Factors influencing the GHG emission consequences of industrial excess heat usage in district heating systems

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ABSTRACT

The potential to increase usage of industrial excess heat is considered to be substantial and an important measure to reach targets of increased energy efficiency and decreased greenhouse gas (GHG) emissions. This paper shows and discusses factors that influence the global GHG emissions consequences of using industrial excess heat in district heating systems. The factors include emissions allocated to the industrial excess heat itself, competing technologies in the district heating system, how emissions related to biomass usage are handled and how different systems are set up and compared. Unavoidable excess heat is defined as excess heat that cannot contribute to decreased usage of primary energy resources in the industrial process. From the examples included in this paper, it can be concluded that if a resource perspective is adopted, it is always preferable to use unavoidable industrial excess heat instead of alternative district heating production from natural gas or biomass-based combined heat and power plants or heat only boilers from a GHG emission perspective.

KEYWORDS

Excess heat, waste heat, industry, GHG emissions, district heating, pinch analysis

INTRODUCTION

With increased concerns about climate change and increased competition for the world's (energy) resources, promoting measures that lead to reduced use of primary energy resources and reduced greenhouse gas (GHG) emissions becomes increasingly important.

Most industrial process plants have significant amounts of low temperature excess heat available. There are different possible usages for this heat, including export to a district heating network or usage in another industrial process. Using excess heat reduces the utilization of primary energy resources that would otherwise be needed for the production of heat (or other energy services). In addition, by exporting the excess heat, the plant can generate revenue for a resource that would otherwise go to waste. The European Union has pointed out increased usage of excess heat as one of the important measures to reach the EU target of increasing energy efficiency by 20% by the year 2020 [1]. It is especially desirable to use excess heat that is unavoidable, that is excess heat that cannot be avoided and cannot reduce the use of primary energy at the industrial plant.

Currently, there is still much excess heat that is not used. The potential to increase usage of excess heat is considered to be substantial [2]. In Sweden, for example, estimations indicate

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that the usage of excess heat for district heating purposes could be doubled (see e.g. [3]). There are several reasons why cooperation between industry and energy companies do not occur, including cultural differences between energy companies and industry and prestige. Furthermore, for district energy companies there is often the desire to own and operate their own heating plants and the desire to be independent [4-6]. However, for Swedish conditions, the most important reason that prevents export of excess heat is competition for the available heat sinks with waste incineration and biomass-fueled combined heat and power (CHP) plants, whose profitability is strongly affected by the landfill ban for waste and the Swedish electricity certificate system promoting production of renewable electricity [6].

Environmental assessments of industrial excess heat in itself, as well as usage of industrial excess heat in district heating systems, are complex. Is all excess heat really devoid of increased usage of primary energy resources? Can excess heat compete with biomass or natural gas CHP in district heating systems? These are some of the questions that will be discussed in this paper. GHG emission consequences of using industrial excess heat in district heating systems has been estimated in a number of studies (see e.g. [2, 7-10]). District heating systems are local and often quite different, particularly with respect to heat production mix. However, it is possible to generalize to a certain extent and there are some factors that in many cases highly influence the GHG emissions consequences of using industrial excess heat in district heating systems. One of them is how the different systems for producing district heating, either from excess heat or other possible district heating production technologies, are set up and compared. Another is how emissions related to biomass usage are handled. Furthermore, it is important to consider possible emissions related to the excess heat itself.

The aim of this paper is to show and discuss factors influencing the global GHG emissions consequences of using industrial excess heat in district heating systems. The factors include emissions allocated to the industrial excess heat itself, competing technologies in the district heating system, how emissions related to biomass usage are handled and how different systems are set up and compared.

STUDIED SYSTEM

Figure 1 shows the system studied in this paper. The system includes an industrial process that generates excess heat. The excess heat can be used in a district heating (DH) system, thereby replacing alternative options for district heating production. This system is connected to the surrounding system, including the electricity grid.

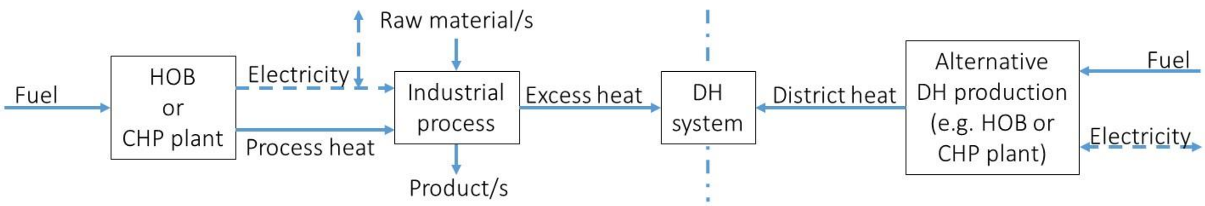

Figure 1. Studied system. (HOB = Heat only boiler).

The change in GHG emissions when using excess heat (EH) in district heating systems are calculated according to Equation 1:

$$\Delta GHG_{TOT} = \dot{q}_{EH} \times GHG_{EH} - \dot{q}_{DH,AP} \times GHG_{DH,AP} \quad (1)$$

where:

ΔGHG_{TOT}	Change in GHG emissions if excess heat is delivered to the district heating system (kg CO_{2eq}/y). Negative values indicate a decrease of GHG emissions.
$\dot{q}_{EH}$	Annual excess heat delivery (MWh_{EH}/y)
GHG_{EH}	GHG emission factor for excess heat (kg CO_{2eq}/MWh_{EH})
$\dot{q}_{DH,AP}$	Annual production of district heat, based on alternative production technology ($MWh_{DH,AP}$/y)
$GHG_{DH,AP}$	GHG emission factor for alternative district heating production (kg $CO_{2eq}/MWh_{DH,AP}$)

The change in GHG emissions when delivering excess heat to the district heating system is both dependent on the GHG associated with the excess heat itself and the GHG emissions associated with the alternative district heating production technology. There are a number of issues connected to the estimation of these GHG emissions factors, such as how emissions related to biomass usage are handled and how grid electric power production is maintained if less power is produced in CHP plants. In addition, how different alternatives and systems are set up and compared also influence the results.

