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# WASTE HEAT AND HEAT PUMPS FOR DISTRICT HEATING

Annex to D.T2.2. Planning Guidelines for Small District Heating

Version 1

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## Content

# 1. Introduction

This document is an annex to the Planning Guidelines for Small District Heating (deliverable D.T2.2. of the ENTRAIN project) and comprises information regarding the utilisation of waste heat for district heating (DH) solutions and the integration of heat pumps into district heating systems. Systems using waste heat sources and heat pump technologies are complex plants and require a careful project developing, design and construction by experienced experts. This annex aims at providing a general overview about the integration of waste heat sources and heat pumps as well as an overview related basic things to be considered. It is a guideline for decision makers (e.g. mayors), planning engineers and operators of district heating plants to foster the development of flexible and renewable district heating solutions and the utilisation of alternative heat sources.

A general overview about the integration of various heat sources and technologies for new flexible DH systems is given in annex "FLEXIBLE DISTRICT HEATING SOLUTIONS – INTEGRATION AND INTERACTION OF VARIOUS TECHNOLOGIES". More detailed information about the integration of solar thermal plants is given in annex "SOLAR THERMAL PLANTS FOR DISTRICT HEATING".

# 2. Basics

Both waste heat utilisation and heat pumps (which may be needed to make alternative heat sources usable) for district heating (DH) systems are very complex issues that need to be investigated in detail on a case-by-case basis according to the individual framework conditions. This report shows starting points, regarding related topics to be considered and further investigated in detail.

## 2.1. Ambient heat and waste heat

*Ambient heat or environmental heat is a renewable, natural and widely available form of energy at a relatively low temperature level. Sources of ambient heat are the air, the upper soil as well as groundwater, sea and river water. Heat pumps can be used to raise ambient heat to a higher temperature level and make it usable. This requires the supply of high-quality energy usually in the form of electricity from another source.* [1]

Except for ground water, which is usually utilised for (small scale) single heating systems only, all ambient heat sources mentioned above are suitable for DH in principle. Generally ambient heat can only be utilised indirectly due to the low temperature levels available (see chapter 2.2).

Waste heat is defined in [1] *as unavoidable heat loss from energy conversion plants or chemical processes. Waste heat generated during a conducted process can be transferred to another process.* Therefore, it has to be considered that waste heat utilisation (heat recovery) is primarily implemented within the respective processes and industries as far as possible. Only waste heat that can no longer be recovered and would be released into the environment is considered for potential use as an alternative heat source for DH.

There is a wide range of sectors and industries where potential waste heat sources can be found. Many companies and industrial processes need for example cooling, compressed air, drying, incineration processes (industrial flue gas/exhaust gas), etc. which might be suitable for waste heat recovery.

Low temperature waste heat sources (e.g. residual heat in waste water from waste water treatment plants, exhaust air from data centres cooling, exhaust air from motorway tunnels, etc.) are becoming of increasing interest for DH by the application of heat pumps. Further examples for potential waste heat sources are shown in Table 1.

**Table 1: Examples for waste heat sources and integration options ( [2] translated and modified)**

| Sector / industry | Waste heat source (process) | Implementation examples |
|---|---|---|
| Automotive industry | Various processes<br>Waste heat from air compressors | |
| Food industry | Afterburning of exhaust gases from production processes<br>Waste heat from cooling or drying processes | Installation of flue gas/water heat exchangers in the flue gas lines of the individual processes<br>Utilisation of waste heat from refrigeration machines for DH with heat pumps |
| Detergent production | Waste heat from steam drying for powder production | Direct utilisation with heat exchanger (exhaust steam condensation) |
| Textile industry/laundries | Steam condensates from washing processes<br>Residual heat in washing waste water | Waste water heat exchanger |
| Waste water treatment plants | Residual heat in waste water | Installation of special sewer/heat exchanger and heat pump |
| Steel production, metal processing industry, foundry | Waste heat from melting and process furnaces | Direct utilisation with exhaust gas heat exchanger |
| Paint shops | Thermal afterburning of solvent vapours from the paint shop or drying rooms | Direct utilisation with exhaust gas heat exchanger |
| Cement industry | Waste heat from the clinker cooling plant | |
| Packaging industry | Various (steam) processes | |
| Chemical industry | Waste heat from sulphuric acid plants | |
| Food supermarket | Waste heat from cooling systems | Utilisation of waste heat from refrigeration machines for DH with heat pumps |

