Dutch industrial waste heat in district heating: Waste of effort?

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Abstract

Industrial efficiency does not stop at the gate of a factory. Deployment of industrial waste heat in district heating systems – including heat from electricity generation – is often mentioned as a promising option for energy savings and CO_2 emission reduction. However, despite a large amount of available waste heat, deployment of industrial waste heat in the Netherlands is still very limited today. If waste heat is to fulfil an important role in future emissions reductions, there is a major implementation gap to be bridged. But is waste heat indeed as promising as it often looks?

This paper presents an analysis of potentials and costs for industrial waste heat utilization in the Netherlands for low temperature deployment in households, services and greenhouse horticulture. It starts with identifying potential combinations of waste heat supply and demand. To estimate the technical potential, it evaluates the match between supply and demand: heat should be available at the right temperature level, the right moment and the right location. To provide realistic potentials, this paper makes a comparison with alternatives, addressing alternative applications of waste heat on the supply side as well as alternative sources of heat on the demand side.

It concludes with an assessment of a realistic role of industrial waste heat utilisation in district heating in the medium to long term, and the roles of major alternatives with regard to their performance in terms of energy savings, emissions reductions and costs. The analysis points out that this realistic potential is rather limited: an estimated 10 to 25 PJ of net energy savings may be realised by the utilisation of 25 to 45 PJ of waste heat in district heating.

Introduction

Industrial efficiency does not stop at the gate of a factory. Deployment of industrial waste heat in district heating systems – including heat from electricity generation – is often mentioned as a promising option for energy savings and CO_2 emission reduction. However, despite a large amount of available waste heat, deployment of industrial waste heat in the Netherlands is still very limited today. If waste heat is to fulfil an important role in future emissions reductions, there is a major implementation gap to be bridged. But is waste heat indeed as promising as it often looks?

This paper presents an analysis of potentials and costs for industrial waste heat utilization in the Netherlands for low temperature deployment in households, services and greenhouse horticulture. It starts with identifying the availability of waste heat and the demand for heat. To estimate the technical potential, it evaluates the match between supply and demand: heat should be available at the right temperature level, the right moment and the right location. To provide realistic potentials, this paper makes a comparison with alternatives, addressing alternative applications of waste heat on the supply side as well as alternative sources of heat on the demand side.

It concludes with an assessment of a realistic role of industrial waste heat utilisation in district heating in the medium to long term, and the roles of major alternatives with regard to their performance in terms of energy savings, emissions reductions and costs. The analysis points out that this realistic potential is rather limited: an estimated 10 to 25 PJ of net energy savings may be realised by the utilisation of 25 to 45 PJ of waste heat in district heating.

This may lead to a total CO_2 emission reduction of 0.6 to 1.3 Mton; outside the European Emission Trading system the emission reduction is higher, ranging from 0.9 to 2.0 Mton.

Within this potential, savings and costs may vary considerably. A limited part of this potential is expected to yield net benefits upon implementation. This involves the options for waste heat supply, which may lead to a substantial energy saving, and which lack better or lower cost alternatives.

5 Criteria for the potential

The share of useful waste heat may seem small. After all, the law of conservation of energy stipulates that all energy that is used in the Netherlands is ultimately released as heat, amounting to 2800 PJ in total. However, the amount of this heat that can actually be deployed in a useful and economic way is limited, and depends on energy savings, CO_2 emissions and costs. These in their turn depend on five main factors :

- Which combinations of heat supply and heat demand are feasible, what are the characteristics of various heat sources and heat destinations and how do these characteristics determine the performance and costs of heat distribution as an alternative to the reference technology. This includes the costs and energy penalty of tapping the heat, as well as costs and energy use of the reference technology that would otherwise supply the heat at the final demand.

- Temperature level: How much heat can be extracted, and at which temperature level? How much heat is needed, and at which temperature level?

- Synchronicity: To what extent does the supply pattern match the demand pattern? Will the source and the destination of the heat continue to exist long enough side by side?

- Vicinity, density and scale: How many sources and destinations of heat are large enough and sufficiently near one another?

- Alternatives: Are there any options to avoid waste heat production, to use the waste heat in an alternative way at the supply side, to decrease heat demand at the demand side or to cater for these needs in some other way? Are these alternatives less costly, or do they have better performance with regard to energy efficiency or emission reduction?

