European
Commission

JRC TECHNICAL REPORT

Defining and accounting for waste heat and cold

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2021

Joint
Research
Centre

EUR 30869 EN

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EU Science Hub
https://ec.europa.eu/jrc

JRC126383

EUR 30869 EN

PDF ISBN 978-92-76-42588-5 ISSN 1831-9424 doi:10.2760/73253

Luxembourg: Publications Office of the European Union, 2021

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How to cite this report: Lyons, L., Kavvadias, K. and Carlsson, J. *Defining and accounting for waste heat and cold*, EUR 30869 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42588-5, doi:10.2760/73253, JRC126383

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Acknowledgements

This report was written by Lorcan Lyons and Konstantinos Kavvadias from the Knowledge for the Energy Union Unit of the European Commission Joint Research Centre in Petten, supervised by Johan Carlsson. It was reviewed by Faidra Filippidou, Juan-Pablo Jiménez-Navarro and Agne Toleikyte. Nadia Mesi provided support during the publication process.

Helpful answers to specific questions on this topic were provided by Aksana Krasatsenka and Pauline Lucas (Euroheat & Power, EH&P); Birger Lauersen (Danish District Heating Association); Astrid Madsen (independent consultant); Daniel Awater (Vattenfall Heat Netherlands); and Marina Galindo Fernández, Alexandre Bacquet and Soraya Bensadi (Tilia). Further comments on a draft version were provided by Kostadin Fikiin (Technical University Sofia); Antti Kohopää, Mirja Tiitinen and Sirpa Leino (Finnish Energy); Marco Baresi (Turboden); Anders Dyrelund (Ramboll); Lex Bosselaar (Rijksdienst voor ondernemend Nederland); Max Gunnar Ansas Guddat (PlanEnergi); Eline Blanchard (European Federation of Intelligent Energy Efficiency Services); Jozefien Vanbecelaere (European Heat Pump Association); Tim Sollberger (European Partnership for Energy and the Environment); Piotr Sprzączak (Polish Ministry of Climate and Environment); and Alexandra Tudoroiu-Lakavice (COGEN Europe).

The work was produced under the direction of Eva Hoos, Jan Ciampor and Madis Laaniste of the Directorate-General for Energy of the European Commission, with comments also received from Niels Ladefoged.

Abstract

This report provides guidance on defining and accounting for waste heat for the purposes of a) comprehensive assessments of waste heat potential under the Energy Efficiency and recast Renewable Energy Directives (EED and RED), and b) the targets under Articles 23 and 24 of the RED (heating and cooling, and district heating and cooling).

Off-site use of waste heat or cold only contributes to decarbonisation if it is truly “waste”, i.e. it could not reasonably be avoided or recovered for use on site. It must be a by-product of power generation, or an industrial or services activity. For cogeneration, all reasonable efficiency measures must have been implemented and in general only the heat from the condenser can be counted. District heating and cooling (DHC) networks are the only recognised end use.

Once those conditions are met, waste heat can be used to meet the heating and cooling target (Article 23 RED), and the DHC target (Article 24 RED), whether it comes from biomass, renewable electricity or even fossil fuels. However, waste heat and cold cannot be counted towards the overall EU renewable energy target of 32%.

For calculating progress towards those two sectoral targets, industry needs bottom-up reporting based on national registries of site-specific calculations. Pinch analysis should be used where possible. For the comprehensive assessments on the other hand, it is sufficient to use default values.

1 Introduction

This Joint Research Centre (JRC) Technical Report clarifies the definition of waste heat and cold and how to account for it, and explains what is eligible under Directive 2018/2001/EU (recast RED) and amending Directive 2018/2002/EU (EED). The report is a scientific analysis of the practical and theoretical implications of the current accounting framework. It aims to help national administrations in the Member States implement the Directives but also be of interest to a wider audience in the heating and cooling sector. It does not in any way prejudice the Commission's prerogative to provide formal guidance and interpretation for the implementation of the Directives, or to propose and adopt legislative amendments, proposals or new policy initiatives.

Both the recast RED and the EED contain provisions to incentivise the use of waste heat and cold. On-site use is an important way of improving energy efficiency. It is an application of the Energy Efficiency First principle and an opportunity to boost industrial competitiveness. Off-site use also has an important role to play in decarbonisation, as part of smart energy systems. Waste heat is specifically referenced in the EU Strategy for Energy System Integration published in July 2020 as being key to integrating energy efficiency with the circular economy (European Commission, 2020a).

However, off-site use of waste heat only contributes to decarbonisation if it is truly "waste", i.e. it could not reasonably be avoided or recovered for use on site. Defining and accounting for this energy accurately is therefore important. Despite recovery technologies being widely available, only very small amounts of waste heat and cold are sold in Europe today.

Chapter 2 discusses the relevant articles and definitions from the recast RED and the EED. The next two chapters discuss accounting for waste heat and cold under each Directive separately.

The recast RED requires a more detailed analysis of what can be accounted for as waste heat than the EED. **Chapter 3** explains how waste heat and cold counts towards the requirements to increase the shares of renewable energy in total heating and cooling and in district heating and cooling (DHC), under recast RED Articles 23 and 24 respectively. The chapter also briefly discusses accounting for waste heat and cold in the energy balances of Eurostat.

For the EED, **Chapter 4** looks at the feasibility of data collection and calculation of heating and cooling potential for the comprehensive assessments under Article 14. Article 14 requires Member States to identify waste heat potential, and then to define policies to realise that potential.

Annex A provides examples of waste heat and cold sources, recovery technologies and uses. **Annex B** lists barriers to the use of waste heat and cold. **Annex C** discusses pinch analysis in more detail. **Annex D** is a literature review on waste heat potentials by sector. **Annex E** outlines some other possible areas of application of these concepts, i.e. Green Public Procurement (GPP) of data centres, Guarantees of Origin, carbon credits and energy portfolio standards. Lastly, **Annex F** proposes draft text for a Recommendation.

