ON THE FUTURE ROLE OF HEAT PUMPS IN SWEDISH DISTRICT HEATING SYSTEMS – COMPETITION WITH WASTE INCINERATION AND COMBINED HEAT AND POWER UNDER GREENHOUSE GAS EMISSION RESTRICTIONS

Marcus Eriksson, PhD student, Department of Chemical Engineering and Environmental Science, Chalmers University of Technology, Gothenburg, Sweden

Lennart. Vamling, Professor, Department of Chemical Engineering and Environmental Science, Chalmers University of Technology, Gothenburg, Sweden

ABSTRACT

Heat pumps play an important role in Swedish district heating systems. Various policy instruments currently introduced, for example tradable emission permits, tradable green certificates and the ban on land filling of combustible waste will have an impact on the role of heat pumps in district heating systems. In this paper, a case study of a district heating system is performed to analyze how the heat production of an existing heat pump and the possibilities to reinvest in a new heat pump if the existing is phased out is changed due to waste incineration. Results are obtained for several scenarios of policy instruments. In most scenarios used in the study, waste incineration will reduce the heat production from the heat pump. However, in some cases, waste incineration replaces an investment in combined heat and power that would have reduced the heat pump even more, thus the results indicate that the impact of waste incineration on heat pumps is ambiguous.

Keywords: ***heat pumps, combined heat and power, district heating, waste incineration.***

Nomenclature

DH	District heating	O&M	Operation and maintenance cost
CHP	Combined heat and power	NGCC	Natural gas combined cycle
GHG	Greenhouse gas	TEP	Tradable emission permit
HOB	Heat only boiler	TGC	Tradable green certificates
MWh	Mega Watt hour = 3600 MJ	SEK	Swedish kronor (1 US$ = 7.35 SEK) 2004 Average value

1 INTRODUCTION

In Sweden, district-heating (DH) systems have an important role in the energy system. Approximately 170 PJ of heat is distributed annually in district heating systems. (Svensk Fjärrvärme 2003) One major energy conversion technology in district heating systems, accounting for approximately 24 PJ/yr of heat production, is heat pumps using mainly seawater or sewage water as heat source.

The DH systems in Sweden are today facing new conditions. Several of these new conditions will have an impact on district heating systems and the technologies that are used.

- Integration of the European electricity markets, which may level out the electricity prices in Europe, thus probably increase the electricity price in Sweden.

- New policy instruments for reducing carbon dioxide emissions, like tradable emission permits (TEP), and increasing the share of renewable sources for electricity, for example tradable green certificates (TGC) are being introduced.

- There is today a ban on land filling of combustible waste in Sweden, which has lead to an increased use of waste incineration in the district heating systems.

Many of the heat pumps that are currently in use in district heating systems were installed in the 70s and 80s and are now starting to become old. Due to the different situation today compared to when the heat pumps where built, an important question is if existing heat pumps should be used in the future and old heat pumps replaced by new heat pumps or not.

2 AIM

The aim of this study is to analyze how and to what extent heat pumps are affected by waste incineration in a Swedish district heating system. Specifically, the following questions are addressed:

- How is the heat production of an existing heat pump affected by waste incineration in a district heating system in a society with tradable emission permits and tradable green certificates?

- How are the possibilities to replace an existing heat pump affected and what is the allowable investment cost if it should be replaced with a new heat pump of the same capacity?

3 POLICY INSTRUMENTS AFFECTING SWEDISH DISTRICT HEATING SYSTEMS

3.1 Waste Incineration

Since 1st of January 2002 there is a ban on land filling of combustible waste in Sweden (MoE 2001). This means that other waste management methods have to be used and one of them is incineration of waste in plants in district heating systems. The regulation has also lead to an increased use of waste incineration since the cost for using waste as a fuel is negative, as a result of the higher cost for alternative treatment methods. In order to make other waste treatment methods than incineration, for example biological treatment, more competitive, a tax on waste incineration has been analyzed by the Swedish government. Four different levels of tax on waste were investigated, 100 SEK/tonne, 400 SEK/tonne and 700 SEK/tonne (MoF 2002). In this study the impact of waste incineration on the use of heat pumps is done with only the first of these three levels of incineration tax i.e. 100 SEK/tonne waste. Since the available amount of waste is normally limited in a region, different levels of available waste have been modeled.