This paper will address the role of these five factors, and demonstrate their meaning for the amount of useful heat and for energy saving. These factors are often interrelated: a larger distance need not render heat supply impossible; however it will raise the costs and decrease the savings, thus making local alternatives relatively more interesting.

Combinations of supply and demand

Waste heat supply can save energy, but it also costs energy. The net saving depends on both supply and demand, and on the characteristics of the heat grid. Auxiliary boilers are needed to cater for peaks in demand and electricity is needed to pump the hot water in the heat distribution system. Part of the heat is lost as a result of losses in the distribution grid. Moreover, heat extraction from power plants and waste incineration plants affects the electricity production. The extent of the impact depends on the temperature level of the heat

extraction[1]. Moreover, these losses also result in additional CO_2 emissions. Given these factors, the net effect of heat distribution depends on the comparison with the reference heat supply at the demand side.

Table 1[2] provides an overview of indicative values for the energy saving, the emission effects and the costs for 16 combinations of users, sources and temperature levels[3]. The saving in primary GJ at the user's side and the savings percentage indicate how much the energy use decreases when deploying heat supply, as compared to the reference technology at the demand side. The saving per GJ of heat delivered by the producer determines the total energy savings that a given amount of available heat can realise.

Heat supply to non-residential buildings yields the largest saving, followed by the existing housing stock and newly-built dwellings. Heat supply to greenhouse horticulture hardly yields any savings, or may even result in a dissaving compared to the commonly used CHP. Deployment of industrial waste heat yields a higher saving compared to the deployment of tap heat from plants and waste incineration plants. If low-temperature systems are deployed, this yields additional savings compared to high-temperature systems[4].

The limited saving or dissaving in greenhouse horticulture can be ascribed to the efficiency of the reference technology, i.e. the gas engine CHP[5]. CO_2 emission reduction is not realised, but a significant decrease of non-ETS emissions is achieved. Of course, heat supply to greenhouse horticulture does yield a saving when CHP is not an obvious option, and it is relatively low-cost in that case. Therefore, waste heat utilisation may still be useful in specific instances. If electricity generation becomes

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1. When tapping 1 GJ of heat at 120 degrees, this is 0.18 GJ electricity, at 80 degrees this is 0.09 GJ. If this is produced elsewhere at a generation efficiency of 50%, this results in 0.36 or 0.18 GJ higher fuel use per tapped GJ of heat.

2. These numbers include the energy use of auxiliary energy, transfer and energy losses in the distribution grid. Costs in non-residential buildings are not indicated because the data were incomplete. However, the finding that costs are generally lower compared to households is robust. Cost indications are not useful in greenhouse horticulture due to the often negative savings and emission reductions. Moreover, there is a wide variety of costs among companies, because of among other the functions combined in horticultural CHP (heating, lighting, CO_2 fertilisation).

3. The 16 configurations represent 8 possible combinations of heat supply and demand, and two different temperature levels of the heat source. Of course, many intermediate configurations are possible, with intermediate values for the temperature level, and hybrid composition of both the supply and demand side. The calculations require concrete assumptions with regard to distance and scale: 10 km distance to a heat source of about 20 MW continuous. This covers about 10,000 newly built dwellings, 5000 existing dwellings, 200 offices or about 50 ha greenhouse horticulture. All cases assume delivery of heat for both space heating and hot tap water. The latter requires a minimum heat level because of health considerations. Another assumption concerns the use of the heat delivered for air-conditioning in non-residential buidlings. While the configurations may be representive, real cases inevitably will be different in many aspects. Therefore, the resulting emissions, energy savings and costs should be regarded as indicative for the cases as described.

4. Low-temperature systems will not be feasible or more difficult to realise in existing buildings compared to high-temperature systems. A low-temperature system in new buildings realises higher savings compared to a high-temperature system in existing buildings. The construction of heat distribution in existing buildings is much more costly compared to new buildings. The costs per unit of saving may therefore be much lower in new buildings.

5. The gas engine CHP is the most commonly used method for producing heat in greenhouse horticulture, and hence the reference for calculating savings. As CHP already saves a significant amount of energy compared to separate generation, the saving yielded by waste heat is much lower compared to CHP, or even negative if the tapping and supply of waste heat also requires additional energy. In case of a reference electricity generation efficiency of 50 %, heat from a gas-engine CHP, costs about 0.37 GJ of fuel per GJ of heat. Heat tapped from a power plant requires about the same amount of fuel. However, this heat needs to travel a larger distance, hence resulting in additional heat losses and additional pumping energy.