2 Waste heat and cold in the Directives

2.1 Energy Efficiency Directive

The EED mentions waste heat and cold several times (Articles 2, 7 and 14) but gives no clear definition. It mentions waste heat from power generation, which could be recovered through cogeneration, and waste heat from industry. The terms "useful temperature level of waste heat" and "useful waste heat" are also used but without additional explanation.

Waste heat or cold recovery, both for use off site and on site, is an important energy efficiency measure. It is widely used in industry and thus plays an important role in achieving the objectives of the EED. This is in contrast to the recast RED, under which only heat or cold that is used *off site* in DHC networks counts towards the targets under Articles 23 and 24. Therefore, waste heat in the context of the EED has a broader scope than in the recast RED.

Member States often claim energy savings from internal use of waste heat under Article 7 of the EED. That waste heat is not counted in the Eurostat energy balances, including when an Organic Rankine Cycle uses it to produce electricity for consumption on site, but is an internal energy efficiency improvement (Filippidou et al., 2021).

Article 14 of the EED requires a Cost-Benefit Analysis (CBA) of the potential to use waste heat when planning or refurbishing industrial installations. In that context, waste heat refers to both internal use, through cogeneration, and external use via a DHC network.

For Efficient District Heating and Cooling, the definition in the recast RED applies. That is, only waste heat coming from a site that has already implemented all reasonable energy efficiency measures is counted (see below and Jiménez-Navarro et al., 2021)).

Both the EED and recast RED aim to respect the Energy Efficiency First principle. The first priority should be to reduce the need for heating and cooling to the greatest extent possible. For buildings, that could mean renovation, better building design and urban planning; in the waste treatment sector, that might mean prioritising mechanical recycling over waste-to-energy (WtE), incineration or so-called chemical recycling (i.e. implementing the waste hierarchy); it could also inform regulation of emerging and potentially energy-intensive activities such as crypto-asset mining. The next priority would be to ensure efficiency in processes and uses (in industry, supermarkets, data centres, etc.), including waste heat recovery on site, so that waste heat sent for use off site is really unavoidable. Finally, reuse for other purposes should be encouraged.

2.2 Renewable Energy Directive

2.2.1 Defining waste heat and cold

Recast RED Article 2(9) defines **waste heat and cold** as "unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a DHC network, where a cogeneration process has been used or will be used or where cogeneration is not feasible". This section presents our understanding of each element of that definition in turn.

First, only **unavoidable** losses are counted as waste heat. An unavoidable waste stream is one that can neither be recovered inside the same process or facility, including by expanding the facility to include new processes (i.e. industrial symbiosis), nor reduced through the use of more efficient equipment (e.g. high-efficiency cogeneration) or other energy efficiency measures (the energy performance of a facility depends not only on investment in more efficient equipment and design but also on the day-to-day operation of the plant). In other words, an unavoidable waste stream can only be used by sending it off site. The technical and economic feasibility of applying energy efficiency options has to be analysed, and all "reasonable" efficiency measures must be implemented first.

For a state-of-the-art installation, avoidable losses would be zero. In the longer term, advances in Best Available Technology (affecting the definition of what is "reasonably" unavoidable) may affect the availability of waste heat for sale. This is sometimes seen as a risk to security of supply by DHC network operators (see Annex B).

Note that this definition of what is unavoidable may exclude the most profitable option in some cases. There may be situations where economically it would be more attractive to use waste heat off site even when it would be technically and economically feasible to use it on site. In such cases, off-site use is still possible but it would not count towards the sectoral targets or the comprehensive assessments of potential.

Some countries already apply a definition of waste heat as being unavoidable through energy efficiency. In France for example, the Agence de l'Environnement et de la Maitrise de l'Energie (Ademe) subsidises waste heat recovery equipment and DHC infrastructure fuelled by waste heat only if that waste heat is part of a coherent, three-step approach to energy efficiency (Ademe, 2019): first, reduce the upstream need for useful heat and fuel consumption; second, use recovered waste heat internally; third, use the recovered waste heat externally if the site is close to a DHC network or other potential user. The first two points must be supported by an energy audit or feasibility study but there is currently no obligation on the waste heat provider to implement the actions recommended by the audit or study.

Second, waste heat and cold should be a **by-product**, i.e. not the intended purpose of the system but an inevitable result due to inefficiency. Importantly, the originally designed heat production from a heat, cogeneration or WtE plant cannot be considered waste heat, but unavoidable waste heat from such a plant can.

This also affects other sources. For example, waste heat from a metro system could be considered a by-product of transport infrastructure. Similarly, waste heat from a mining operation could be considered a by-product of mining activity. However, waste heat from the mine water left over in a disused mine might not be considered waste heat (because the activity in question has ceased) but could be considered a kind of ambient heat instead. Geothermal energy that takes advantage of such infrastructure (e.g. energy tunnels) should also be separated from waste heat (EHPA, 2020).

Taking another example, heat from wastewater treatment can be included in waste heat as long as it is considered a by-product of the treatment, which is a tertiary activity. However, heat recovered from the pipes and tunnels in public wastewater or sewage networks is considered ambient heat and therefore renewable (recast RED Article 2(2)) but not waste heat (Box 2).

Third, waste heat or cold must be **used via DHC** in order to count as waste heat eligible for the heating and cooling target (Article 23) and district heating and cooling target (Article 24). This is explained in more detail in sections 2.2.2 and 2.2.3.

Box 2. Why not sewage heat?

Sewage in underground pipes contains heat that can be extracted through various types of heat exchangers. This can provide heat at a usable temperature for a district network by passing it through a heat pump. For the avoidance of confusion, note that we are not referring here to renewable energy from the burning of wastewater treatment plant gas or sewage treatment plant gas.