3.2 Tradable Emission Permits

In January 2005, a system for tradable emission permits (TEP) is established in Europe. Approximately 12000 plants is part of the system, including DH plants, power plants and large industries like pulp and paper (EU 2003). In a cap and trade emission permit system; a regulatory authority determines the aggregate emission quantity that can be emitted within the system, which is the cap. The authority would thus issue emission permits equal to the cap emissions.

The allocation of these permits is however left to the market. The key is to make greenhouse gas emission reductions as cost efficient as possible. Cost efficiency is achieved by allowing trade of emission permits between actors within the TEP system. Each actor will determine if it is better for them to reduce their emissions further or buy permits from someone else who can reduce their emissions at a lower cost. Thus a market price on the emission permits is established equal to the marginal cost of emission reductions within the system. This means that plants included in the TEP system has to buy emission permits for CO_2 emissions emitted and can sell permits if they reduce their emissions (Baumol, Oates 1988).

3.3 Tradable Green Certificates

Another policy instrument are tradable green certificates (TGC), implemented in Sweden in May 2003. The aim of TGC is to increase the share of electricity produced from renewable energy sources. The TGC system means that for each MWh of electricity produced in a conversion unit that is accepted to receive certificates, the producer receives one certificate. Currently, wind power, small-scale hydropower, solar power, tidal power, geothermal power and power based on different biofuels receives certificates. There are still uncertainties if electricity from waste that has a biological origin can receive certificates; however, in this study no certificates are given to electricity from waste.

The certificates can be sold and an extra income is generated to compensate for the higher cost of producing electricity with renewable sources. Consumers of electricity are obligated to buy a certain amount of certificates corresponding to a quota of their total electricity consumption, thus ensuring a demand for certificates. The quota is then raised every year, until 2010, according to the proposition by the Swedish government (MoI 2003).

4 METHODOLOGY

4.1 General Outline

The methodology used to analyze how the heat production of an existing heat pump and the possibilities to reinvest in a heat pump is affected by waste incineration consists of the following steps:

- An optimization model of a district heating system is made. It includes existing plants and possible new investments.

- Three different basic scenarios that represent consistent possible future prices are constructed. Each scenario also has an added possibility to include TGC at 2 different prices, thus a total of 9 scenarios. Each scenario is assumed to prevail for the whole lifetime of a possible new investment, i.e. 20 years.

- For each scenario, the model calculates the optimal configuration and new investments made when an investment in waste incineration can be made. This is done when the available waste is unlimited and one case with a limited amount of available waste, corresponding to a 20 MW heat only plant.

- A baseline is calculated in each scenario as the optimal configuration when waste incineration is not a possible new investment. The baseline is thus an estimate of what would have been done in the absence of waste incineration. Two different cases are used as baseline, one when natural gas is an available fuel and thus gas-based technologies are possible investments and one when gas is not available.

- The impact on the heat pump from waste incineration in a scenario is measured as the difference between delivered heat from the heat pump when waste incineration is an alternative investments and the corresponding baseline. A comparison is also made to the heat production of the heat pump in the existing system, i.e. heat pump heat production with scenario today and no investments allowed.

- The allowable investment cost for a reinvestment in a heat pump is calculated as the maximum investment cost in the heat pump per kW delivered heat to be a part of the optimal configuration with the same capacity as the existing heat pump. It is assumed that no reinvestment in other existing plants in the system is assumed.

4.2 Description of Existing System.

In the first step, an existing system is constructed. Most of the heat pump capacity in Swedish DH is found in the largest DH systems. This study focuses on a system of a smaller size. In this case study, the existing system is described by the energy demand given as the load duration curve, based on a system in the middle of Sweden. Characteristics of the system are summarized in Table 1.

Table 1. Characteristics of the existing DH system

Heat demand (GWh/Yr)	Conversion Technology	Heat production[a] (GWh/Yr)	Share of heat production[a] (%)
234.5	Heat pump	61.3	26.1
	Biofuel HOB	150.5	64.2
	Electric boiler	21.3	9.1
	Oil boiler	1.4	0.6

[a] With existing conditions.