The change in GHG emissions when delivering excess heat in district heating systems can be compared with other options for using the excess heat such as biomass drying, providing heat required for carbon capture processes or as heat source for low temperature electricity generation. The first term in Equation 1, i.e. the emissions associated with the excess heat itself, will naturally be the same also for other usages. Hence, the discussion here regarding the excess heat itself and associated GHG emissions is general and not connected specifically to usage in district heating systems. Furthermore, issues regarding handling of emissions associated with biomass usage and changes in power production together with different system setups are also things that are relevant for other usages of excess heat.

INDUSTRIAL EXCESS HEAT – DEFINITIONS

Different terms are used for the heat left over from an industrial process, including residual heat, excess heat, surplus heat and waste heat. To try to develop a common terminology within this area, IEA Annex XV – Industrial excess heat recovery [2] has suggested the following definitions:

- **Excess process heat** = heat content of all streams (gas, water, air, etc) which are discharged from an industrial process at a given moment.
- **Usable excess heat =** the excess heat that it is technically and economically possible to re-use in the industrial process or an external heat sink.
- **Internally usable excess heat** = excess heat that can be used internally in the process, considering both technical and economic aspects. This usage is normally preferable compared with external usage.
- **Externally usable excess heat** = excess heat that can be delivered to an external heat sink (e.g. district heating network), considering both technical and economic aspects.
- **Non-usable excess heat** = remaining part of the excess heat, when the internal and external usable fractions have been deducted. This part can be called **waste heat**.

Thus, according to these definitions the term waste heat means that the excess heat has no usage. However, waste heat is very often used to describe all forms of excess heat generated by an industrial plant. What actually is usable excess heat is dependent on a number of factors including temperature level, proximity to heat sinks and economic conditions. Residual or surplus heat could be used instead of excess heat in the definitions above, as they basically are synonymous.

If the excess heat is internally usable, is it then really an *excess* of heat? Since it could be avoided, the term **avoidable excess heat** can be used. The opposite would be **unavoidable excess heat**, i.e. excess heat that cannot be avoided and cannot reduce the use of primary energy at the industrial plant. This terms can e.g. be found in [11]. Another term for unavoidable excess heat is true excess heat, which is used in [2, 12].

Figure 2 illustrates different types of industrial excess heat. Externally usable excess heat often includes heat that could be used internally, thereby reducing the need for primary steam (or other hot utility) and then in turn primary energy resources (fuel) at the industrial plant. Thus, the externally usable excess heat constitutes a mixture of unavoidable excess heat and avoidable excess heat.

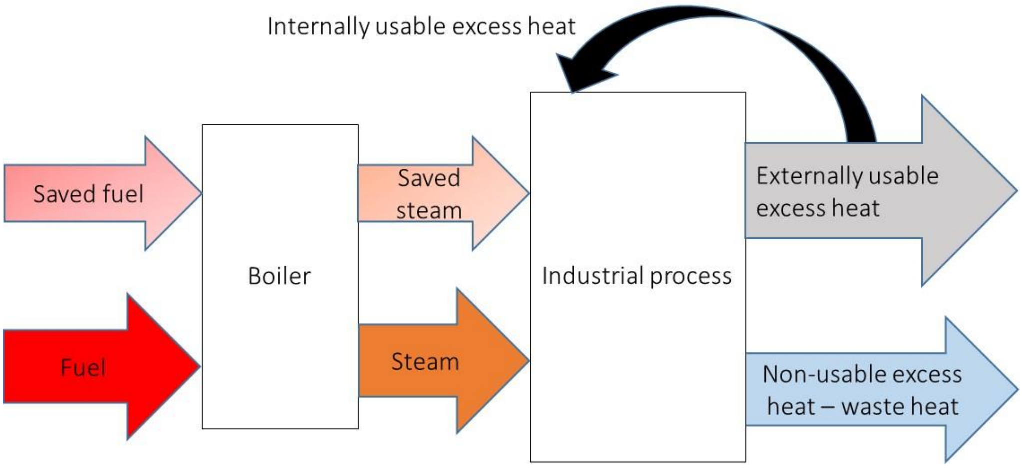

Figure 2. Different types of industrial excess heat.

A similar approach to using Equation 1 is to compare internal and external usages of excess heat (see e.g. [7]). Then, the possibilities for internal usages and its associated GHG emissions consequences are investigated. This could then be compared with external usages, e.g. usage in a district heating system. If internal usage is not possible (from an economic and technical point of view), the first term in Equation 1 will be eliminated. Naturally, all studies have limitations and it is not possible to consider all possible usages. Even if not included in a specific study, some reflection regarding the excess heat itself and whether possible internal usages are possible should be included.

HOW TO DETERMINE WHAT IS UNAVOIDABLE EXCESS HEAT

Pinch analysis (see e.g. [13, 14]) can be used to determine what is unavoidable excess heat without primary energy use and environmental impact.

An industrial process usually consists of several tens, perhaps even hundreds, of process streams[1]. Based on the stream data for these streams, it is possible to create the hot and cold composite curves, representing all the hot and cold streams respectively. Figure 3 shows an example of composite curves for a process. If no exchange of heat between hot and cold streams occurs (see left part of the figure), the entire heat demand has to be satisfied with hot utility (e.g. steam produced in a boiler) and the entire cooling demand by using cold utility (e.g. cooling water) or by delivering the excess heat to an external heat sink. However, if heat is exchanged between hot and cold streams, the need for fuel to generate steam (or other hot utility), as well as the amount of excess heat, is reduced (see right part of the figure). There must be a certain minimum temperature difference (ΔT_{min}) between the hot and the cold stream in a heat exchanger, otherwise the heat exchanger becomes infinitely large. At ΔT_{min}, the minimum hot utility demand, as well as the minimum amount of excess heat, occurs (see right part of the figure).