Table 1. Indicative savings, emission effect and costs in different supply-demand combinations.

Destination for heat		Primary energy saving		Avoided CO_2		Avoided CO_2 non-ETS	Cost effectiveness €/t CO_2		
Heat source	T °C	GJ/GJth demand	%	tonne/GJth demand	%	tonne/GJth delivered	€/t CO_2	non-ETS	€/GJ p
New residential									
Waste heat industry	120	0.63	58%	-0.03	56%	-0.06	119	67	6
Waste heat industry	80	0.75	69%	-0.04	67%	-0.06	39	26	2
Power plant/waste incineration	120	0.28	26%	-0.01	9%	-0.06	803	74	16
Power plant/waste incineration	80	0.66	61%	-0.03	54%	-0.06	-1	-1	0
Existing residential									
Waste heat industry	120	0.67	65%	-0.04	63%	-0.06	184	116	10
Waste heat industry	80	0.73	70%	-0.04	69%	-0.06	143	98	8
Power plant/waste incineration	120	0.39	38%	-0.01	23%	-0.06	577	135	20
Power plant/waste incineration	80	0.65	63%	-0.03	56%	-0.06	160	90	8
Non-residential									
Waste heat industry	120	0.80	72%	-0.04	71%	-0.06	neg.	neg.	neg.
Waste heat industry	80	0.82	74%	-0.05	73%	-0.06	neg.	neg.	neg.
Power plant/waste incineration	120	0.56	50%	-0.02	39%	-0.06	neg.	neg.	neg.
Power plant/waste incineration	80	0.75	68%	-0.04	62%	-0.06	neg.	neg.	neg.
Greenhouse horticulture									
Waste heat industry	120	0.06	16%	0.03	-25%	-0.11	-	-	-
Waste heat industry	80	0.08	21%	0.03	-24%	-0.11	-	-	-
Power plant/waste incineration	120	-0.18	-49%	0.05	-43%	-0.11	-	-	-
Power plant/waste incineration	80	0.01	2%	0.04	-31%	-0.11	-	-	-

more efficient in the future, or if the share of renewable energy increases, heat supply to greenhouse horticulture will also become more appealing, as in this case, the attributed heat generation efficiency of the CHP becomes lower[6]. As figure 1[7] shows, other heat demand-supply combinations for heat distribution also benefit with higher electricity generation efficiencies, but to a lesser extent. The main cause here is the lower attributed fuel input for pumping energy and other electricity consumption.

The total of avoided CO_2 emissions is affected by roughly the same factors as energy efficiency. However, from a national policy perspective, the CO_2 emission reduction outside the ETS is more favourable in all cases: waste heat supply prevents emissions outside the ETS, while resulting in a (usually smaller) increase within the ETS. Waste heat supply thus operates in an opposite way compared to small-scale CHP, which explains the large decrease in non-ETS emissions when replacing CHP with waste heat from greenhouse horticulture.

Cost data for non-residential building are too poor to allow for an exact estimate. However, the available data suggest that non-residential buildings score well when it comes to costs, followed by existing and new residential buildings. A favourable factor for non-residential building is that cooling demand may also be met by waste heat supply, using an absorption heat pump. In that case, the benefit of avoiding an conventional air-conditioning system contributes significantly to the favourable costs.

The grid costs take up the largest share of the costs of heat distribution: the supply pipe, the district distribution system and the connections with the dwellings and buildings. The exact costs depend to a high degree on the local conditions: the density of the buildings, the number of connections, and the distance to the heat source, new buildings or existing buildings, etcetera. Additional costs stem from the provisions for heat tapping at the source. These, too, will differ per individual case.

The 16 combinations in the table still do not do justice to the actual variation in circumstances: there is a large variety within the different categories, and mixed systems are also possible, both on the demand side and the supply side. Given that waste heat and heat distribution projects require tailored solutions, and that local conditions are very important for the options, costs and savings, these 16 situations only allow for indicating the potential and the costs.

Table 2 lists the qualitative effects on costs for a number of factors.

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6. The attributed heat generation efficiency of the CHP is calculated by subtracting the part of the fuel input that would be required in case of stand-alone power generation. The remaining part of the fuel input is attributed to the heat production. In case of slightly lower reference efficiency for electricity generation (48 % instead of 50 %); heat supply to greenhouse horticulture will result in a dissaving in all instances as compared to the gas engine CHP. However, in case of a higher reference efficiency for electricity generation, the savings of CHP decrease, which results in a comparably better performance of waste heat distribution.