Note that this system is not a result from an optimization under current conditions, neither is it a real system in Sweden.

4.3 Description of Scenarios

To account for the complex interrelation between prices and policy instruments, 3 scenarios are used in this study. One scenario is representing conditions in year 2002 and two scenarios reflecting possible futures under common CO_2 reduction commitments and tradable emission permits.

4.3.1 Scenario today

One feature of Swedish taxes in the stationary energy sector is that the producer pays taxes on fossil fuels while the consumer pays taxes on electricity. The fuel taxes for DH systems consist in 2002 of an energy tax, a CO_2 tax, SO_2 and a NO_x tax. Both the CO_2 tax and the energy tax are paid fully for heat production. Combined heat and power do not pay any energy or CO_2 tax for the part of the fuel used for electricity production but full CO_2 tax and half of the energy tax for the part of the fuel used for heat production. This tax system is under change in 2004, for example changes in the taxation of combined heat and power. Heat pumps and electric boilers are paying an electricity tax for the electricity used; this electricity tax differs depending on geographical location. In the study the taxation levels are based on 2002 taxes. Waste price including an incineration tax of 100 SEK/tonne is based on Holmgren. (Holmgren, Alemayehu 2004)

4.3.2 Future scenarios

There are two scenarios that represent prices when a common CO_2 abatement commitment is introduced. One very important assumption is that it is assumed that current Swedish taxes in DH systems, current CO_2 tax, electricity tax and heat tax are removed when a TEP system is introduced in order to have equal policy instruments for all plants in the TEP system and thus keep cost efficiency. There are thus no CO_2 or energy taxes on fuels but only the cost for CO_2 emission permits. Important for the heat pump is that it is assumed that the current electricity tax is removed since a policy instrument (TEP) is introduced on the supply side of electricity.

Compared to current Swedish DH taxes, it is likely that a common market for tradable emission permits (TEP) will reduce the total fuel tax, at least for lower commitments in CO_2 reductions. Electricity prices are based on the long-term marginal cost for electricity including the CO_2 cost. Combined heat and power gets revenues from electricity sales according to the assumed market price and biofuel combined heat and power (CHP) also receives TGC in the TGC case. Table 2 summarizes the characteristics of the three basic scenarios.

Table 2. Fuel and electricity prices in the basic scenarios including taxes and CO_2 cost. Scenario 2 and Scenario 3 is based on Adahl. (Adahl 2004)

	Scenario today [SEK/MWh]	Scenario 2 [SEK/MWh]	Scenario 3 [SEK/MWh]
Electricity price	205[a]	301	392
Oil price	443	164	219
Biofuel price	129	129	161
Gas price	280[b]	130	171
Waste price 100[c]	-50	-50	-50
CO_2 cost [SEK/kg CO_2]	-	0.05	0.25
Electricity tax	174[d]	-	-
Electricity transmission cost	-	25	25

[a]Wholesale price, assumed value, [b] For use in heat only boiler, [c] Including incineration tax, [d] For heat pump

4.4 Description of the Model

The model minimizes the annual cost, given by the annuity method to produce the energy demand given by the load duration curve. That is to minimize the cost described in Equation 1.

$$C = \sum_{1}^{NoT} a \cdot I_i \cdot \dot{Q}_i + b_i \cdot E_i \quad (1)$$

NoT is the number of technologies, a is the annuity factor, I is the average specific investment cost, Q is the capacity, b is the running cost and E is the heat produced annually from technology i. The average specific investment cost I is size dependent according to Equation 2.

$$I_i = \frac{sizebase_i \cdot sizevalue_i \cdot \left(\frac{capacity_i}{sizebase_i}\right)^{size\exp_i}}{capacity_i} \quad (2)$$

The model adds the technologies with the technology with lowest running cost first to cover the total energy demand. The annuity factor a, is defined in Equation 3.

$$a = \frac{r}{1-(1+r)^{-n}} \quad (3)$$

In Equation 3, n is the lifetime of the investment and r is the calculation rent. An annuity factor of 0.08 has been used in this study. The conditions in each scenario are assumed to prevail for the whole lifetime of the investments made; the same apply for the heat demand of the DH system. The model does not account for minimum load requirements, part load characteristics or temporary shut down periods. Data for district heating plants used in the study are summarized in Table 3.