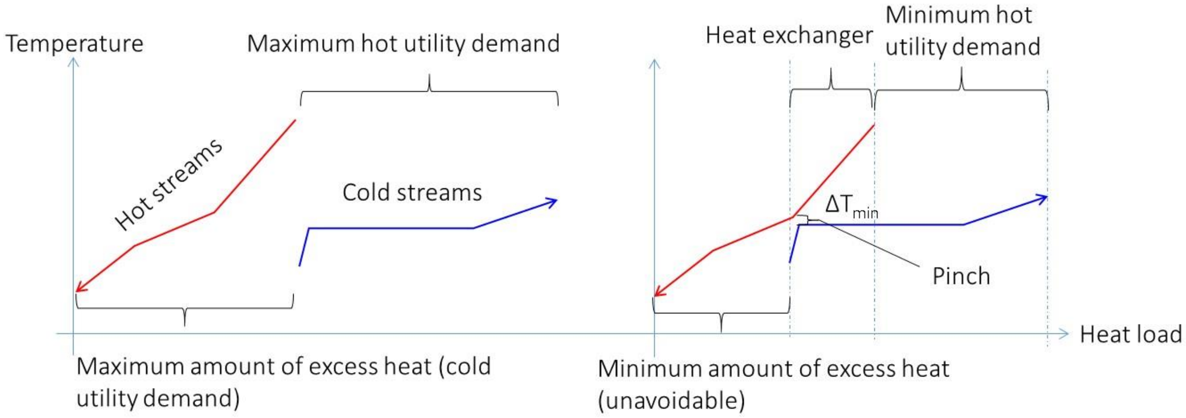

Figure 3. Hot and cold composite curves of an industrial process. The left part illustrates a situation where the maximum hot utility demand and the maximum amount of excess heat occur. The right part of the picture illustrates a situation where the minimum hot utility demand and the minimum amount of excess heat occur.

The optimal value of the minimum temperature difference results from the trade-off between investment costs (heat exchanger area) and operating costs (fuel prices). Increasing the minimum temperature difference decreases the investment cost but increases the operating costs as the (hot) utility demand increases.

So what is a suitable ΔT_{min} for determining the minimum amount of unavoidable excess heat? 0°C? 5°C? 10°C? 15°C? This economic optimum is dependent on the specific process and its streams (liquid, steam, air, etc) as well as the development of investment costs and energy prices. Furthermore, when determining the minimum amount of excess heat and the corresponding minimum hot utility demand, technical development, making alternative process routes or process units available, is something that needs to be considered as well. There is also a number of technical and practical issues that need to be considered such as controllability of the heat exchangers and if streams should be excluded from the analysis of internal heat recovery (due to e.g. location in the plant or technical reasons making heat exchanging with another process stream inappropriate). It is thus clear that determining the

[1] A process consists of streams that either undergoes heating or cooling. A stream is characterised by a start temperature, a target temperature and a heat load. Streams that needs to be cooled are called *hot streams* (regardless of absolute temperature), and streams that needs to be heated are called *cold streams*.

amount of unavoidable excess heat and the corresponding minimum hot utility demand is not straightforward. However, naturally, a ΔT_{min} of 0°C is not realistic, since this leads to infinitely large heat exchangers and investment costs.

As is clear from this paper, excess heat in general is not a sign of "inefficiency". Sometimes it is implied that if the process were more efficient, no excess heat would be available. Most industrial processes will have excess heat (to different extents) even if ΔT_{min} is very small (or even 0) and the internal heat recovery is maximized (this can be seen from the example given in Figure 3).

GHG emissions allocated to avoidable excess heat

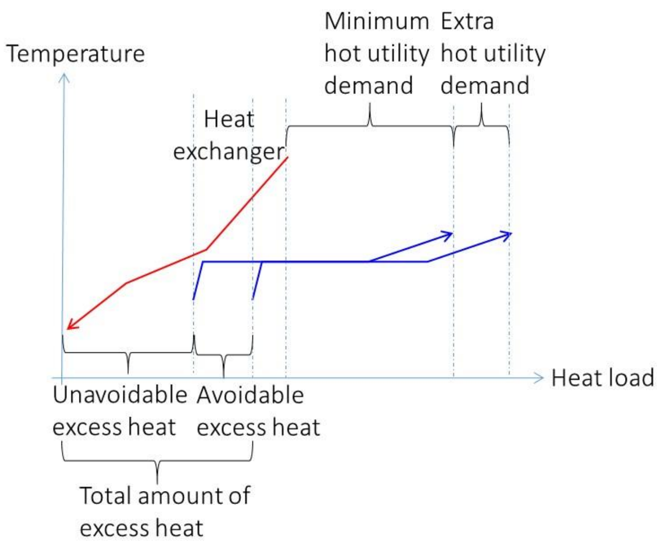

Figure 4. Illustration of how the amount of avoidable excess heat and the corresponding extra hot utility demand can be determined.

By comparing a process and its current hot utility demand and amount of excess heat (which corresponds to a certain ΔT_{min}), with the hot utility demand and amount of excess heat corresponding to a reasonable ΔT_{min}, the extra, avoidable amount of excess heat and the corresponding extra hot utility demand can be determined (these are equal). This is illustrated in
Figure 4. Using this, the GHG emission factor for excess heat can be calculated according to Equation 2 (assuming that the process heat demand is satisfied by a CHP plant or HOB):

$$GHG_{EH} = \frac{\dot{q}_{EHUD} \cdot \left(\frac{1}{\eta_{heat}} \times GHG_{fuel} - \alpha \times GHG_{el}\right)}{\dot{q}_{EH}} \quad (2)$$

where (see also explanations in connection to Equation 1):

$\dot{q}_{EHUD}$	Extra hot utility demand (MWh_{EHUD}/y)
η_{heat}	Heat efficiency for CHP plant or HOB (MWh_{heat}/MWh_{fuel})

GHG_{fuel}	GHG emission factor for fuel used in CHP plant or HOB ($kg\ CO_{2eq}/MWh_{fuel}$)
α	Power-to-heat ratio for CHP plant (MWh_{el}/MWh_{heat})
GHG_{el}	GHG emission factor for electricity ($kg\ CO_{2eq}/MWh_{el}$)

Equation 2 is based on system expansion in the case of CHP plants. Instead of allocating GHG emissions between the different products, i.e. heat and electricity, assumptions regarding emissions for alternative electricity generation are made.