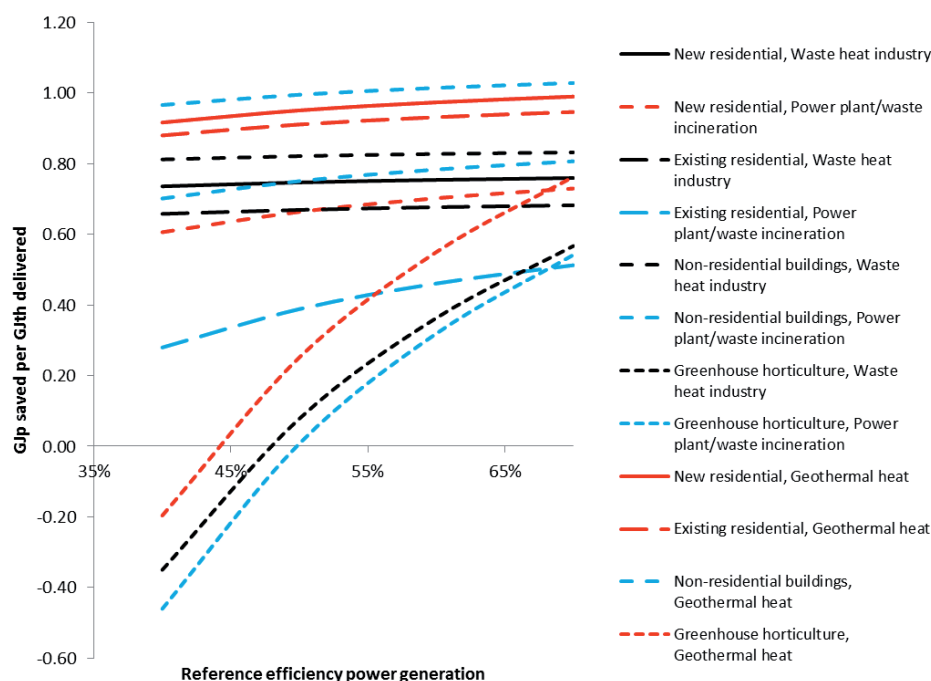7. Varying supply demand combinations, all based on 80 degree celsius temperature source.

Figure 1. Savings of heat distribution depending on reference efficiency of electricity generation.

Most of the factors in Table 2 still have many degrees of freedom at the local level. An important consequence is that the cost of deploying the waste heat potential in the Netherlands is not unequivocal: the way in which local opportunities are deployed determines the costs. In the Rotterdam region, for example, a large-scale integrated approach that combines multiple sources and delivery areas in one system can lead to lower costs compared to an approach in which supply and demand are combined one-on-one.

In many other regions, combining different heat sources will probably be a necessity: the individual industrial waste heat sources can usually cater for only 100 to 1000 dwellings. The costs are particularly high when there is a larger distance between the source and the destination.

Temperature level

The total amount of heat available at a sufficiently high temperature level is expected to amount to 440 to 480 PJ in 2020. If this were to be fully deployed, this could result in a saving of 150 to 310 PJ.

Heat supply is only obvious when the heat source has a higher temperature level than the destination. Heat demand at a lower temperature level usually involves space heating and hot tap water. This demand can mostly be found in households, non-residential buildings and greenhouse horticulture. Depending on the design of the heating system, this will require a heat source of 80 to 120 degrees Celsius. Heat distribution systems can be designed for various temperature levels.

Waste heat supply at a temperature level of 80 to 120 degrees Celsius is usually available in industry. An estimated 55 PJ of waste heat is available at 120 degrees and 95 PJ at 90 degrees.

Waste heat at a temperature of 80 to 120 degrees Celsius can also be tapped from electricity generation, but this will affect the electric efficiency. If waste heat were to be tapped from all plants, this would yield about 330 PJ of heat in 2020.