A special case of waste heat recovery exists for combined heat and power (CHP) plants. For power production from biomass it is essential to use the available waste heat from the power production process in order to maintain economic as well as ecologic viability. Therefore, (small scale) biomass CHP plants are usually operated in a way to maximise the heat production of the plant (base load operation) with the power production as a “side product” to heat generation. An overview of biomass CHP technologies can be found in [1].

## 2.2. Direct and indirect utilisation

Direct use of a (waste) heat source for DH is possible if the heat source has a sufficiently high temperature level. In this case, heat exchangers are used for the direct heat exchange between the heat source and the heating water of the DH system (e.g. for the pre-heating of the return flow from the grid). Feasible operating conditions for such heat exchangers can be achieved with a minimum temperature difference of about 15 K between the heat source and the heating water. Therefore, a minimum heat source temperature level of about 70 °C is needed for direct utilisation (with usual return flow temperatures from the grid of about 55°C).

Low temperature heat sources (e.g. residual heat in waste water from waste water treatment plants, exhaust air from data centres cooling, exhaust air from motorway tunnels, etc.) can be recovered and used for DH by the application of heat pumps. With heat pumps it is possible to raise the available low temperature heat to a temperature level suitable for DH (see following chapter).

## 2.3. Heat pumps

Heat pumps are used to raise heat from a lower to a higher temperature level. Mainly two technologies are currently used in DH applications: compression and absorption heat pumps.

Compression heat pumps use electric energy to raise heat from a lower to a higher temperature level. Figure 1 shows a functional scheme of a compression heat pump for heating purposes (utilisation of waste heat).

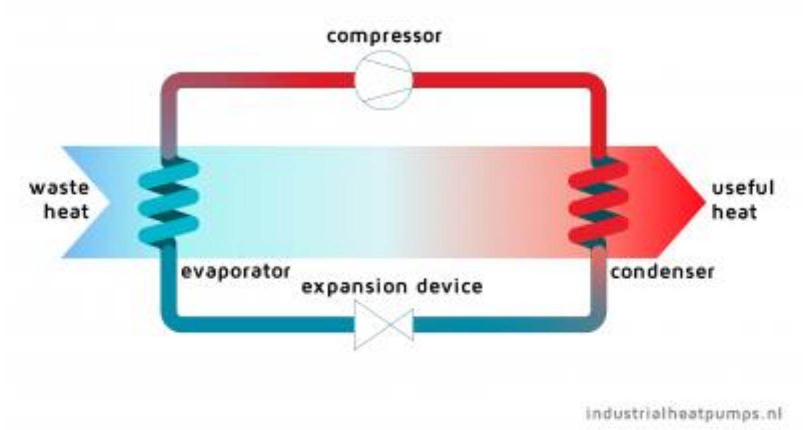


**Figure 1: Functional scheme of a compression heat pump for waste heat utilisation (source: industrialheatpumps.nl)**

The waste heat is transferred to a refrigerant which is evaporated in a heat exchanger (evaporator) at low refrigerant pressure and temperature. An electrically operated compressor brings than the refrigerant vapour to a higher pressure and temperature level which is high enough to exchange the heat (useful heat) with the heating water for DH. The refrigerant condenses during the heat release (see condenser in Figure 1). After heat exchange at the high pressure/temperature level, the refrigerant is expanded again to the low pressure/temperature level and re-circulated (closed refrigerant circuit).

The efficiency of a compression heat pump is indicated with the Coefficient of Performance (COP) which is defined for heating purposes as useful heat (output) divided by the electric energy (input). The maximum achievable efficiency is thermodynamically limited with the Carnot efficiency (Carnot-COP). This theoretical efficiency limit is determined by the temperature difference between high (supply temperature) and low temperature (temperature of the waste heat source) of the heat pump process.