As discussed previously, if ΔT_{min} is increased, the amount of excess heat also increases. However, the temperature level of the excess heat is naturally crucial for its possible usage. Even if the total amount of excess heat is increased, it is not certain that the amount of excess heat at a sufficient temperature level for district heating is increased. The opposite could actually occur. This is for example illustrated in some of the cases shown in [12].

If excess heat is an unavoidable by-product of an industrial process, it cannot contribute to decreased usage of resources in the process (considering both technical and economic aspects) and it is reasonable to argue that emissions should not be allocated to the heat in this case. For CHP plants, the situation is different. To be able to use the “excess heat” from a CHP plant in an industrial process or a district heating system, the temperature level must usually be significantly higher than the temperature level of the excess heat discharged from a condensing power plant. Thus, the electrical efficiency of a CHP plant is usually lower than that of a condensing power plant based on the same heat engine technology. The emissions associated with the heat produced in a CHP plant can therefore be considered to be equal to the emissions associated with the “lost” power production when comparing the CHP plant with a condensing power plant using the same amount of fuel.

ALTERNATIVE DISTRICT HEATING PRODUCTION

There are two main types of district heating systems in Europe: electricity coupled systems and cost ranked systems [15]. In Europe, many district heating producers are also operators of large power plants from which some of the steam can be tapped at a higher temperature level to provide heat to a city. For every unit of heat produced the electricity production decreases (with approximately 0.15 units), in accordance with the discussion in the previous section. In cost ranked systems, which includes e.g. all Swedish district heating systems, industrial excess heat can be in competition with e.g. biomass or natural gas CHP or HOB. Thus, a district heating system could be in a situation where they will either invest in a biomass CHP plant or make an agreement with an industry regarding excess heat deliveries. Assuming equal annual operating time, the saved GHG emissions from using the excess heat is equal to the GHG emissions associated with the alternative investment option.

The GHG emission factor for the alternative district heating production can be calculated according to Equation 3 (assuming a CHP plant or HOB):

$$\mathrm{GHG}_{\mathrm{DH,AP}} = \frac{1}{\eta_{\mathrm{heat}}} \times GHG_{fuel} - \alpha \times GHG_{el} \quad (3)$$

See explanations of the terms in connection to Equations 1 and 2. Equation 3 is similar to Equation 2, also assuming system expansion.

Figure 5 presents examples of GHG emissions factors for alternative district heating production [15, 16]. Electricity produced in CHP plants is assumed to replace electricity produced in coal-fired condensing power plants, which is currently the marginal power generation technology in many Northern European electricity markets. Two different values are presented for heat produced from biomass fuel in district heating systems, both in HOB and in CHP plants. The first value considers only emissions related to collection and transportation of the biomass fuel, and corresponds to conventional practice in which biomass is not considered to be a truly limited resource. The other value also includes indirect emissions associated with the biomass usage. In a medium to long term perspective, biomass is likely to become a truly limited resource. Under such conditions, using biomass reduces the amount of biomass available for other applications. To account for this, an alternative biomass usage has been assumed to be co-firing with coal (i.e. coal is replaced). Thus, it is assumed that using biomass in a CHP plant or HOB reduces the amount of biomass available for co-firing, thereby increasing the usage of coal.

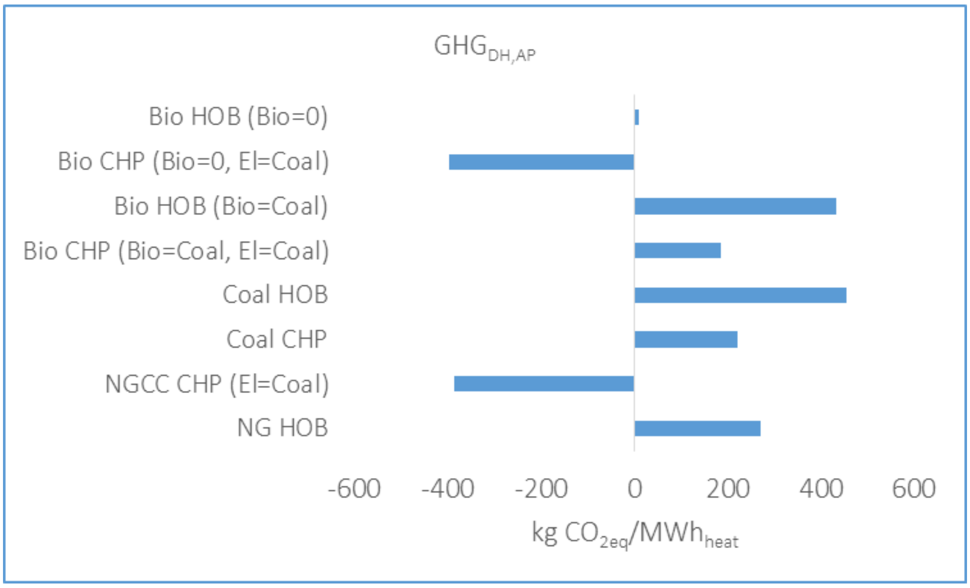

Figure 5. GHG emission factors for alternative district heating production, $GHG_{DH,AP}$. (NG = natural gas, NGCC = natural gas combined cycle)