Synchronicity

Synchronicity refers to the temporal match between supply and demand, with regard to the short term as well as the long term. Of the total amount of 440 to 480 PJ that can be made available at a suitable temperature level, 90 to 120 PJ would be eligible on the basis of synchronicity and sufficient guarantees for long-term availability. This can result in an energy saving of 30 to 70 PJ. It is difficult and expensive to store heat for a longer period of time: to be useful for heat supply, waste heat also needs to be available at the right time[8]. Moreover, the expected life of the heat source and the consuming market should be sufficiently high and the availability of heat needs to be sufficiently secure.

SUPPLY AND DEMAND PATTERN

The heat demand for space heating and tap water is unevenly divided in time, whereas waste heat from industry is usually available in a relatively constant flow. A small part of this lack of synchronicity can be solved by storing heat in heat buffers, but even then the available heat can usually only be deployed for 30 to 45 %, whereas peaks in heat demand also require an auxiliary boiler to cater for 10 to 15 % of the heat demand. Absorption cooling makes it possible to use heat for cooling purposes. This allows for using a larger part of the available heat in office buildings, for example. In dedicated electricity generation, the potential availability of heat is determined by the production of electricity. In case of low electricity demand,

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8. Long-term heat storage may be feasible, but comes at additional costs. The current calculations have only explored conventional configurations without long-term storage.

Table 2. Effect of various factors on the cost of heat supply (+ favourable, - unfavourable).

Factor	Effect on cost/GJ, favourable (+) or unfavourable (-)	Explanation
More dwellings	++	Benefits of scale: part of the cost is constant, which is divided across a higher heat demand
	-	Large projects have a larger period of time between investment and full deployment: Higher initial losses and interest charges.
Larger heat sources	+	The costs per kW thermal capacity decrease due to scale benefits
Larger distance to heat source	-	Higher cost and slightly more energy loss
More existing buildings instead of new buildings	+	Higher heat demand per connection in existing buildings, dividing the costs across a higher heat demand, resulting in lower losses per connection.
	-	Cost of constructing the distribution grid is higher for existing buildings.
More (large-scale) non-residential buildings	++	Much higher heat demand per connection in existing buildings, dividing the costs across a higher heat demand, resulting in relatively lower losses per connection.
Catering for cooling demand with absorption heat pump	++	The operating time increases, and the avoided cost of an individual air-conditioning system lowers the additional investment for heat supply
More high-rise buildings with collective heating	++	Higher heat demand per connection, dividing the costs across a higher demand. Losses per connection are relatively lower.
More low-rise buildings and more spacious set-up of the district	-	Higher construction cost of distribution grid, higher energy losses
Waste heat instead of tapped heat	-	Cost of tap system for waste heat is usually higher.
	+	Higher energy saving in case of waste heat
Connection to existing heat distribution system	++	Lower investments, lower initial costs

some plants will not be in operation and hence not deliver any waste heat. Plants with low operating hours are therefore not suitable. For plants that do qualify, the tapped heat is expected to match demand for about 30 to 45 %.

LONG-TERM AVAILABILITY

Another aspect of synchronicity is the remaining life of the heat source and the consuming market. Heat supply projects have a long life, meaning that both the availability and the demand for heat need to be secured for a long period of time, e.g. 40–50 years. Older electricity plants and older individual industrial sources offer lower certainty compared to new plants and clusters of multiple heat sources, unless there is a reasonable degree of certainty that alternatives will become available.

Distance, density and scale

Taking into account the factors of distance, (spatial) density and scale, the waste heat that can be deployed decreases from 90–120 PJ to 50–75 PJ, and the saving decreases to 20–45 PJ. Distance, density and scale are only meaningful in an interrelationship: large-scale systems and a higher local density of heat demand allow for a larger distance to the source than small-scale systems. When there is a large distance between matching sources and the deployment opportunities of the heat, the cost of heat distribution rises accordingly. The heat losses also increase slightly, but this effect is less important because the largest losses occur in the more finely branched parts of the distribution grid. Density is the main factor here.

DISTRIBUTION OF SUPPLY AND DEMAND ACROSS THE NETHERLANDS

High concentrations of housing and non-residential buildings can be found in the agglomeration of cities in the Netherlands ('Randstad') and in several peripheral urban areas. Large heat sources, both industrial and electricity plants, can be found in the Rijnmond area. More heat sources are distributed across the Netherlands, but some of the locations are too distant from large potential consumer markets, such as for example the (new) power plant in the Eemshaven area. Here, local heat demand may absorb only a minor part of local potential heat supply.