In practice actual achievable COP values are considerably lower than the Carnot-COP. The ratio between actual COP and Carnot-COP is known as quality grade of a heat pump. COP values in the range of 50% to 70% of the Carnot-COP can be achieved (quality grade 0.5 to 0.7).

Figure 2 shows Carnot-COP and actually achievable COP values (for a quality grade of 0.5 - 50% of the Carnot-COP) in dependence of the system temperatures (t_high and t_low).

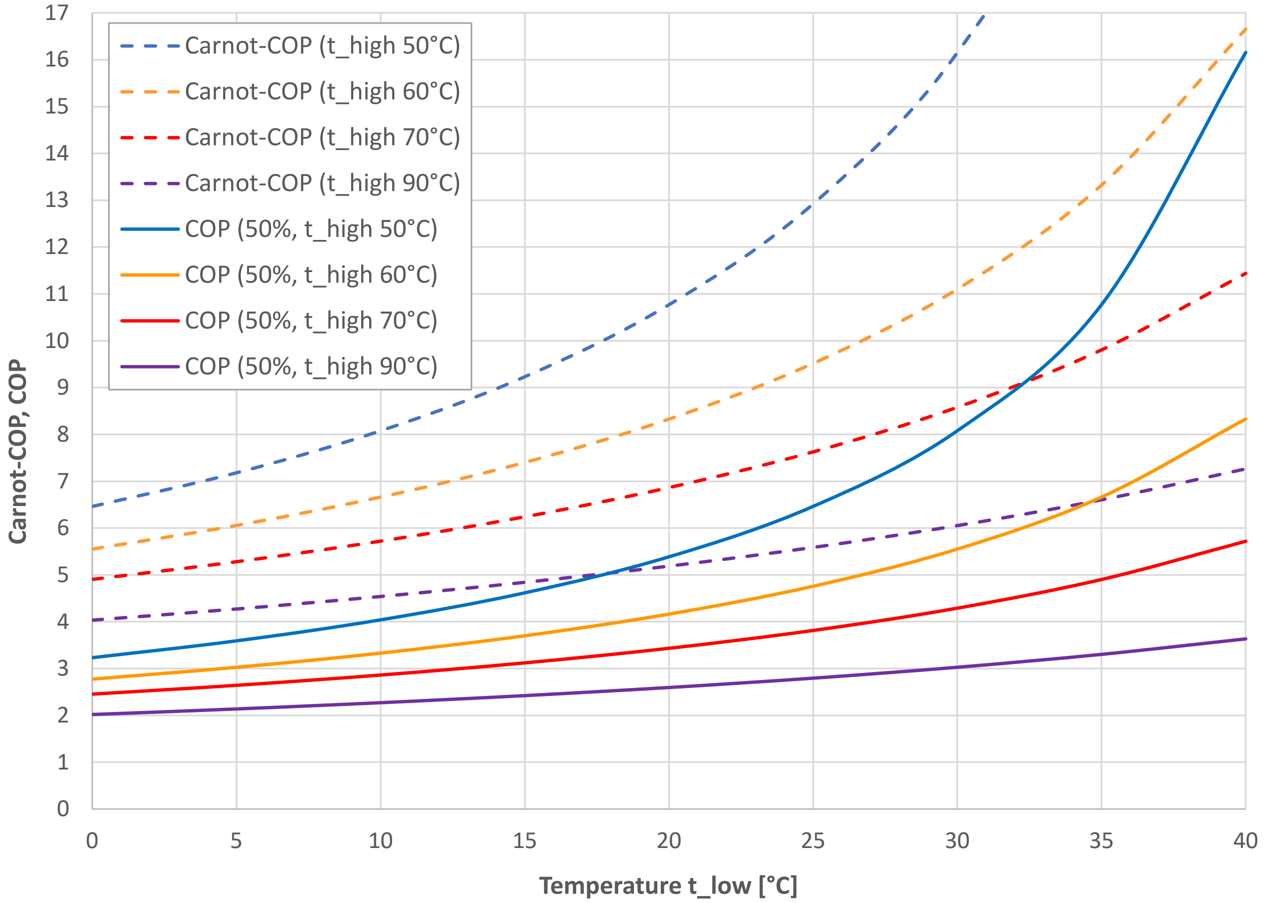


**Figure 2: Carnot-COP and COP for a quality grade of 0.5 (COP = 50% Carnot-COP)**

The higher the temperature difference to be overcome between heating side (t_high) and heat source (t_low), the lower the COP. Heat pump efficiencies are greater than 1 since the energy amount of the heat source itself is not considered for COP calculation.