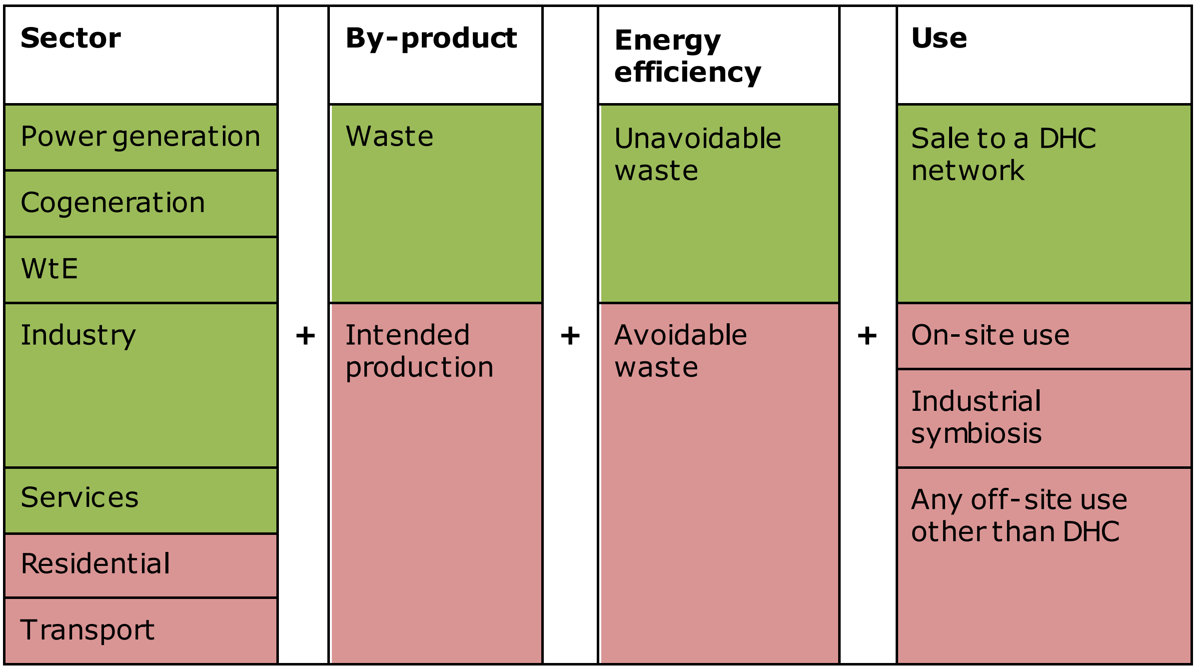
Roughly 14% of residential energy consumption is for hot water, and about 574 TWh of low-grade waste heat from tap water is lost unused to the sewage system (Pelda and Holler, 2019). Waste heat from industry also ends up in those same sewage pipes, increasing volumes and temperatures still further (AIT, 2020).

A distinction can be drawn between heat recovery directly in buildings using small heat recuperators, heat recovery in the sewer system using an internal or external heat exchanger, and heat recovery at the outlet of the wastewater treatment plant. Heat recovery from the sewer system has two advantages: its flow is more constant than that from a single building, and it is at a higher temperature than heat from a wastewater treatment outlet. It is also particularly suited to integration with DHC networks in urban settings, as demonstrated for instance in Helsinki (Helen Oy, 2015).

Heat recovered from the sewer system is considered ambient heat and therefore renewable but not waste heat. Based on the definition of waste heat from the recast RED, an argument could be made that at least the share of sewage heat that is a by-product of industry or services should be considered waste heat. However, there doesn't seem to be an easy way of calculating the shares of sewage from the residential sector and other sectors once it has been combined in sewage pipes.

Table 1 summarises which waste heat streams can be considered for the purposes of the recast RED heating and cooling targets. Theoretically, the residential and transport sectors could have been included in the RED definition of waste heat but from a practical point of view sources in those sectors are very diffuse and it would be hard to meet the criteria of "by-product", "unavoidable" and use via DHC. DHC networks serve the residential sector, but return water should not be double-counted.

Table 1. Eligibility of waste heat and cold for the recast RED heating and cooling targets



Sector		**By-product**		**Energy efficiency**		**Use**
🟩 Power generation		🟩 Waste		🟩 Unavoidable waste		🟩 Sale to a DHC network
🟩 Cogeneration						
🟩 WtE						
🟩 Industry	+	🟥 Intended production	+	🟥 Avoidable waste	+	🟥 On-site use
						🟥 Industrial symbiosis
🟩 Services						🟥 Any off-site use other than DHC
🟥 Residential						
🟥 Transport						

Notes: Green = Meets the eligibility condition; Light red = Does not meet the eligibility condition. All four conditions must be met. WtE = Waste-to-energy. DHC = District heating and cooling.

Taking the example of cogeneration, it is an eligible sector (first column) but the intended heat production cannot be considered (second column), only that which would otherwise be dissipated unused. Furthermore, it would have to be shown that the stream could not reasonably be avoided through energy efficiency improvements (third column), and that the heat is being sold to a DHC network (fourth column).

Taken together, the relevant provisions of EED and the recast RED require that all reasonable energy efficiency measures should be applied first, to fulfil the targets and objectives of the EED. Only then should waste heat be applied to meet the targets under the recast RED, i.e. after all energy demand reduction possibilities have been exhausted. This sequence for dealing with waste heat is an application of the Energy Efficiency First principle.

2.2.2 District heating and cooling in the Directive and Eurostat guidance

According to Article 2(19) of the recast RED, "district heating" or "district cooling" means the distribution of thermal energy in the form of steam, hot water or chilled liquids, from central or decentralised sources of production through a network to multiple buildings or sites, for the use of space or process heating or cooling. This definition has several elements.

