District Heating and CHP – a Vital Role for the Development Towards a Sustainable Society?

LOUISE TRYGG
Division of Energy Systems
Linköping University
SE-581 83 Linköping
SWEDEN
louise.trygg@liu.se
www.liu.se

GÖRAN BROMAN
Department of Strategic Sustainable Development
Blekinge Institute of Technology
SE-371 79 Karlskrona
SWEDEN
goran.broman@bth.se
www.bth.se

CESAR LEVY FRANCA
Department of Strategic Sustainable Development
Blekinge Institute of Technology
SE-371 79 Karlskrona
SWEDEN
clf@bth.se
www.bth.se

Abstract: **-** In Sweden, district heating (DH) is quite well developed and is already mainly based on non-fossil fuels. Increased use of DH is therefore considered as a way of phasing out fossil energy for heating purposes. Furthermore, increased use of DH provides an increased basis for combined heat and power production (CHP). Considering that coal condensing is the marginal production of electricity in Europe, increased use of bio-fueled CHP leads to even greater reductions of global carbon dioxide (CO_2) emissions. However, in a sustainable society, where there is no longer a systematic increase of CO_2 (and no other sustainability problems), the benefits of DH are less obvious. The aim of this work is to explore the impact of DH and CHP in the development towards such a society. A local energy system is studied for five different time periods from 2010 to 2060 with different marginal technologies for electricity production. Results show that when the local energy utility co-operate with a local industry plant and invests in a new CHP plant for waste incineration the global CO_2 emissions for the whole studied time period will be reduced with about 48 000 tonnes, which corresponds to over 100 % of the emissions from today's system for the same time period. When considering that bio fuel is a scarce resource, and that the amount of CO_2 emission linked to waste probably will be lower in sustainable society, the global CO_2 emissions will be about 250% lower compared to the system of today. The studied DH related cooperation and introduction of CHP will reduce the system cost for the whole studied energy system with 2 500 MSEK for the studied period. In general, the results indicate that the modeled measures will not have any major advantages over other heating technologies in a sustainable society but that it can play a vital role for the development towards such a society.

Key-Words: - Sustainable Society, Energy Systems, District Heating, Combined Heat and Power, Global CO_2 Emissions, Coal-fired Condensing Power Plant

1. Introduction

Current energy systems are identified as significant contributors to society's currently unsustainable course [1], [2], [3]. Measures that will help redirect our energy system towards sustainability are therefore most vital to find.

In a fully deregulated European electricity market, it is usually coal-fired condensing power plants that have the highest variable cost and thus work as the marginal source of electricity. Electrical efficiencies of such coal-condensing plants are normally between 35% and 45%. However it should be the plants with the poorest efficiency that supply the margin. Assuming the marginal power production with a 33% electrical efficiency, each MWh of electricity generated in such a coal fired condensing plant releases approximately 1 tonne of carbon dioxide [4]. The global CO_2 impact of 1 tonne per MWh for electricity can thus be compared to, e.g., 0.3 tonne CO_2 per MWh oil, 0.2 tonne per MWh natural gas and to biofuel that according to IPCC is considered as CO_2 neutral.

The principle of coal condensing power being on the margin of the Swedish electric power systems is supported in a report from the Swedish Energy Agency [5], where it is claimed that coal condensing power has been the last dispatched source of power that changes as demand rises or falls in recent years. The same report also states that in the short run, coal condensing power will remain the marginal source, and in a longer perspective the marginal source in a European system will be natural gas based power plants. This above argumentation means that coal condensing is the marginal source today in Sweden as well as in the rest of the EU when considering a fully deregulated European electricity market with no restrictions on transfer capacity,

Several studies have analyzed different heating alternatives for detached houses including the primary energy use of the whole energy system, from the natural resource to the end-user. The results from these analyses show that DH using cogeneration is one of the most energy efficient heating systems and a means towards reaching the European Union's goal of reducing the use of energy. In DH systems with combined heat and power (CHP) generation, this increased used of DH and district cooling (DC) is particularly interesting, since the increased heat production in the CHP-plants contributes to extra electricity generation.

Since Swedish DH systems are primarily supplied by renewable energy sources. DH in a CHP system means that the extra electricity produced in the CHP system can replace electricity produced with marginal condensing power plants and as a result lower global emissions of CO_2. But when instead considering future energy scenarios that present a possibility to supply the world energy demand with renewable and sustainable energy sources, the positive climate benefits of replacing marginal production of electricity will need to be reevaluated since the marginal production of electricity will then not be based on fossil fuels.

The aim of this study is to analyze the impact of introducing CHP in the development towards a sustainable energy system where global energy demand is supplied with only renewable and sustainable energy sources. A regional energy system in Sweden is studied in a system perspective where global CO_2 emissions and system costs are optimized within different time periods from 2010 to 2060.