Heat pumps with a heat capacity from 100 kW are known as industrial heat pumps which are available up to about 1.5 MW ( [3]). Table 2 shows temperature ranges and exemplary COP values for industrial heat pumps.

**Table 2: Temperature levels of heat sources and supply temperatures of compression heat pumps ( [3] translated)**

| Heat pump type | Heat source temperature range | Maximum supply temperature | COP examples |
|---|---|---|---|
| Single-stage | 35-55°C | 98°C<br>for low heat source temperatures: 65-75°C | COP: 3-5<br>W40°C/W80°C: COP 4.6 |
| Two-stage | 8-25°C | 98°C | W10°C/W85°C: COP 2.5 |
| Special applications | | 120-140°C | |

The operating conditions for heat pumps change constantly depending on many influencing factors. Main factors are the actual temperature level of the heat source (e.g. seasonal fluctuations of ambient heat sources, fluctuations in industrial processes) and the actual supply temperature demand (changing return flow temperatures from the DH grid). Therefore, annual COP values are used in order to characterise the annual average efficiency of a heat pump (ratio of the annual useful heat output to the annual electricity input) in addition to the (best point) COP values.

Depending on the operation temperature range different refrigerants are chosen by manufacturers and applied for compression heat pumps. Some refrigerants have significant global warming potentials (GWP) and are therefore restricted in use by law. In the future, only (if possible natural) refrigerants with low or zero GWP shall be used ( [4]) as for example Ammonia ($NH_3$).

Absorption heat pumps use thermal energy (at a high temperature level) for the raise of heat from a low temperature level to a medium temperature level (between the low and driving heat temperature levels). This technology is based on a refrigerant and additional sorbent cycle. Commercially available absorption heat pumps use water (or Ammonia for temperatures below 0°C) as refrigerant and lithium bromide salt as absorbent. A basic scheme of an absorption heat pump is shown in Figure 3.

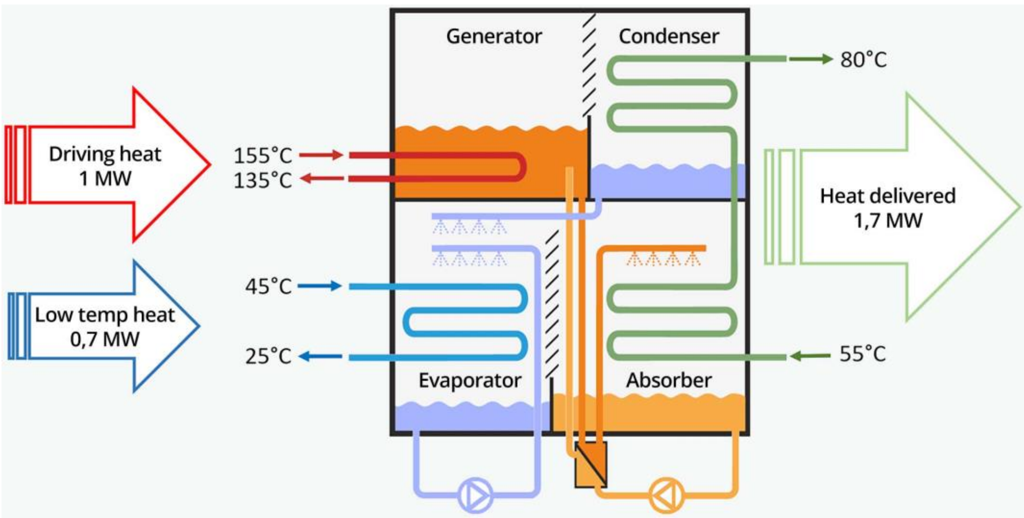


**Figure 3: Basic scheme of an absorption heat pump (source: stepsahead.at/en)**

Some further configuration options are possible in comparison to the basic configuration shown in Figure 3 (see http://stepsahead.at/en/heat-pumps/ for further information). Absorption heat pumps are especially applied for flue gas condensation in bigger DH plants (with a total heat output above 5 MW) if the return temperature level from the DH grid is not low enough for efficient direct flue gas condensation. The COP of an absorption heat pump is defined as ratio of useful heat to heat input. For the example shown in Figure 3 COP is 1.7 (1.7 MW heat delivered/1 MW driving heat).

