Energy 86 (2009), 441-451.

[16] IPCC, Revised 1996. IPCC guidelines for national greenhouse gas inventories: reporting instructions. IPCC homepage: www.ipcc.ch, information obtained in September 2004.

[17] Statistics Sweden. Emissionsfaktorer för CO_2, kg/MWh (emission factors for CO_2, kg/MWh, in Swedish), http://www.scb.se/templates/tableOrChart__24672.asp. Visited 2007-05-20, 2007.

[18] S. Grönkvist, J. Sjödin, M. Westermark, Models for assessing net CO_2 emissions applied on district heating technologies. International Journal of Energy Research 27 (6), (2003) 601-613.

[19] Swedish Energy Agency. Electricity market 2000. Report ET 18:2000, Eskilstuna, Sweden; 2000.

[20] Nordpool 2006. The Nordic power exchange, Information obtained through Nordpool's homepage: www.nordpool.com, 2006.

[21] Sandberg E. What is the cost of connecting single-family houses? (Vad kostar småhusanslutningen?, in Swedish) Värmegles 2003:4. 2003.

[22] M. Melkerson, S.O. Söderberg, Dynamic electricity prices - pricing in an integrated European electricity market (Dynamiska Elpriser- elprissättning på en integrerad europeisk elmarknad, in Swedish), LiTH-IKP-Ex-2114, Institute of Technology, Department of Mechanical Engineering, Linköping University, Sweden, 2004.