Table 3. Investment costs and efficiencies of technologies used in the study

Technology	Total efficiency	Electricity -to heat ratio	Sizevalue [kSEK/MW$_{heat}$]	Sizebase [MW]	Sizeexp	O&M [SEK/MWh]
Biofuel CHP	0.90[a,d]	0.5[d]	9050[b]	40[b]	0.68[b]	15[c]
NGCC CHP	0.88[e]	1.0[e]	8894[b]	40[b]	0.68[b]	15[c]
Waste HOB	0.85[e]		9434[b]	40[b]	0.68[b]	30[e]
Waste CHP	0.85[e]	0.3	16653[b]	40[b]	0.68[b]	30[e]
Biofuel HOB	1.05[e]	-	3600[b]	1.0	1.0	15[c]
Oil HOB	0.90[e]	-	1500[e]	1.0	1.0	15[c]
Gas HOB	0.93[d]	-	1300[d]	1.0	1.0	5[c]
Biofuel HOB*	1.05[e,f]	-	-	-	-	15[c]
Heat pump*	3.10[e]	-	-	-	-	5[c]
Electric boiler*	1.00[e]	-	-	-	-	1[c]
Oil HOB*	0.90[e]	-	-	-	-	15[c]

*Existing technologies in the DH system [a]Without flue gas condensation, [b]Olofsson 2001, [c]Knutsson 2003, [d]Rydèn 2003, [f] With flue gas condensation, [e]Assumption

5 RESULTS AND DISCUSSION

5.1 Running Cost

The running cost for different technologies in district heating is presented in Figure 1.

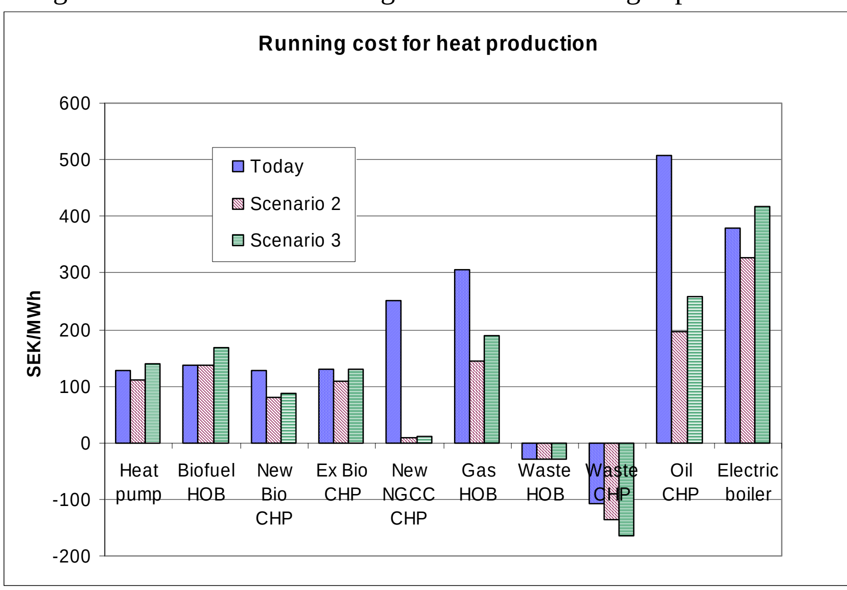

Fig. 1. Running cost for heat production with different technologies in the three scenarios used, no TGC.

As shown in Figure 1, technologies, which use fossil fuels, have lower running cost in scenario 2 and scenario 3 with a common TEP market compared to scenario today due to the current higher taxes on fossil fuels in Swedish district heating systems. This is especially the case for natural gas combined cycle combined heat and power (NGCC CHP), which is also favored by the increasing wholesale price of electricity. The running cost for heat pumps is decreased in scenario 2 due to the lower retail price (incl. tax) when the electricity tax is removed and replaced by TEP on the producer side for electricity production. For higher CO_2 commitments in scenario 3, the retail price increases again due to higher TEP prices resulting in a technology shift from coal condensing power to NGCC condensing plants as marginal power plants in the grid electricity system.