# 3. Characterisation of waste heat sources

Waste heat sources have individual characteristics which have to be investigated in detail and thoroughly analysed in order to evaluate the suitability of a potential waste heat source for DH utilisation. The following relevant Points regarding the basic characterisation of a waste heat source should be considered:

- Type of waste heat source (see Table 1 for examples)
- Location and availability

- Is it a single or various sources and locations (e.g. within a company/industrial process)?
  In a large company, it is often not a single source or location where waste heat occurs. Many different sub-processes with various waste heat sources and different characteristics can exist. In a first step it should be ensured that the company and process internal heat recovery is already optimised. Otherwise, there is a risk that the waste heat will no longer be available for DH purposes in the same amount or at all after implementation of company internal optimisation measures at some point in the future.
- Location and distance in relation to the heating plant – see chapter 4.1

- Temperature level and temperature behaviour
  - Constant temperature level (independent of season/production/…)
  - Fluctuating (seasonal/dependent on process parameters/…) – what temperature range and (annual) temperature profile of the waste heat source has to be expected?
    Daily and seasonal temperature fluctuations have to be especially considered for ambient heat sources (ambient air, flowing or standing water); dependencies on the industrial process for waste heat sources in industry (especially for non-continuous processes).
  - For heat pumps, the minimum available temperature level during the intended period of use (during a year) of the heat source is relevant for the worst case.
- Load characteristic
  - Load profile - daily/weekly/yearly curve of the available heat capacity
  - Constant or (strongly) fluctuating?
    (base load, peak load, ratio of base load and peak load)
    As constant as possible is advantageous - especially for heat pumps.
  - Planned operation interruptions - e.g. holiday shutdowns, weekend brakes, (periodic) service and maintenance shutdowns
  - Rather uncritical for ambient heat sources (as "quasi-inexhaustible")
- Expected future development of the framework conditions
  - Production extension/reduction, possible uncertainties regarding operating site and future development of a company (see chapter 6.2)
- Heat transfer medium (water, air, flue gas, thermal oil, steam, …)
- Space demand and availability – is sufficient space for plant equipment available on site?

# 4. Technical issues

## 4.1. General technical issues

General technical issues to be considered regarding waste heat utilisation for DH relate primarily to temperature level issues in combination with the question how to integrate the waste heat source (possibly heat pump needed) into the DH system. The following technical parameters and framework conditions are of major relevance:

- Supply and return temperature levels of the heating grid; DH system temperatures are relevant for the hydraulic integration options of the waste heat recovery (heat pump)
- Location of the waste heat source and distance to the location of the DH plant/network
- Central integration; single location of the waste heat source with the option to integrate the heat supply either directly in the heating plant (possibly via a new/separate pipeline) or at a single feed-in point in the existing DH network
- De-central integration – distributed waste heat sources; e.g. at certain heat consumers (prosumers – see annex "FLEXIBLE DISTRICT HEATING SOLUTIONS – INTEGRATION AND INTERACTION OF VARIOUS TECHNOLOGIES") / at own location(s)
- Temperature level and characteristic of the waste heat source (see chapter 3)

## 4.2. Waste heat utilisation integration

For the integration of waste heat utilisation into DH systems some interlinked questions need to be solved. In a first step it has to be evaluated if the waste heat source is suitable for direct utilisation without a heat pump. Usually this is possible with a minimum temperature level of the heat source of about 70°C (see chapter 2.2). However, this cannot be answered separately from the question of the intended hydraulic integration into the DH system.