CONNECTION TO EXISTING GRIDS

When sources or consumer markets are in the vicinity of heat grids, and connection is possible, this will usually lead to lower costs. A disadvantage may be that various characteristics of the heat grid, such as the temperature level, are largely fixed. Examples of areas that have combinations of existing heat grids, heat sources and consumer markets are the Rotterdam-The Hague region and Amsterdam.

Alternatives

Taking into account the availability of alternatives, the share of useful waste heat will decrease from 50–75 PJ to 25–45 PJ, and the realised saving will decrease to 10–25 PJ. The choice of whether or not to deploy waste heat depends to a large extent on the availability of alternatives. From the viewpoint of energy efficiency, emission reduction and/or costs, alternatives may be

more appealing. Barriers such as administrative or legal bottlenecks may also play a role in this choice, but they have not been part of the analysis.

TYPES OF ALTERNATIVES

Alternatives may decrease the availability of heat:

- Alternative deployment of heat within or outside the company that produced the heat (CCS, electricity generation, industry-to-industry heat delivery).

- Energy saving in the company that produces the heat (energy-effiency, process-integration).

They can also decrease the demand:

- Energy efficiency measures at the potential buyer (building insulation).

- Heat from other sources that can be deployed instead of waste heat (heat pumps, geothermal energy dedicated CHP).

INDUSTRIAL ENERGY EFFICIENCY

Improving industrial energy efficiency, for example through different processes or more efficient use of energy in existing processes, may affect the availability of waste heat. One example is heat integration, an option in which available heat of a certain temperature level is used as much as possible within a company to cater for heat demand at a lower temperature level. This lowers the externally available heat.

INDUSTRY-TO-INDUSTRY HEAT DELIVERY

Compared to heat delivery to the built environment, delivery to industry has the advantage of a better match in operating hours. The utilization rate of the heat can be much higher. Hence, energy savings and emissions reduction are better, and the costs generally lower.

DECREASING THE HEAT DEMAND

Lowering of energy demand, for example through building insulation, or by deploying different heat sources such as solar boilers, geothermal or heat pumps, may undermine the market options for waste heat. Generally, on those locations where waste heat can be deployed easiest and low-cost, as for example in new buildings and in large buildings, alternatives can also be deployed more easily. It is possible to design new dwellings such that they hardly have any heat demand. This will make a heat distribution grid less appealing: It will take a more vast and expensive heat distribution system to deliver the same amount of heat. There are fewer alternatives in existing buildings, but here, the deployment of heat distribution is also more difficult and more expensive. Alternative individual supply options for heat are usually very expensive in housing. Collective systems, involving multiple dwellings, are much more affordable due to scale effects. These scale effects are also clearly visible in larger non-residential buildings where alternatives are often more cost-effective, particularly in new buildings.

GEOTHERMAL

Geothermal resembles waste heat in terms of scale and temperature level[9]. When geothermal energy is possible, the energy saving renders the waste heat supply from plants and waste incineration plants less interesting: geothermal realises higher savings. The costs of a geothermal source are somewhat compensated by the avoided cost of a (long) heat supply pipe. One disadvantage of geothermal is that sources are usually depleted after about 30 years.

CCS

The industrial plants and power generation plants that are most suitable for waste heat supply are also that ones that are most eligible for deployment of CCS. When these plants deploy CCS, and apply waste heat for this, probably hardly any waste heat will be available, as CCS requires heat in the same temperature range as heat distribution systems. Per GJ of available tapping heat, CCS yields an emission reduction of an estimated 0.1–0.2 tonnes of CO_2, compared to a reduction of 0.01 to 0.02 tonnes of CO_2 when deploying heat distribution. CCS does not contribute to fuel saving but it increases fuel use.

OCCASIONAL SYNERGY

Alternatives that also use heat distribution, such as geothermal energy, may occasionally increase the opportunities for waste heat utilisation. When the available waste heat sources are small-scale, or when their existence is uncertain in the longer term, the availability of alternatives may lower the average costs or risks for waste heat deployment. However, the heat grid needs to be suitable for these alternatives. Waste heat could be stored in geothermal sources, for example.

Concluding remarks

So, despite large amounts of available waste heat, the potential for waste heat utilisation is rather limited: an estimated 10 to 25 PJ of net energy savings may be realised by the utilisation of 25 to 45 PJ of waste heat in district heating. This may lead to a total CO_2 emission reduction of 0.6 to 1.3 Mton. Within this potential, savings and costs may vary considerably.

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