Figure 1 indicates that heat pumps under CO_2 commitments have hard competition from other technologies for base load heat production, especially biofuel CHP, NGCC CHP, and waste incineration. It can further be seen that a biofuel heat only boiler (HOB) has a higher running cost than heat pumps in all scenarios meaning that the merit order between them does not change. Waste incineration has a negative running cost with an incineration tax of 100 SEK/ton due to the higher cost for alternative waste treatment methods.

5.2 How Is the Use of Existing Heat Pumps Affected by Waste Incineration and Combined Heat And Power in the District Heating System?

Basically, waste incineration might lead to three different impacts on the heat production from heat pumps compared to what is done if waste incineration is not used i.e. if another investment in combined heat and power is made.

- Heat production from the heat pump is reduced. This happens as the heat pump is moved up in the load duration curve due to the introduction of waste incineration, which reduces the operating hours. The baseline is to make no alternative investment or that the investment in a waste incineration plant replaces an alternative investment with a lower capacity.

- Heat production from the heat pump increases, or more correctly, is reduced less compared to the baseline. This is the case if the investment in waste incineration replaces another investment that would have been built to a larger capacity or that the added capacity of the waste incineration plant and another investment (if it is possible to build both) is smaller than the alternative investment.

- Heat production from the heat pump is not affected, or affected to a very small extent, which happens if the capacity of an alternative investment is approximately of the same size as the waste incineration plant.

Which of these cases that occur is dependent on the level of available waste and local availability of other fuels but also on the future development of fuel prices and policy instruments since this have an impact on what would have been done otherwise, i.e. the possible alternative investment. The results are presented in Table 4 and as can be seen, all the described cases occur.

Table 4. Results for studied cases

Scenario description			Results				
Basic Scenario	**Available waste**	**TGC in SEK/MWh**	**Measure done**	**Change in heat pump use compared to baseline in GWh/Yr**	**Baseline[a]**	**Waste incineration impact on heat pump compared to present in GWh/Yr**	**Heat pump compared to present (100% is present)**
Scenario today	Optimal	TEP no gas	Invests in waste HOB	-42.06	Existing	-42.06	31.4
		TGC 75		-42.06	Existing		
		TGC 150		-20.72	Invests in bio CHP		
		TEP gas		-42.06	Existing		
	20 MW	TEP no gas	Invests in waste HOB	-28.59	Existing	-28.59	53.4
		TGC 75		-28.59	Existing		
		TGC 150		-7.24	Invests in bio CHP		
		TEP gas		-28.59	Existing		
Scenario 2	Optimal	TEP no gas	Invests in waste CHP	-39.12	Existing	-39.12	36.2
		TGC 75		-39.12	Existing		
		TGC 150		-5.30	Invests in bio CHP		
		TEP gas		-7.00	Invests in NGCC CHP		
	20 MW	TEP no gas	Invests in waste HOB	-28.59	Existing	-28.59	53.4
		TGC 75		-28.59	Existing		
		TGC 150		5.23	Invests in bio CHP		
		TEP gas		3.54	Invests in NGCC CHP		
Scenario 3	Optimal	TEP no gas	Invests in waste CHP	-44.7	Existing	-44.7	27.1
		TGC 75		-17.47	Invests in bio CHP		
		TGC 150		-4.58	Invests in bio CHP		
		TEP gas		-3.79	Invests in NGCC CHP		
	20 MW	TEP no gas	Invests in waste CHP	-22.31	Existing	-22.31	63.6
		TGC 75		4.91	Invests in bio CHP		
		TGC 150		17.81	Invests in bio CHP		
		TEP gas		18.60	Invests in NGCC CHP		

[a] Existing means that the baseline is to keep the existing system and make no investment.

5.2.1 Gas is not available

In all three scenarios there is no alternative investment to waste incineration under only a TEP system when gas is not available. This means that any investment in waste incineration reduce the use of existing heat pumps by pushing the heat pump up in the load duration graph. However, with TGC at high prices, there is an alternative investment in biofuel CHP that is built if waste incineration is not invested in. If the available waste is limited, this investment is built to a larger capacity than waste incineration, thus reducing the heat pump more. It is in no scenario economical to invest in both waste incineration and other CHP production since waste incineration reduces the available heat sink significantly.