First, the consumption must be *off site*, i.e. by a different economic entity. For example, using heat from a production facility for an office building belonging to the same company would be internal recovery rather than waste heat.

Second, waste heat must be *sold*, as per the Eurostat guidance on completing annual questionnaires (Eurostat et al., 2019). There are situations where waste heat is provided free of charge, though the cost of extraction is not always included. This could be to generate local goodwill, benefit employees living locally or simply avoid regulatory or tax burden. Free provision could also be motivated by corporate social responsibility in large industrial companies or data centres (which face costs associated with cooling towers, fans etc. anyway). Provision of "free" heat may be set to grow as low-temperature sources become more available or as DHC network operators make required investments. There are also situations where waste heat is provided free of charge during summer months. Waste heat, or any other form of energy, provided free of charge is not accounted for in energy statistics however. One way around this, in the absence of a revision to the Eurostat guidance, would be to sell the heat under contract for a symbolic euro.

Third, waste heat must go to a heat *network* of some kind, i.e. more than one customer and more than one building or site. Supply of heat to one building only is excluded from DHC and therefore from the definition of waste heat under the recast RED. Situations where only one customer is connected should not be reported either. Industrial sites often outsource their energy generation to companies that exclusively supply them with the required energy. The "at least two different customers" criterion is applied in order to exclude such "closed" industrial networks. In other words, waste heat consumption off site without a DHC network cannot be counted towards the goal. That said, despite the colloquial meaning of the word "district", smaller networks connecting at least two buildings are included. Eurostat (2017) provides more detail and examples.

From the reporting perspective, the Eurostat DHC template (row 9) covers heat recovery units recovering heat from chemical and other processes (e.g. other industrial processes, manufacturing, data centres, metro systems, or any other process). Only units that recover heat in order to use it for district heating, and if this surplus heat would otherwise have been dissipated unused into the air or water, are to be reported there. Heat produced by cogeneration plants is not to be reported.

2.2.3 Targets

Under the recast RED, waste heat that cannot be avoided or used on site, which is then sent for use off site, can be counted towards the targets for renewable heating and cooling

(Article 23) and renewable DHC (Article 24). In the case of the heating and cooling target, the use of waste heat and cold to meet targets is optional for Member States and subject to an upper limit, i.e. only a maximum of 40% of the 1.3 percentage points annual average increase can be achieved with waste heat or cold. In the case of the DHC target, the use of waste heat or cold is also optional but is not subject to a limit, i.e. the entire one percentage point annual average increase can be achieved with waste heat or cold.

Under Article 23(1), Member States have to endeavour to increase the share of renewables in heating and cooling by an indicative 1.3 percentage points as an annual average for the periods 2021 to 2025 and 2026 to 2030 compared to 2020, expressed in terms of final energy consumption. Achievements prior to 2020 cannot be counted.

Under Article 23(2), waste heat and cold can supply a maximum of 40% of the average annual increase. The increase is limited to an indicative 1.1 percentage points for Member States where waste heat and cold is not used. Use of waste heat and cold to meet the heating and cooling target is optional for Member States that do not have significant DHC, because waste heat and cold are only eligible if used in DHC. Even Member States where such infrastructure has been developed can opt out from using waste heat and cold to meet the heating and cooling and DHC targets. That could be because they want to be more focused and ambitious on renewable heating and cooling.

If the share of renewables in heating and cooling is greater than 60% in 2020 (the base year for the obligation), the average annual increase is deemed to be fulfilled automatically. This rewards early effort and aims to reflect the considerably diverse level of development in renewable heating (in 2018, only Sweden had a renewable share of heating and cooling greater than 60%) (Eurostat, 2020). The same 60% threshold applies for the one percentage point DHC target, i.e. where this threshold is met in 2020, the increase is deemed fulfilled.

The Directive also rewards renewable shares of heating and cooling that are less than 60% but still high. If the share of renewables in heating and cooling is less than 60% but greater than 50%, then half of the annual increase is fulfilled (in 2018 this was the case for Latvia, Finland and Estonia). In other words, the annual average increase requirement is only 0.65 percentage points if such a Member State chooses to use waste heat and cold to achieve it, or 0.55 percentage points if that Member State uses only renewables.

The flexibility to use waste heat and cold is intended to encourage the development of efficient DHC, which is also a major enabler of the use of decentralised renewables. The reduced- or zero-increase requirements are intended to reward early efforts and to recognise that at high shares of renewable heat, further increases become progressively more difficult.

Under Article 24(4), Member States have to endeavour to increase the share of energy from renewables and waste heat and cold in DHC by at least one percentage point as an annual average calculated for the period 2021 to 2025 and 2026 to 2030, based on 2020 levels and expressed in terms of share of final energy consumption (point (a)). Member States can, instead of that increase, implement third-party access to DHC networks for suppliers of renewable and waste heat and cold, as well as from high-efficiency cogeneration (point (b)); such access is currently blocked in many cases.

Article 24(10) contains exemptions from these provisions for Member States where the national share of DHC is less than 2% (point (a)), and if this low share of DHC increases to above 2% by developing new efficient DHC as set out in National Energy and Climate Plans or comprehensive assessments. The other exemption is where efficient DHC or small and medium systems make up more than 90% of the DHC market.[1]

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[1] The threshold is 20 MW according to point (c) of Article 24(10). If networks with capacities below 20 MW constitute more than 90% of total sales of DHC, the exemption applies.

Efficient DHC is networks that meet the definition in Article 2(41) of the EED and also applied under the recast RED and those based on high-efficiency cogeneration.[2] DHC networks that are not efficient at the time the Directive is transposed but for which a plan exists to become efficient by 31 December 2025 can also benefit from the exemption.