2. Case study

The municipality of Olofström is situated in the south of Sweden and has about 7 300 inhabitants. The local energy utility is wholly owned by the municipality and has a DH system with a total heat demand of 40 GWh annually. Energy supply units used by the utility today include two biofuel-fired boilers with stack gas condensing which normally runs as base load production. LPG-fired heating boilers and electricity-driven boilers also produce heat for the DH grid. The Volvo Car plant, situated in the municipality, has a total heat demand of 36 GWh annually. The plant has a local heating system of its own supplied by LPG-fired boilers. Both the local energy utility and the Volvo Car plant are interested in co-operating on heat supply. This would mean that the boilers situated at Volvo Car would become part of the municipality's district heating production. It would also mean investment in a pipeline that connects the plant with the municipality's DH grid. There are also ongoing discussions regarding co-operation on excess heat from a large paper mill in the municipality.

In this paper, the above mentioned co-operation between the local energy utility and the Volvo Car plant, is analyzed together with possibilities to use the industrial excess heat for heat supply. Besides that, the effects of investing in a CHP plant are also studied. All measures are analyzed and optimized assuming a strategic development towards a situation where global energy demand is supplied with only renewable energy and sustainable sources in 2050.

3. Modeling

3.1 Method

To analyze the effects of the above mentioned DH related energy supply measures, an optimization model was used to minimize the costs of existing and potential new plants. The model is called MODEST, an acronym for Model for Optimization of Dynamic Energy System with Time-dependent components and boundary conditions [6], [7]. MODEST is a model framework developed for simulation of municipal and national energy systems and is based on linear programming. The aim of the optimization is to minimize the total cost of supplying the demand for heat and steam by finding the best types and sizes of new investments and the best operation of existing and potential plants. The total system cost is calculated as the present value of all capital costs of new installations, operation and maintenance costs, fuel costs, taxes and fees. In this study, the system is optimized over a period of 10 years for each time period and the capital costs are based on a discount rate of 6 %. Each year in the optimization model is divided into 12 months.

The method assumes an ideal situation where, e.g., the demand for district heating and electricity is known and the capacity of the plants is available. MODEST is not primarily a model for operational optimization, even if such can be made. Hourly and daily operations are not the aim of the model, although every hour of the year could be reflected. Even faster or continues fluctuations can, however, not be treated at all. MODEST has no other objective function than the total system cost. Minimization of emissions or the use of certain energy forms at cost maximum cannot be automatically dealt with. These drawbacks have not stopped the performances of the many case studies that have been carried out with MODEST. The model has been tested and applied to the electricity and district heating supply for approximately 50 local utilities, biomass use in several regions, and Swedish power supply [7], [8], [9].

3.2 Scenarios

The aim of the scenarios is to describe potential future cases under given circumstances. Different boundary conditions are simulated and their impacts on the energy system in its entirety are evaluated. Two scenarios for five different time periods; 2010-2020 (T1), 2020-2030 (T2), 2030-2040 (T3), 2040-2050 (T4) and 2050-2060 (T5) are analyzed in this study. Short descriptions of the scenarios are presented in table 1. Based on future renewable energy scenarios develop by Greenpeace, fuel costs for the five time periods are assumed according to table 3.

Table 1. Description of scenarios.

No	Title	Description
S1	Reference	The existing energy system of Olofström DH and of Volvo heating system
S2	COOP, CHP	Co-operation between Olofström DH - Volvo heating system, and an introduction of a CHP for waste incineration

3.3 Prerequisites for the scenario S2

3.3.1 Modeling co-operation

In scenario S2, the Volvo Car plant is connected to the municipality’s DH grid through a two-way pipe. The investment in the pipeline is assumed to be 210 MSEK and the depreciation time is assumed to be 30 years. Since there are on-going discussions regarding supplying the municipality’s DH grid with excess heat from an industrial paper mill, this is also included. The price that the Volvo Car plant pays for heat is assumed to be equal to the cost of producing heat.

3.3.2 Modeling a new CHP plant

Inputs for modeling a new CHP plant for waste incineration are presented in table 2. Since the local energy company is planning to condense moisture from the stack gases, this is also included in the scenario. The CHP plant is assumed to be shut down for maintenance and repairs in July. The income from selling electricity produced in the new CHP plant is assumed to be equal to the price of buying electricity in a common electricity market.

Table 2. Inputs for modeling new CHP plant.

Inputs for modeling a new CHP plant	
Maximum capacity, steam	20 MW
Relation between electricity and heat production	0.24
Investment, CHP boiler and steam turbine	77MSEK/MWel
Depreciation time, CHP and steam turbine	20 years

3.4 Fuel costs, electricity prices and CO_2 emissions

Costs for fuel are shown in table 3. The cost of electricity used is based on historical data from Nordpool 2012 [10] and varies from 622 SEK/MWh down to 278 SEK/MWh. An electricity grid cost of 215 SEK/MWh and energy tax of 290 SEK/MWh are added.