ASSESSING THE GHG EMISSIONS BENEFIT OF EXPORTING EXCESS PROCESS HEAT TO DISTRICT HEATING SYSTEMS

If the GHG emission factor for alternative district heat production, $GHG_{DH,AP}$, is larger than zero, it is better to use unavoidable excess process heat (with no emissions allocated to it, i.e. GHG_{EH}=0) than alternative district heating production from a GHG emission perspective. If the same type of heating plant (with similar efficiencies) and fuel is used for heat (and electricity) production at an industrial plant as in the district heating system, it is better to use the industrial excess heat if $q_{EH}<q_{EHUD}$, i.e. if some of the excess heat is unavoidable. If $q_{EH}=q_{EHUD}$, i.e. all excess heat could be avoided, there is no difference from an emissions perspective if the excess heat or alternative district heat production is used (still assuming similar heating plant and fuel). From an economic perspective, the total system cost could be lower if the excess process heat that is available is used for district heating than to invest in energy efficiency measures at the industrial plant and at the same time invest in an alternative

district heat production plant (here the costs associated with using the excess heat for district heating, including pipelines, needs to be considered). However, other industrial plants may also have (unavoidable) excess heat available, and there could be competition for delivering excess heat to the district heating system. Considering this, internal usage could be preferable both from a total economic and GHG emission perspective.

If a CHP plant is in place for providing heat and power to the industrial plant site and a HOB constitutes the alternative production in the district heating system, all industrial excess heat can be avoidable but it may nevertheless still constitute the most attractive option from a GHG emission perspective. It is not unusual, especially in smaller district heating systems, that it is not profitable to invest in CHP plants.

Hereafter, some examples will be presented and discussed. In all cases the district heating demand is assumed to be 250 GWh/y, to be covered with excess heat or alternative district heat production.

Example 1

Figure 6 presents Example 1 where unavoidable excess heat from a fossil-based industrial process is used for district heating purposes instead of heat from a biomass-fired HOB.

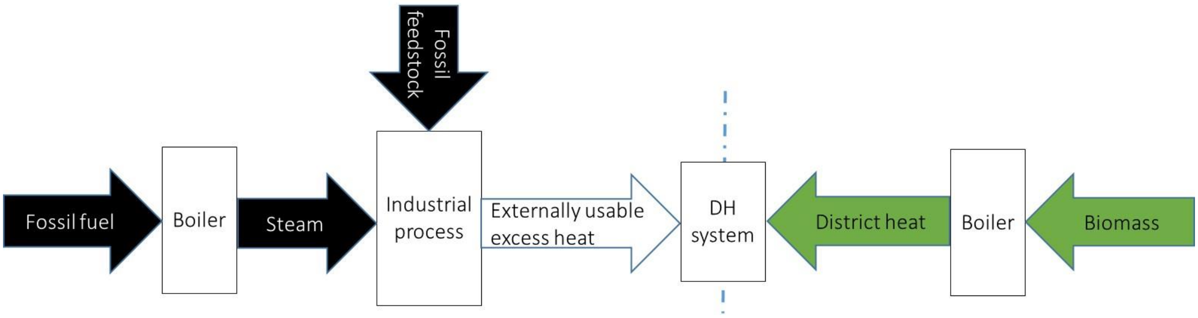

Figure 6. Example 1: Unavoidable excess heat from an industrial process based on fossil feedstock, using fossil fuels for steam generation, is used for district heating production instead of using district heat from a biomass-fired HOB.

Figure 7 presents the change in GHG emissions, according to Equation 1, when unavoidable excess heat is used instead of a biomass-fired HOB for district heating production. Two cases are presented in
Figure 7, using the different GHG emission factors for biomass-fired HOB presented in
Figure 5. If only emissions related to biomass handling are considered (i.e. biomass is not considered to be limited), there is only a slight decrease of the GHG emissions. There could also be emissions related to the distribution of the excess heat (not considered here) that could be in the same range as the emissions for biomass handling (this is of course dependent on the specific case where factors such as average biomass transportation distance and distance between the industrial plant and need for district heating influence the exact emissions). However, considering also other environmental aspects, and not the least costs, the unavoidable excess heat should be the preferred option.

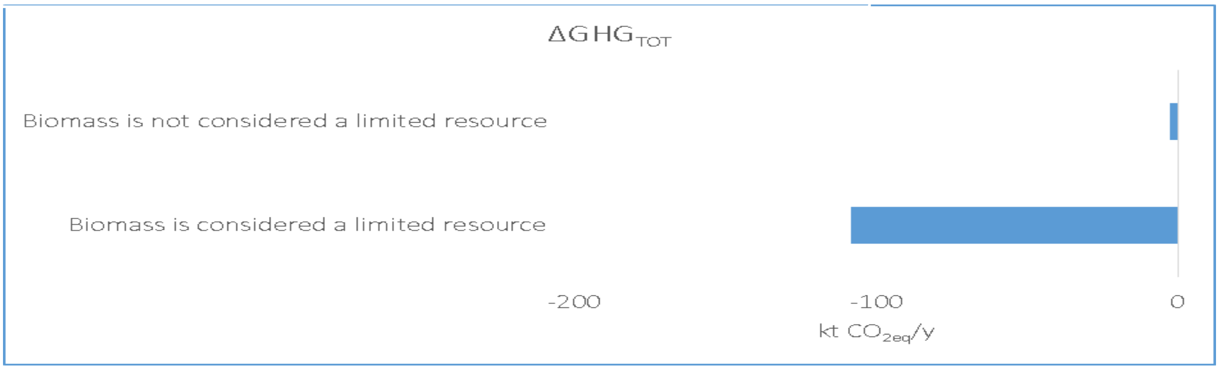

Figure 7. Example 1: Change in GHG emissions when unavoidable excess heat is used instead of a biomass-fired HOB for district heating production (250 GWh/y).