The eligibility of waste heat and cold does not depend on the fuel mix of the source. Any waste heat can be used to meet the heating and cooling sector target, and the DHC sub-sector target, whether it comes from biomass, renewable electricity, fossil fuels, or even another waste heat source via cogeneration.[3]

It also must be noted that the eligibility of a waste heat and cold stream for the purposes of those targets does not render it renewable in a broader sense, as waste heat and cold cannot be counted towards the overall (non-sectoral) EU renewable energy target of 32% under Article 3(1) of the recast RED. This is analogous to the sectoral transport target, which can be met using non-renewable (such as waste-based) fuels that do not count towards the overall EU renewables target either.

In other words, heat or cold used externally that could not be used internally is considered equivalent to renewable energy under Articles 23 and 24 of the recast RED but it does *not* count towards the overall EU renewables target or national renewable energy contributions. It also does not count as renewable energy in the context of renewable energy levels in buildings (Article 15(4)), even if it can be delivered through DHC networks along with renewables. This can be a barrier to waste heat integration in DHC networks (see Annex B).

2.2.4 Comprehensive assessments

Article 14 of the EED focuses mainly on the promotion of high-efficiency cogeneration and efficient DHC but also covers waste heat and cold, as well as individual renewable heating and cooling technologies. It requires each Member State to carry out a comprehensive assessment of the potential for efficient heating and cooling, with a view to promoting it.[4] The assessment is made at national level must be updated every five years.

Member States are also required to assess waste heat and cold potentials for heating and cooling together with those of renewable potentials under Article 15(7) of the recast RED.[5] This assessment must be part of the comprehensive national heating and cooling assessments under Article 14 of the EED.

Each comprehensive assessment must identify potential off-site supply of waste heat or cold in GWh per year; and reported shares of energy from renewable sources and from waste heat or cold in DHC final energy consumption over the past five years. Data that cannot be gathered directly should be derived indirectly, and Member States must also map the potential sources of waste heat and cold that could satisfy future demand (European Commission, 2019).

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[2] The definition of efficient DHC under Article 2(41) of the EED has been incorporated by reference in Article 2(20) of the recast RED. It is defined in the following way: "efficient district heating and cooling" means a DHC network using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat.

[3] Waste heat can be an input to cogeneration just like any other fuel. It is included in the Commission Decision on reference values for calculating the efficiency of cogeneration, see https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32008D0952&from=EN. There is an efficiency reference value in Commission Delegated Regulation 2015/2402 (Annex 1, category O14), which is being reviewed.

[4] The assessment is also required by recast RED Article 15(7).

[5] Article 15(7) reads: "Member States shall carry out an assessment of their potential of energy from renewable sources and of the use of waste heat and cold in the heating and cooling sector. That assessment shall, where appropriate, include spatial analysis of areas suitable for low-ecological-risk deployment and the potential for small-scale household projects and shall be included in the second comprehensive assessment required pursuant to Article 14(1) of Directive 2012/27/EU for the first time by 31 December 2020 and in the subsequent updates of the comprehensive assessments".

The first round of comprehensive assessments (due by 31 December 2015) did not consider waste heat sources to the fullest degree possible. JRC analysis found that they could benefit from the gathering of new data, descriptions of new potential for heating and cooling, and better interaction between national and local administrations. The second cycle of assessments is required by 31 December 2020.

For the purposes of comprehensive heating and cooling assessments, the following categories should *not* be considered waste heat:[6]

- heat that was generated with the main purpose of being directly used on or off site and is not a by-product of another process, irrespective of the energy input;
- cogenerated heat from combined heat and power plants, because cogeneration is an energy efficiency measure by design (it reduces waste heat by using the energy of the input fuel in a more efficient way); and
- heat that is or could be recovered internally on the same site.

Once the above conditions have been met, the following *should* be considered examples of waste heat:

- data centres, shops or shopping centres that need to be cooled, where the heat resulting from the operations can be delivered off site instead of being dissipated to the environment;
- direct use of condenser cooling stream from power plants (e.g. to warm greenhouses); and
- heat generated from renewable fuels as a by-product of a main process (e.g. biodegradable waste incineration and biomass).

Point 2(b) in Annex VIII of the EED lists heat generation installations to be analysed for their potential to meet heat and cooling demand:

i. thermal power plants that can supply, or be retrofitted to supply, waste heat with a total thermal input exceeding 50 MW (condenser heat only);
ii. cogeneration installations using technologies referred to in Part II of Annex I with a total thermal input exceeding 20 MW (condenser heat only);
iii. waste incineration plants (treated like power generation or cogeneration);
iv. renewable energy installations with a total thermal input exceeding 20 MW other than the installations specified under i. and ii. generating heating or cooling using energy from renewable sources;
v. industrial installations with a total thermal input exceeding 20 MW that can provide waste heat (unavoidable only).

Member States may go beyond the waste heat and cold sources listed above, in particular from the tertiary sector. For the purposes of linking the authorisation and permitting records laid out in Article 14(7) EED with the potential identified in the comprehensive assessments, Member States can assess the waste heat generation potential of thermal power generation installations with a total thermal input between 20 and 50 MW (European Commission, 2019).

It might also be useful to describe the quality of energy produced, e.g. temperature (steam or hot water) available per application for which it could typically be used. If the quantity or quality of the waste heat or cold are not known, they can be estimated. For example,

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[6] In line with points 2(b) and 2(c) of Annex VIII of the EED and Commission Recommendation (EU)2019/1659. The rest of this sub-section is based closely on that Recommendation.

there are various methods and technologies for recovering waste heat from power generation.

In order to show waste heat and cold projects on maps, Member States are advised to collect:

- name and location of plant;
- quantity (GWh/year) and quality (usual temperature and medium) of current and potential waste heat and cold available; and
- availability of waste heat and cold (hours per year).[7]

Reporting of waste heat potential can also be based on a survey of industrial sites. The survey could ask respondents to quantify:

- total energy input;
- heat capacity;
- how much of the generated heat is already used; and
- how much of the heat is cooled (or how much of the cold is warmed) or emitted to the environment.