Table 4 also show that in scenario today and scenario 2, the waste incineration plant is built as a heat only plant when the available waste is limited, while in scenario 3 it is a waste CHP plant because of the higher electricity price. Part of the lost heat production, due to some waste being used for electricity production, is compensated for by the heat pump and the reduction for the heat pump is less than in scenario 2 for the same amount of available waste.

5.2.2 Gas is available

When gas is available, NGCC CHP is an economical investment under the TEP system and reduces heat production from the heat pump more than waste incineration if the available waste is limited to the level studied here.

5.2.3 Sensitivity analysis

Since the capacity of an alternative investment is dependent on the investment cost of the technology, a sensitivity analysis has been made of the investment cost of biofuel CHP. The levels tested in the sensitivity analysis are shown in Table 5.

Table 5. Tested levels of investment cost for biofuel CHP in sensitivity analysis

Sizevalue	Sizebase	Sizeexponent
7250	60	0.72
8400	40	0.8

Only minor differences in the results were obtained for the values in Table 5, in some cases more biofuel CHP and in some cases less, depending on the changed marginal investments cost, i.e. the cost to build one unit larger plant.

5.3 Results for Maximum Allowable Investment

5.3.1 Replacement alternatives

If the heat pump is moved upwards in the load duration graph due to new investments in waste incineration, biofuel CHP or NGCC CHP the possibilities to make reinvestments in heat pumps when their lifetime is coming to an end is affected. In general, the higher up in the load duration curve the less important is it to have a low running cost i.e. good COP and the more important to have a low investment cost. When old heat pump has to be replaced, six alternatives are possible:

- The existing heat pump is replaced by a new heat pump.

- The existing heat pump is partly replaced by a new heat pump and partly by a new investment.
- The existing heat pump is replaced by a new investment that is built to a higher maximum capacity than if the heat pump did not have to be replaced and increased use of other existing technologies that has available capacity when the new investment is made.
- The heat pump is replaced only by existing technologies with available capacity due to a new investment that is done despite the fact that the heat pump has to be replaced
- The heat pump is replaced by another new investment.

In case that the heat pump is replaced by a new heat pump, no considerations have been made on what kind of heat pump, i.e. choice of working fluid etc. Figure 2 show results for the maximum allowable investment cost to replace the existing heat pump with a new heat pump with the same capacity.

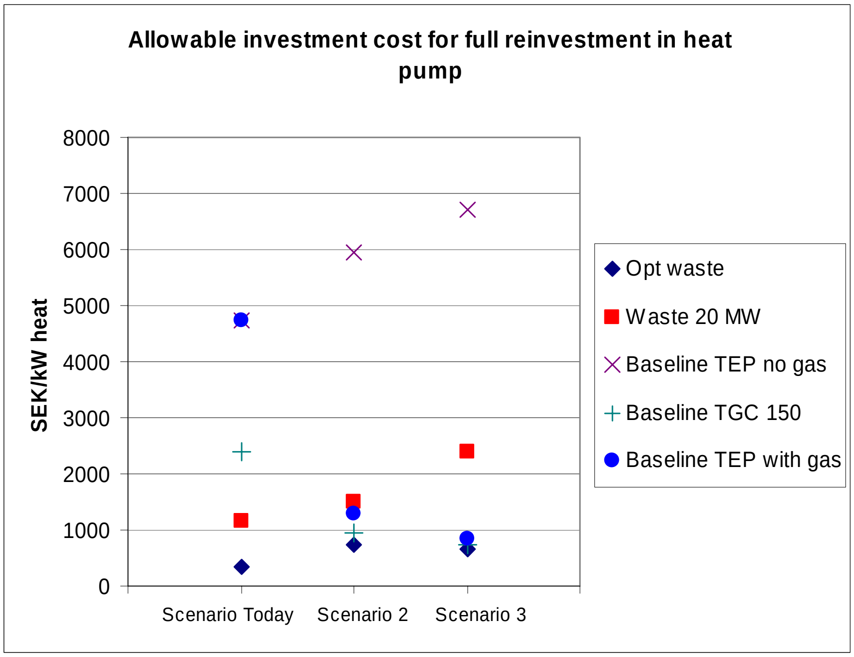

Fig. 2. Maximum allowable investment cost in SEK/kW$_{heat}$ for full reinvestment (7 MW) in a new heat pump.