If biomass is considered to be a limited resource and indirect emissions related to the biomass usage are included in the analysis, the usage of unavoidable excess heat results in a large decrease of GHG emissions, i.e. it is better from a GHG emission perspective to use the available unavoidable excess heat from the fossil-based industrial plant than to use heat from a biomass-fired HOB.

Even if biomass is not a truly limited resource, a similar reasoning can be adopted. Instead of discharging available excess heat to the environment and using primary biomass resources to produce heat, the biomass could instead be used to replace fossil feedstock/fuel at the industrial plant, thereby decreasing GHG emissions. Thus, instead of comparing the two options for district heat production according to the set up in
Figure 6, the option with the industrial excess heat will also include usage of the same amount of biomass resources as is used in the HOB. This will result in reductions of the same order of magnitude as presented in
Figure 7 for biomass as a limited resource (the exact reduction depends on which fossil fuel that is replaced).

In Sweden, heat from renewable resources can be eco-labelled [17]. For Example 1, this means that the heat generated in the biomass-fired HOB would be eco-labelled, while the unavoidable excess heat from the fossil-based industrial plant would not be eco-labelled. Considering what has been illustrated and discussed here regarding Example 1, this is something that definitely could be questioned.

Example 2

Figure 8 presents Example 2 where unavoidable excess heat from an industrial process is delivered to a district heating system where it replaces heat from a NGCC CHP plant.

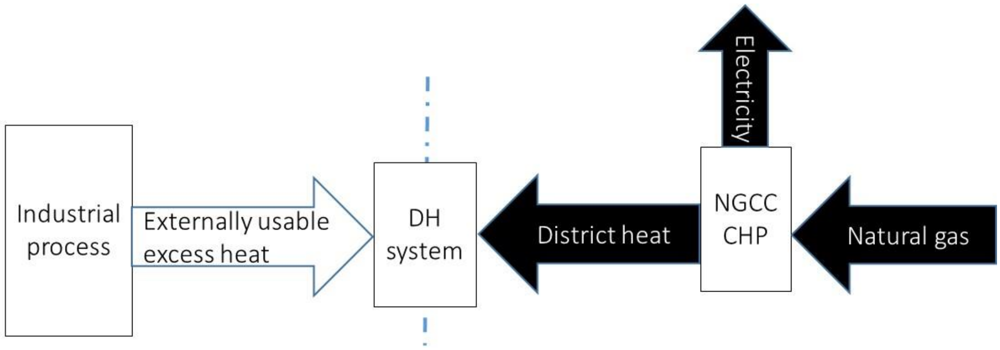

Figure 8. Example 2: Unavoidable excess heat from an industrial process is used for district heat production instead of heat from a NGCC CHP plant.

The change in GHG emission will in this case be positive (i.e. an increase), if ΔGHG_{TOT} is calculated according to Equation 1 using the GHG emission factor for NGCC CHP presented in
Figure 5. This is because the co-produced electricity in the NGCC CHP plant is assumed to replace electricity generation in a coal-fired power plant.

If, in addition to producing the same amount of district heat in the two systems, they also consume the same amount of fuel, it becomes necessary to investigate a different system configuration. Figure 9 illustrates this configuration, where the same amount of natural gas is used in the system with industrial excess heat as in the system with alternative district heat production. However, in the system where industrial excess heat satisfies the district heating demand, all natural gas is used for electricity production in a NGCC condensing power plant instead of an NGCC CHP plant.

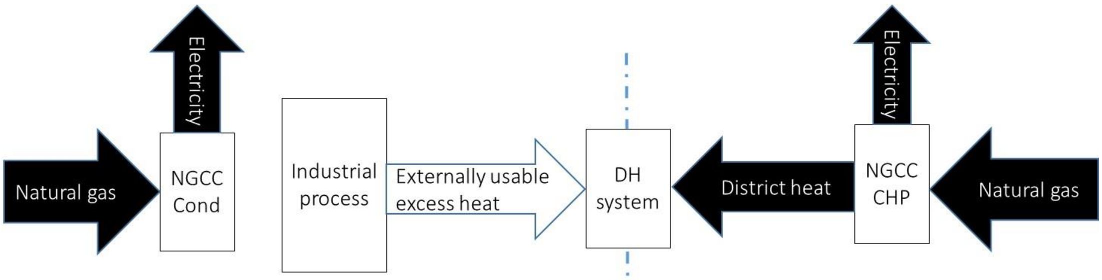

Figure 9. Example 2: Different system configuration where the district heat production is the same in the two compared systems as well as the fuel usage.

To calculate the change in GHG emissions for this system configuration, Equation 1 is expanded. The change in GHG emissions is calculated according to Equation 4:

$$\Delta GHG_{TOT} = \dot{q}_{EH} \times GHG_{EH} + \frac{\dot{q}_{DH,AP}}{\eta_{heat}} \times GHG_{Fuel,DH,AP} - \frac{\dot{q}_{DH,AP}}{\eta_{heat}} \times \eta_{el,cond} \times GHG_{el} - \dot{q}_{DH,AP} \times GHG_{DH,AP} \quad (4)$$

where (see also explanations of the terms in connection to Equations 1 and 2):

$GHG_{Fuel,DH,AP}$ GHG emission factor for fuel used for alternative district heat production (kg CO_{2eq}/MWh_{fuel})

$\eta_{el,cond}$ Electrical efficiency for condensing power production (MWh_{el}/MWh_{fuel})

Since the NGCC condensing plant has a higher electrical efficiency than the NGCC CHP plant, more electricity will be generated from the same amount of fuel. Consequently, this enables a larger reduction of GHG emissions as a consequence of replacing coal-based power production. Figure 10 presents the change in GHG emissions for Example 2 using the different system configurations presented in Figure 8 and Figure 9 (called System configurations 1 and 2).