Another way to assess the potential for waste heat and cold supply is to estimate it indirectly by assuming similar heat-temperature profiles per tonne of product for plants in the same sector, of a similar age, using the same technology for recovery, with the same degree of energy integration, and subject to similar measures to reduce energy losses.

It is strongly recommended that Member States report the temperature grade and the medium (liquid water, steam, molten salt or other) of waste heat and cold; these factors determine possible applications and transmission distances (Box 1), thus influencing the analysis of the scenarios.

Box 1. Transmission distances

Recovered waste heat needs to be transported to where it will be used, with the temperature decreasing along the way. This could make off-site use of waste heat particularly difficult for industrial sources, which are often sited far from DHC networks. That raises the question of the distance between the source of waste heat and the heat sink that still makes it economic to use the energy. sEEnergies (2020) uses a heat transmission threshold of 10 km. Member States use various thresholds of their own.

Kavvadias and Quoilin (2018) analyse long-distance heat transmission by using a detailed techno-economic model to estimate heat transport costs. They conduct sensitivity analysis to show the effect of transmission distance, supply temperatures and market prices. The model is also used to identify the maximum economically feasible transmission distance that meets a specified economic criterion and to derive a rule of thumb: maximum delivery distance is proportional to the square root of heat sent.

Kavvadias and Quoilin (2018) find that current heat pipelines rarely exceed 30 km in length, with an observed maximum of 60 or 70 km. While most literature sources use a common threshold for feasible heat transmission distance in the range of 30–50 km, their techno-economic model suggests that longer distances are feasible for specific techno-economic parameters and market conditions.

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[7] Jakubcionis and Kavvadias (2015) provides guidance to Member States on the structure and methods of preparation of a map of the national territory, identifying heating and cooling demand points, district heating and cooling infrastructure and potential heating and cooling supply points.

The most common media used to recover waste heat include:

- **combustion exhausts** from glass-melting furnaces, cement kilns, fume incinerators, aluminium reverberatory furnaces and boilers;
- **process off-gases** from steel electric-arc furnaces, aluminium reverberatory furnaces, and drying and baking ovens; and
- **cooling water** from furnaces, air compressors and internal combustion engines.

Steam rarely appears as waste heat, because it is usually generated on demand and exhausted or condensed during the process.

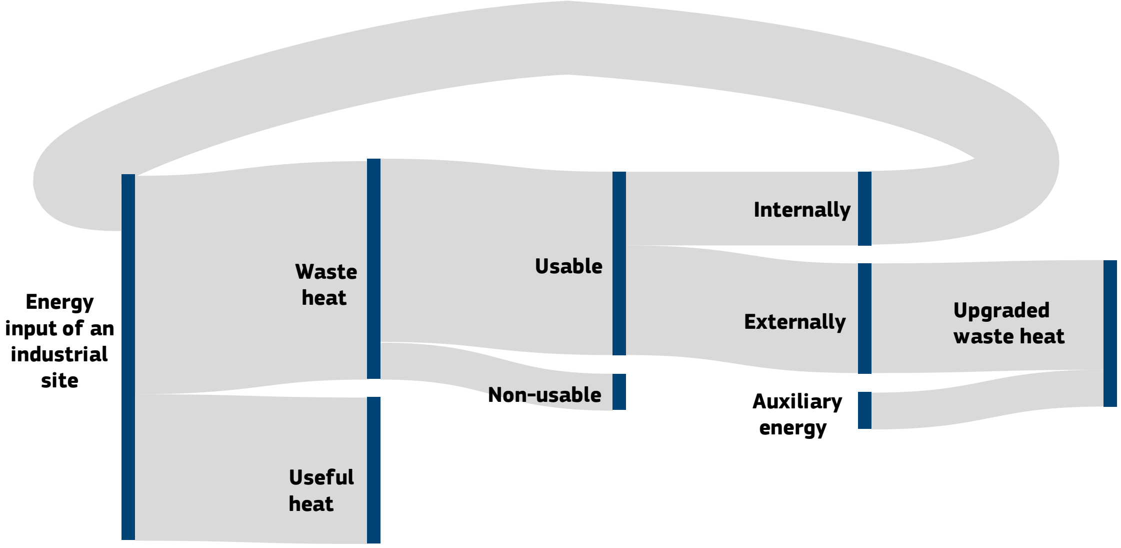
3 Accounting for waste heat and cold

3.1 General principles

The recast RED says that waste heat can be counted towards the increase in the share of renewable energy in the heating and cooling sector, and the renewable share of DHC, but that only waste heat that could not reasonably have been used internally is eligible. Hence, the analysis to identify waste heat has to be done at site level.

The first step in accounting for waste heat is to identify the internally and externally usable heat. **Internally usable heat** can be used on site to improve energy efficiency. **Externally usable heat** can be used off site – either directly, after upgrading using a heat pump (Figure 1), or for cooling using an absorption chiller (section 3.2).