Depending on how the heat source is integrated into the network, additional pumps may be necessary for its utilisation. This raises the question of who is responsible for the operation of these pumps and who bears the costs. In addition, the type of integration may possibly have an impact on the efficiency of the existing system which has to be considered (e.g. reduced efficiency of the existing heat generators when the return temperature is raised, increased network losses). Further information regarding basic options for the hydraulic integration of de-centralised waste heat sources (for direct utilisation) is given in [5].

## 4.3. Heat pump integration

If a direct utilisation due to a too low temperature level of the heat source is not possible, heat pumps can be used (see chapter 2.2). The following points are relevant regarding the (hydraulic) integration of heat pumps into DH systems:

- Temperature requirements of the heat source – especially freeze protection has to be considered for the evaporator heat exchangers of air source heat pumps or in case pure water is used as heat transfer medium for the utilisation of the heat source.
- Possibly necessary separation of the heat source and the heat pump circuit with an intermediate heat exchanger to protect the heat exchanger of the heat pump from contamination and increased maintenance effort. Consider related negative effects on the efficiency of the heat pump due to the increased temperature difference to be overcome. [6]

- Interaction of the heat pump(s) with the other existing heat producers (regarding hydraulic integration and control strategy)
- Temperature requirements at the heating side of the heat pump according to the intended hydraulic integration of the heat pump – this has a great influence on the achievable efficiency of the heat pump depending on the required temperature level.
- Hydraulic integration of the heat pump – see [6] and chapter 8.3 in [7] for further information; basic options are:
  - in parallel to other heat generators (heat pump feeds in at supply temperature level)
  - in the return flow (increase of the return flow temperature)
  - special hydraulic circuits – mainly with absorption heat pumps (e.g. applied for flue gas condensation)
- Permissible operating range (operating limits) of the compressor of compression heat pumps according to the specifications of the compressor manufacturer (depending on the type of compressor and refrigerant used)

# 5. Profitability

Due to the extensive influencing factors, profitability calculations in the context of waste heat utilisation and heat pumps for DH systems are complex. Evaluation of the profitability should be carried out by experts with the appropriate know-how in a first step as part of a (pre-)feasibility study, taking into account the given framework conditions. In addition to reliable data regarding the technical issues involved (see chapter 0) various economic parameters have to be specified and evaluated as input for profitability calculations.

The following important parameters have a significant influence on the profitability of waste heat utilisation (heat pumps) for DH:

- Heat price (of the existing heat production plant)
- Calculated heat price for the utilisation of the alternative heat source or heat tariff. For economic viability this must be competitive to the heat price of the existing heat production.
- Investment costs (heat transport line, pumps, heat exchangers, heat pump, etc.)
- Available subsidies
- Electricity price (that can be applied for waste heat utilisation/operation of heat pumps)
  - Electricity from the grid (electricity purchase)
  - Own electricity production (own consumption)
- Heat pump efficiency - annual COP according to the given operation conditions during a year (see chapter 2.3) and guaranteed annual COP by the heat pump manufacturer (is a possible COP degradation over time considered by the manufacturer for the guaranteed value?)
- Credits that are possible due to the avoidance of costs through the further utilisation of waste heat (e.g. avoidance of costs for cooling)

For the basic methodology of the profitability calculation, the series of guidelines VDI 2067 (*Economic efficiency of building installations*) may be used. Further information about the techno-economic evaluation of heat pumps (including data regarding estimated investment costs and emissions) can be found in [6].

# 6. Administrative issues

Several administrative topics are affected in the context of waste heat utilisation for DH. Firstly, official permits can be necessary. Thereby it should be considered, that the effort for negotiations with authorities can be considerably increased. Similar to what is stated in [4] with regard to heat pumps this also applies in a generalised manner to waste heat recovery applications: *In general, it should be noted that due to the small number of projects, this technology is largely unknown to authorities and agencies, which can lead to more enquiries and possibly to longer processing times. (translated)*

A second topic is related to the utilisation of a waste heat source in private or company ownership. All relevant points (see chapter 6.1) must be specified in a reliable heat supply contract between the DH plant operator and the party providing the waste heat source. This is particularly important with respect to heat supply safety (see also chapter 6.2). Previous heat customers may also become heat suppliers in some cases.