From Figure 2 it can bee seen that the impact on the allowable investment from waste incineration on the possibilities of reinvesting in heat pumps are ambiguous when compared to the alternatives investments that would otherwise have been done i.e. biofuel CHP and NGCC CHP.

5.3.2 Impact of waste incineration

In scenario today waste incineration decreases the allowable investment cost. With an investment in waste incineration, the heat pump has fewer operating hours and since all other existing plants is moved up in the duration graph there is available capacity if the heat pump is taken out of operation.

A reinvestment in the heat pump thus has to compete with only the running cost of increased use of other existing plants since an increase is not allowed in the waste incineration plant when the available waste is limited. This is the case in all scenarios when waste incineration is built. The upward trend in scenario 2 and 3 when the available waste is limited is because the heat pump gets relatively cheaper to the other already existing technologies, mainly oil and biofuel, and that in scenario 3, part of the waste is used for electricity production as a waste CHP plant is built in scenario 3.

5.3.3 Alternative investments

In this case study, biofuel CHP only affects the possibilities to reinvest in a heat pump if there are TGC. With TGC, and a high TGC price, a biofuel CHP plant is built despite the fact that the heat pump has to be replaced, which means that there is available capacity in existing plants. The alternative to reinvest in the heat pump is in that case to invest in a slightly larger CHP plant and increase the use of existing plants. As a consequence, the allowable investment cost for the heat pump decreases since it has to compete with the running cost for existing plants and that the utilization time has decreased due to that the heat pump has been pushed up in the load duration graph due to the investment in a biofuel CHP plant.

If gas is available as an alternative fuel, the allowable investment cost decreases to very small levels in scenario 2 and scenario 3 due to the alternative of increased NGCC CHP capacity and increased use of existing plants. In the other cases, that is if waste incineration is not built and there are no gas available and low TGC price are summarized in Table 6.

Table 6. Replacement alternatives in terms of capacity and heat production to heat pump in scenarios when there are no gas, low TGC price and no waste incineration

Scenario	Replacement alternative capacity	Replacement alternative energy
Scenario Today	New biofuel HOB	New biofuel HOB
Scenario 2	New oil HOB	Mostly increased use of existing biofuel HOB, partly new oil boiler
Scenario 3	New biofuel HOB	New biofuel HOB

In scenario 2, the cost for fossil fuels like oil is lower than with the current tax system. Thus, in this scenario, the alternative to invest in a new heat pump is to install a new oil HOB. However, even though an oil boiler is the alternative investment in terms of capacity most of the lost heat if the heat pump is taken out of operation would be compensated for by increased use of the existing biofuel boiler. In scenario 3, as in scenario today, the alternative to a heat pump is a biofuel HOB but in scenario 3, the running cost relation is more in favor of the heat pump due to the higher biofuel price and that the retail electricity price only increases a little compared to in scenario today.

6 CONCLUDING DISCUSSION

The impact of waste incineration on the use of heat pumps in a district heating system has been investigated. Different scenarios for policy instruments and levels of available waste have been used in a case study. Since the results are based on a case study and Swedish district heating systems are much diversified in terms of size, existing technologies etc., the results should be interpreted with care.

The results indicate that waste incineration will be a hard competitor for heat pumps in district heating systems. However, the impact on existing heat pumps of waste incineration depends on what would have happened in the absence of waste incineration and thus dependent on the policy instruments in the energy market. Waste incineration is, in this study, a profitable investment in all the scenarios considered, reducing heat production from the heat pump compared to existing production by moving the heat pump up in the load duration graph. However, if the available waste is limited, it might lead to waste incineration replacing an investment in combined heat and power that would, if invested in, have reduced the heat pump even more. Thus, the results indicate that although waste incineration reduces heat production from existing heat pumps and the possibilities for reinvestments in old heat pumps, the impact may be ambiguous when compared to the alternative investments.

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