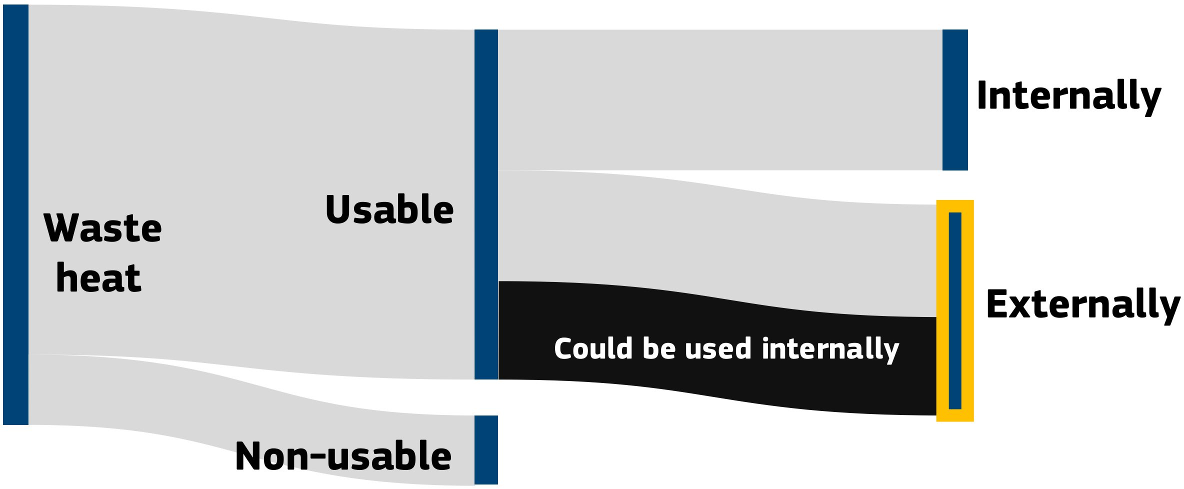
Figure 1. Heat flows at site level



Note: Some or all of the externally usable heat could also be fed directly into a DHC network.

The second step in accounting for waste heat is to identify the share of the externally usable heat stream that could not reasonably be avoided or recovered for internal use (Figure 2).

Figure 2. Potential waste heat flows at site level



Waste heat is either **avoidable** or **unavoidable** (Bendig et al., 2013). Unavoidable waste heat is that which occurs even though process heat recovery (also known as process integration) is maximised. Gustafsson et al. (2013) call this “true” waste heat (Box 3).

Avoidable heat is the result of a bigger heat input to the process than is required for a plant with maximum heat recovery for a given minimum temperature difference allowed in the heat exchangers.

Box 3. Waste heat, excess heat, surplus heat?

The term waste heat is sometimes reserved for heat that is not used at all, i.e. "wasted". For example, BCS (2008) defines industrial waste heat as "energy that is generated in industrial processes without being put to practical use". Similarly, Navigant (2018) defines waste heat as residual heat of industrial processes dispatched to the environment with no value.

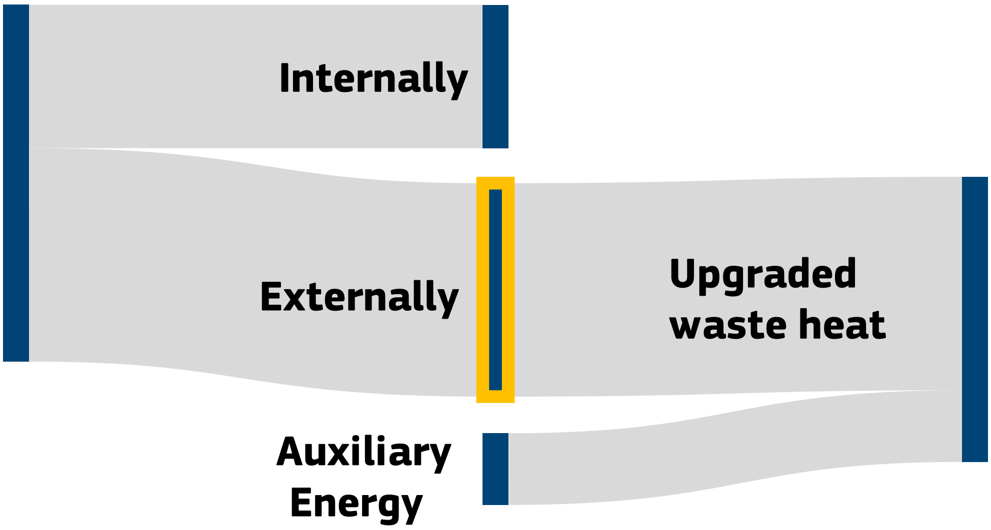
If it can be recovered and used, the term excess heat is often employed instead, for example by Gustafsson (2013) and many industry stakeholders. Some sources also use the terms surplus or residual heat, or *chaleur fatale* in French. The recast RED itself uses "excess heat" and "excess useful heat" in some places, but to refer to heat produced by cogeneration as a consequence of electricity production.

There seems to be a desire among some stakeholders to avoid the negative connotations of the word waste. However, from an energy efficiency perspective the word waste could even be helpful in order to effectively communicate that these streams should be reduced or eliminated as much as possible.

Semantics aside, European Directives and energy statistics use the term waste heat and this Technical Report follows that practice, qualifying it as necessary in order to avoid ambiguity.

In some cases, low-temperature heat can be upgraded using a booster heat pump (Figure 3). However, the amount of auxiliary energy used should not be counted as waste heat.

Figure 3. Upgrading heat flows



Relationships among these flows are sector-specific and even site-specific for the same product. For power generation, calculation is relatively straightforward, as internal heat recovery is usually not applicable. For industrial sites, some best practices by sector can be found in the Best Available Techniques Reference Documents (BREFs) under the Industrial Emissions Directive 2010/75/EU. However, as some sectors use very heterogeneous technologies and processes, site-specific conditions are determinant.

In some sectors, scale is also important. For example, heat from a small data centre or server room could conceivably be fully reused within the same building, for space heating of offices for example. For a very large data centre on the other hand, such uses will be completely marginal compared to the overall waste heat produced. The next sections discuss cogeneration and cooling in more detail.