Table 3. Fuel costs.

Time period	Biofuel [SEK/ MWh]	Waste [SEK/ MWh]	LPG [SEK/ MWh]	EUETS [EUR/ tonne]
T1	195	-120	950	10
T2	233	-97	1117	20
T3	253	-84	1289	30
T4	261	-79	1289	40
T5	266	-76	1289	50

Table comments: Prices for T1 are collected from the local energy utility. Price development for all fuels for the periods T2 – T5 are based on Greenpeace estimations [11].

Net emissions of CO_2 are presented in table 4. Biofuel is considered to be carbon dioxide neutral, according to the IPCC guidelines for national greenhouse gas inventories. However, when considering that biofuel is a scarce resource, the use of biofuel will lead to increased use of coal somewhere else [12].

Table 4. Net emissions of CO_2 [kg/MWh].

Fuel	Waste	LPG	Biofuel	Biofuel a scarce resource[1]
Emissions	100	265	0	336

[1] Replaced by coal.

Due to the deregulated European electricity market the change in electricity production and use is assumed to affect the European marginal electricity production. In this study different marginal electricity facilities are considered for the studied time periods; coal condensing power, gas combined cycle condensing power and renewable energy sources according to table 5.

Table 5. Marginal production of electricity and global CO_2 emissions.

	Marginal production of electricity	Global CO_2 emissions [kg/MWh]
T1	CC Coal condensing power[1]	974
T2	CC Coal condensing power[1]	974
T3	NGCC Gas combined cycle condensing power[2]	374
T4	NGCC Gas combined cycle condensing power[2]	374
T5	Renewable energy sources	0

[1]) electricity efficiency 38%
[2]) electricity efficiency 58%

4. Results

As described earlier, the system cost includes the present value of all the capital costs of new installations, operation and maintenance costs, fuel costs, taxes, and fees for a period of ten years. This means that the investment cost of a new pipeline between the municipality DH grid, the paper mill and the Volvo Car plant is included, and also the investment costs of a new combined heat and power plant.

4.1. Global CO_2 emissions

The electricity generated in scenario S2 will affect the global emissions of carbon dioxide when assuming that the marginal source of electricity in a European power system is coal-fired condensing power plants or natural gas combined cycle as in the time periods T1 – T4 (see table 5). However, in the time period T5 when the marginal production of carbon dioxide is renewable energy sources, there will be no reduction of global CO_2 emissions due the extra electricity produced in the new CHP plant. As can be concluded from figure 1, the global emissions of CO_2 due to an introduction of CHP for waste incineration, varies from -4 600 tonnes per year for the period T1 to 5 100 tonnes per year for period T5. The electricity produced in the new CHP plant will lead to a reduction of CO_2 emissions in another European country, which explains why the global emissions of CO_2will be negative in some scenarios. In figure 2 the reduction of global CO_2 emissions between scenario S1 and S2 is presented.

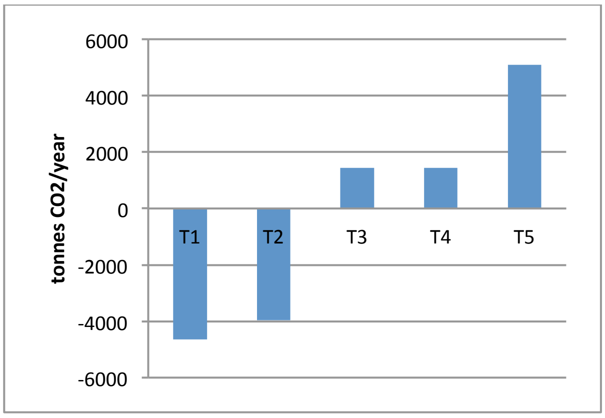

Figure 1. Global CO_2 emissions, scenario S2.

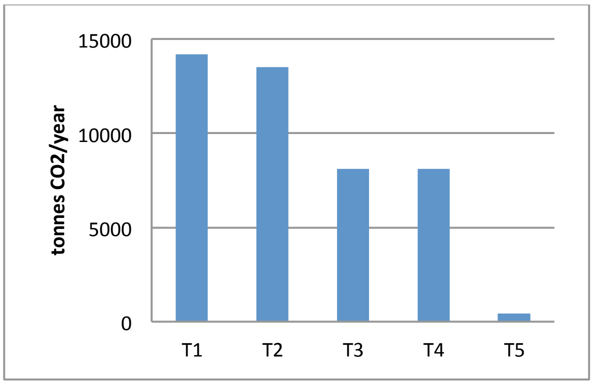

Figure 2. Reduced global CO_2 emissions due to introduction of CHP for waste incineration (S2) compared to the reference scenario (S1).