Finally, the potentials for waste heat utilisation should also be considered for energy spatial planning. So far this is not taken into account to the necessary extent. Spatial planning is according to [7] *usually ignorant to available heat sources. Intelligent energy planning should avoid the emergence or continued existence of double infrastructures (e.g. DH and gas network at one site). These could also be DH preferential areas. For example, no holistic tools exist, which provide an overview of development areas and possible heat sources.*

## 6.1. General administrative issues

The following general administrative issues may occur in the context of waste heat utilisation for DH:

- Official permits may be required depending on the type of heat source
  - E.g. utilisation of residual heat from a waste water treatment plant: permission to cool the clear water from the competent authority with regard to minimum discharge temperature (species protection) needed
  - A permit may be required for the extraction of heat from the heat source (e.g. geothermal).
- Available (local) subsidies
  - Eligibility requirements for subsidies
  - Consider timing of the funding process (application deadlines, timing of disbursement)
- Ownership and property boundaries – which parts of the plant equipment are owned by
  - DH plant operator
  - Company/private person providing the waste heat source and possibly related equipment - consider operating (pumping) and maintenance costs
- Responsibilities – who is responsible for what?
- Liability in case of accidents or lack of heat supply
- Guarantees regarding technical characteristics of the heat source and agreements on parameters to be observed (e.g. thermal capacity or monthly/annual heat delivery, temperature level)
- Heat tariff (heat price of the waste heat for the DH operator)

The mentioned points concerning the framework conditions of the heat supply with the waste heat source (ownership, responsibilities, liability, guarantees, …) must be specified in a reliable heat supply contract between the DH plant operator and the party providing the heat source.

The negotiation of heat tariffs for waste heat utilization can be complex. For economic viability, the heat price of the waste heat must allow the DH operator an economic benefit compared to conventional heat generation. Thereby, the costs for the DH operator associated with the use of the heat source must be fully considered (investment, energy- and operation-related costs, maintenance, etc.).

## 6.2. Long term supply guarantee for waste heat

District heating plants generally have very long operating periods with planning horizons in the range of 20 to 30 years. In the case of a planned waste heat utilisation of commercial or industrial enterprises, problems arise due to different planning periods. Such companies usually do not plan so long into the future. Therefore, it is frequently not possible or realistic to get long term guarantees for the utilisation of a waste heat source over the whole intended operation period of a DH plant.

At least a supply guarantee, as long as the company is active on site should be agreed. Furthermore, a suitable backup solution for the heat supply in case the heat source is not available any longer should be considered (worst case scenario). Continued use of existing infrastructure at the company (e.g. natural gas connection/natural gas boiler) could be an option and contractually agreed, if applicable.

# References


[1] T. Nussbaumer, S. Thalmann, A. Jenni and J. Ködel, Handbook on Planning of District Heating Networks, Bern: Swiss Federal Office of Energy, 2020.

[2] M. Pehnt, J. Bödeker, M. Arens, E. Jochem and F. Idrissova, “Die Nutzung industrieller Abwärme - technisch-wirtschaftliche Potenziale und energiepolitische Umsetzung,” Heidelberg, Karlsruhe, 2010.

[3] klimaaktiv Programmmanagement, “Leitfaden für Energieaudits für betriebliche Abwärmenutzung,” Austrian Energy Agency, Vienna, 2014.

[4] J. Kühne and T. Roth, Praxisleitfaden Großwärmepumpen, Frankfurt am Main: AGFW, 2020.

[5] IEA Annex 47, “Task 3: Review of concepts and solutions of heat pump integration,” 2019.

[6] IEA Annex 48, “Training materials for industrial heat pumps, Final report,” 2019.

[7] IEA Annex 47, “Heat Pumps in District Heating and Cooling Systems, Final Report,” Heat Pump Centre RISE - Reserach Institutes of Sweden, Sweden, 2019.

[8] J. Neves and B. V. Mathiesen, Heat Roadmap Europe: Potentials for Large-Scale Heat Pumps in District Heating, Copenhagen: Department of Planning Aalborg University , 2018.