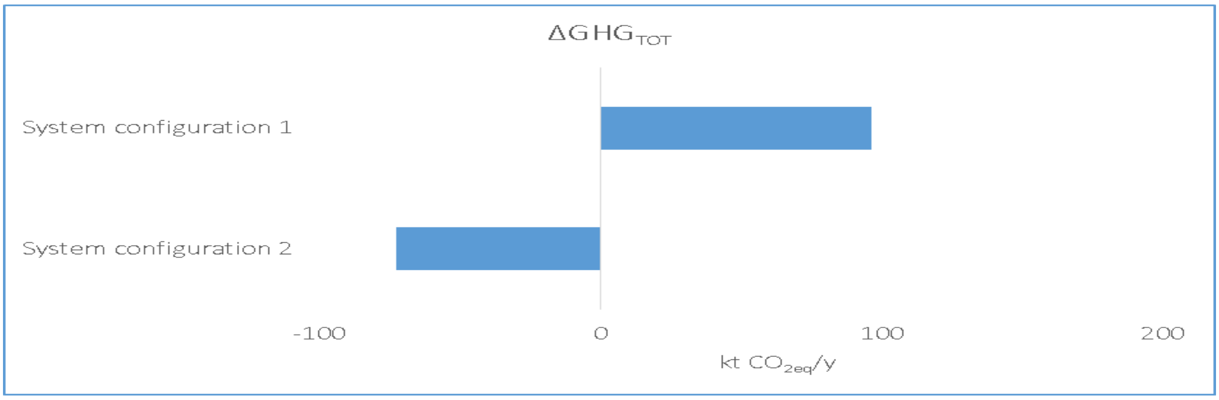

Figure 10. Example 2: Change in GHG emissions when unavoidable excess heat is used instead of a NGCC CHP for district heat production (250 GWh/y)[2].

Thus, when the systems are set up to not only produce the same amount of district heat, but also to use the same amount of fuel, the system where industrial excess heat is used is preferred from a GHG emission perspective. Since the systems in this set up are using the same amount of resources, this shows that the resource efficiency is higher for the system using industrial excess heat.

Instead of introducing Equation 4, the same result would be achieved if the heat from the NGCC CHP plant would have been allocated the emissions associated with the reduced electricity production resulting from CHP mode instead of condensing mode electricity generation (see discussion above). Thus, GHG_{DHAP} would be positive, resulting in a decrease of GHG emissions using unavoidable excess heat instead of a NGCC CHP according to Equation 1.

Example 3

Example 3 is similar to Example 2, but instead of natural gas CHP, biomass-fired CHP is considered to be the alternative district heat production technology. Figure 11 presents Example 3 where unavoidable excess heat from an industrial process is delivered to a district heating system where it replaces heat from a biomass-fired CHP plant. As for Example 2, two different system configurations are considered.

[2] Data used (in addition to the data presented in Figure 5) [15,16]: n_{el}=0.46 and n_{heat}=0.44 for NGCC CHP, n_{el}=0.60 for NGCC condens and GHG_{el}=913 kg CO_{2eq}/MWh_{el}.

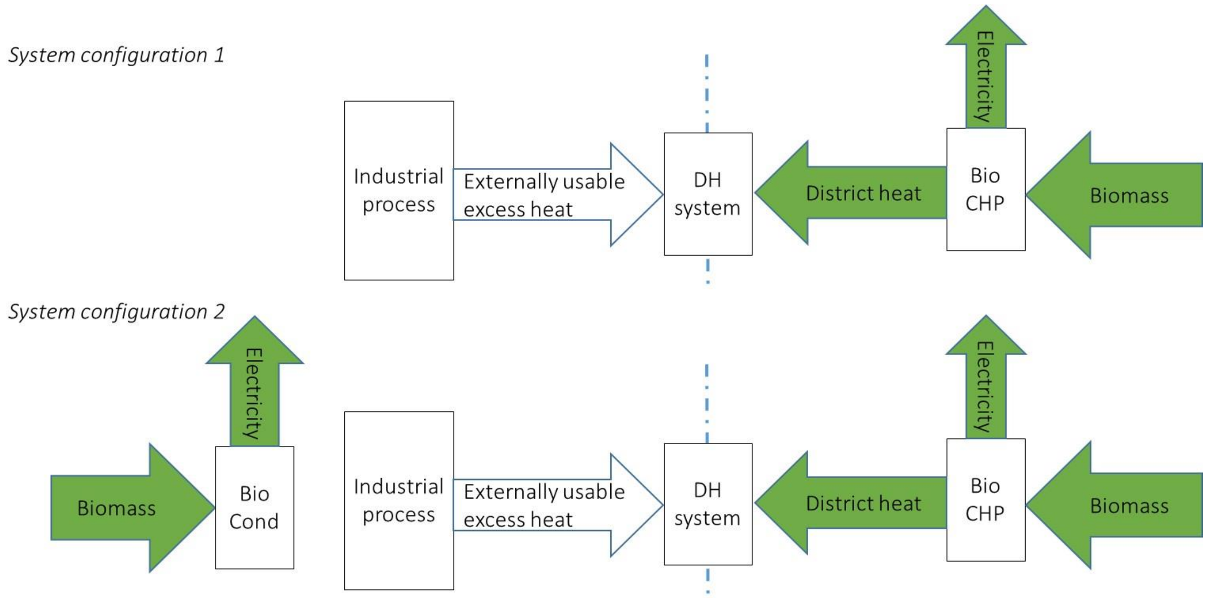

Figure 11. Example 3: Unavoidable excess heat from an industrial process is used for district heat production instead of producing district heat in a biomass-fired CHP plant. Two different system configurations are considered: System configuration 1 and System configuration 2.

The change in GHG emissions is calculated according to Equation 1 for System configuration 1 and according to Equation 4 for System configuration 2. The results are presented in Figure 12. For System configuration 1, two different GHG emission factors are considered for biomass-fired CHP (see Figure 5). One where biomass is not considered to be a limited resource and one where biomass is considered to be a limited resource.