The total amount of global CO_2 emissions for the whole period from T1 till T5 equals -600 tonnes. This can be compared to the CO_2 emissions of 47 700 tonnes for the same period with today's system (S1), a reduction corresponding to 101%% for the studied system.

The reduced global CO_2 emissions shown in figure 1, are based on a CO_2 emissions factor from waste of 100 kg/MWh (see table 5) for each time period. If instead CO_2 emissions from waste are assumed to decrease to 50 kg/MWh for time period T3 and– T4 and reduced to zero in T5, the total reduction of global CO_2 for the whole period from T1 to T5 will be 58 200 tonnes corresponding to a reduction of 122% (see figure 3). When considering that biofuel is a scarce resource, and that use of biofuel will lead to increased use of coal somewhere else, the reduction of global CO_2 when introducing CHP will instead be 118 500 tonnes for the same period corresponding to a reduction of 248% (see figure 3).

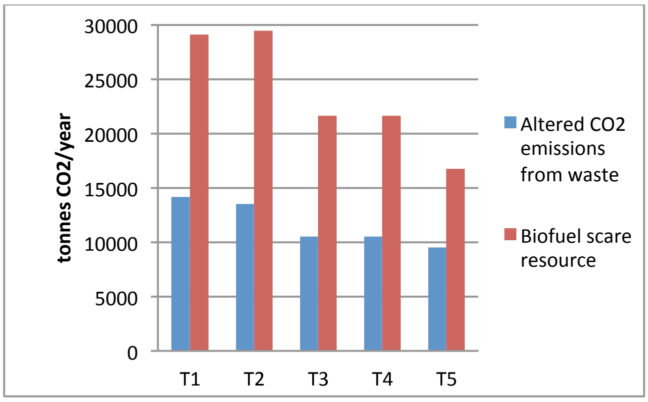

Figure 3. Reduced global CO_2 emissions due to introduction of CHP for waste incineration (S2) compared to the system of today (S1).

4.2. System costs

The system costs for the modeled scenarios represent the cost to meet the demand of DH for the municipality and the Volvo Car plant including income from sold electricity. In figure 4 the reduced annual system costs for each time step are presented. The system cost shown in the figure represents the difference between the reference scenario S1 and the scenario when a CHP for waste incineration is introduced, S2. The total reduction in system cost for the whole period from T1 to T5 equals 2 500 MSEK.

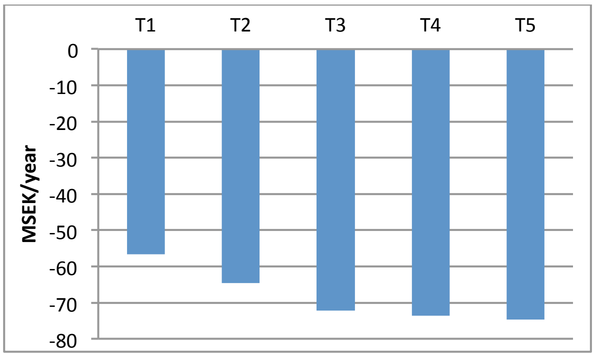

Figure 4. Reduced annual system cost due to introduction of CHP for waste incineration (S2) compared to the reference scenario (S1).

5. Concluding discussion

When coal condensing is the marginal production of electricity in Europe, CHP in a DH system will lead to increased possibilities to lower global CO_2 emissions as the increased electricity production in CHP replaces marginal electricity. However, in a sustainable society, where there is no longer a systematic increase of CO_2 (and no other sustainability problems), the benefits of DH and CHP are less obvious. In this paper the impact of DH and CHP in the development towards such a society has been analyzed. Results from the optimizations show that when considering cooperation on heat between a local energy utility and an industry plant, investment in a CHP plant for waste incineration will lead to reduced global CO_2 emissions with 48 300 tonnes, which corresponds to about 100 % of the emissions from today's system for the same time period. When considering that today's CO_2 emission factor for waste most likely will be lower in a future sustainable society the reduction of global CO_2 will be even higher. Taking into account that biofuel is a scarce resource, the reduction of CO_2 will be yet even higher, almost 250% compared to the system of today.

Implementing the analyzed measures will also give financial benefits. The total system cost for the studied system will 118 MSEK for the studied period, which can be compared to 2 600 MSEK for today's system.

The benefits of investing in CHP are less obvious when considering a future sustainable society, where all electricity is produced by renewable energy sources. This paper show however that DH related energy supply measures like investing in a new CHP for waste incineration are vital to take in the development towards this sustainable situation. Results show both reduced global CO_2 emissions as well as a decreased system cost for the studied system due to an introduction of CHP. For utilities, municipalities and other DH stakeholders to rationally develop viable investment strategies, decision support of the type used in this study is therefore obviously important.

Acknowledgements

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