For System configuration 1 and if biomass is not considered to be a limited resource, the GHG emissions are significantly increased if excess heat is used instead of a bio CHP plant. This is, as for the case of NGCC CHP, due to the assumption that co-produced electricity in the CHP plant replaces electricity generation in a coal-fired power plant. However, if biomass is considered to be truly limited resource, the opposite results are obtained and the GHG emissions are significantly decreased if excess heat is used instead of a bio CHP plant. If a different system configuration is used, where also the same amount of biomass fuel is used, similar results are obtained.

System configuration 2, includes a biomass-fired condensing power plant. Ideally, these types of power plant should be avoided. If possible, excess heat should be used in district heating systems where available, whereas biomass-fired CHP could be used where excess heat is not available.

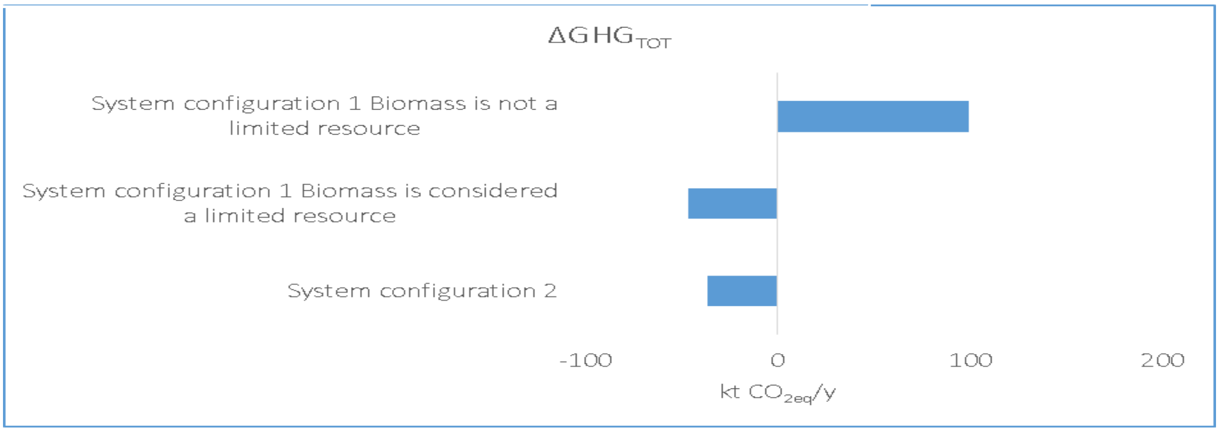

Figure 12. Example 3: Change in GHG emissions when unavoidable excess heat is used instead of a biomass-fired CHP unit for district heat production (250 GWh/y)[3].

CONCLUDING SUMMARY

Many industrial processes have excess process heat, even if they are very energy efficient. However, some excess heat can be avoided in many cases. It can be used internally to decrease the usage of primary energy in the process. The excess heat that cannot be avoided and that cannot contribute to decreased primary energy usage at the process plant, can be called unavoidable excess heat. The emissions associated with this excess heat are thus zero. However, if excess heat is avoidable, primary energy usage and corresponding GHG emissions should be allocated to the industrial excess heat.

Industrial excess heat has several potential external usages, including delivery to a district heating system. When assessing the GHG consequences of using industrial excess heat for district heating, in addition to emissions associated with the excess heat itself, the emissions assumed for alternative district heating production are decisive. When determining the GHG emission factors, both for the excess heat itself and for alternative district heating production, factors including handling of biomass and emissions associated with electricity production are important. In addition, how different systems are set up and compared also influence the results from comparisons of industrial excess heat with alternative district heating production.

In this paper, we have included three different examples to illustrate the complexity of assessing GHG emissions consequences of using industrial excess heat in district heating systems. If unavoidable industrial excess heat is used instead of a NGCC CHP plant to satisfy a certain district heating demand, the GHG emissions are increased assuming that the marginal electricity production is coal power. However, if the two options compared are assumed to use the same amount of resources (fuel), in addition to producing the same amount of district heat, the opposite results are obtained. The system with industrial excess heat then has both a higher energy efficiency and lower GHG emissions. Similar results are shown for a case with biomass-fired CHP. For this case, the effect of regarding biomass as a truly limited resource is also shown. Then, if biomass is used for e.g. biomass CHP, less biomass is available for other applications, thereby increasing the usage of fossil fuels elsewhere in the system. If this is accounted for, similar results as when the systems are set up using the same amount of resources are obtained.

[3] Data used (in addition to the data presented in Figure 5 and in connection to Example 2) [15,16]: n_{el}=0.31 and n_{heat}=0.69 for bio CHP and n_{el}=0.42 for bio condens.

For a case with a biomass HOB in competition with unavoidable excess heat from a fossil-based industrial process, it has been shown that using the excess heat should be the preferred option for district heating production from a GHG emission perspective. Instead of wasting excess heat that cannot be avoided, and at the same time use biomass to produce the same amount of heat, the biomass could instead be used to replace fossil fuel/feedstock in the industrial process.

From the examples in this paper, it can be concluded that if a resource perspective is adopted, it is always preferable, from a GHG emission perspective, to use unavoidable industrial excess heat instead of alternative district heating production from natural gas and biomass-based CHP or HOB plants.

In this paper we have focused on an emission and resource perspective of using industrial excess heat for district heating. The economic performance is in the end decisive for the outcome. A number of different factors influence the probability of cooperation between industries and energy companies such as distances, business models, fuel prices, and not least also policy instruments. It is important to be aware of the effect that different policies have and see that they actually contribute to decreased GHG emissions and increased energy efficiency.

ACKNOWLEDGEMENTS

This work was funded by Chalmers Energy Area of Advance, based on strategic funding provided by the Swedish Government.

NOMENCLATURE

CHP	Combined heat and power
DH	District heating
EH	Excess heat
GHG	Greenhouse gases
HOB	Heat only boiler
NG	Natural gas
NGCC	Natural gas combined cycle

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