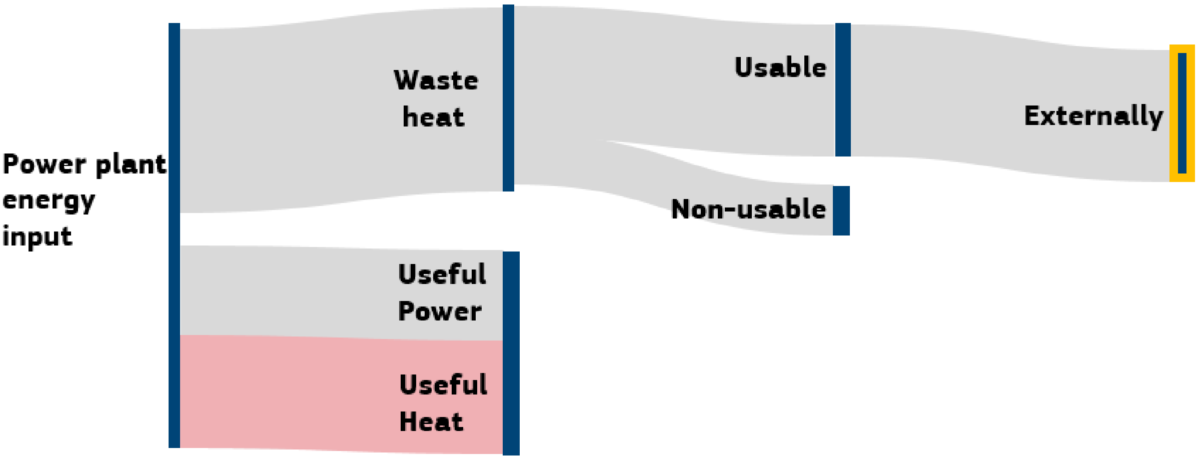
3.2 Cogeneration

The heat output a cogeneration unit was designed to produce is not waste heat. When a power generation process is deliberately modified to produce heat as well, that heat should not be considered a by-product and therefore not a waste heat stream. The residual amount of by-product heat resulting from some remaining inefficiencies of cogeneration, e.g. if it is only 75-80% efficient, is waste heat and could be recovered in principle.

However, since cogeneration results in a more efficient process, it reduces waste heat availability significantly. We can assume that the maximum amount of waste heat is always lower than the overall efficiency of the cogeneration (waste heat < 1 - η) (Figure 4). η is the total efficiency of the cogeneration, so if it has 40% electricity efficiency and 45% heat efficiency, then the waste heat is < (1–0.85).

This is why the revised Annex VIII of Directive 2012/27/EU Part 1 point 2(b) lists cogeneration installations using technologies referred to in Part II of Annex I with a total thermal input exceeding 20 MW among the installations that generate waste heat or cold. So, for high-efficiency cogeneration that is assumed to operate with at least 85% efficiency, this amount will always be less than 15% and of very low value. In practice, recovery of such a small amount of waste heat from cogeneration may not be economically feasible due to the need for investment in heat recovery and thus is not expected to be used to any great extent.

Figure 4. Cogeneration heat flows



3.2.1 Specific cogeneration technologies

In steam-based cogeneration, where the primary purpose is to produce heat, only the heat from the condenser can be counted as waste heat. Figure 5 shows how the waste heat stream is reduced by extracting heat at a higher temperature.

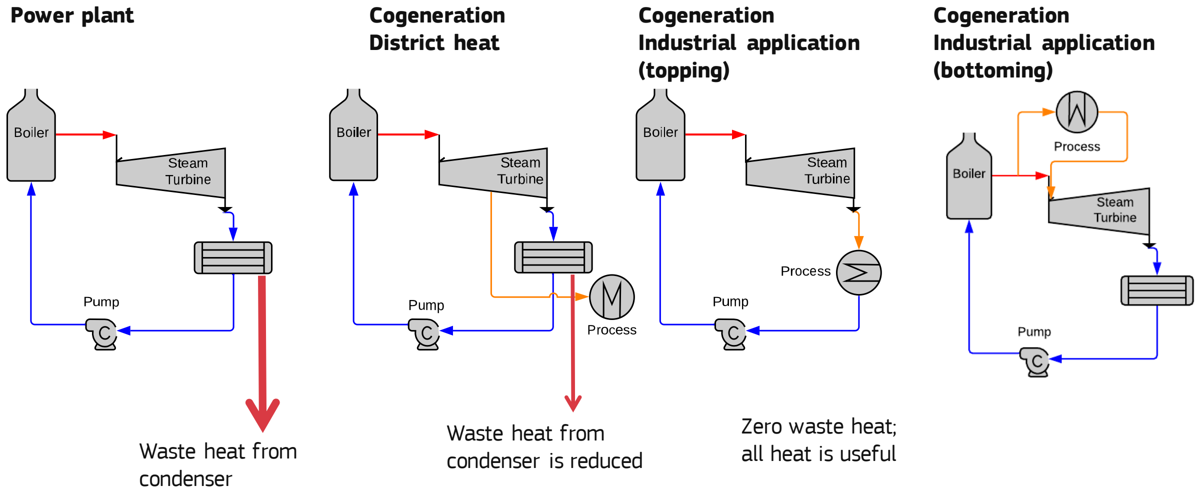
In an extraction-condensing turbine – usually used in district heating applications – the steam is extracted at a higher temperature and pressure from a turbine outlet. This extraction reduces both the amount of heat rejected through the condenser and the power generated through the turbine. Such effects are caused by design and cannot be considered a process by-product, and therefore are not waste heat.

In a topping cycle, where electricity is first produced and then heat, an industrial process replaces the condenser, but with an elevated pressure that matches the process requirements (back pressure turbine). In this case, the process utilises the entire stream of the turbine outlet so there is no by-product "waste" heat.

In a bottoming cycle, the steam is first used by the process and then expanded through a turbine in a similar way to a single-purpose plant. The heat rejected from the condenser is therefore considered waste heat.

In all cases, the heat stream extracted from the steam turbine for an existing application lowers the efficiency of the plant and cannot be considered waste heat. The waste heat rejected by the condenser is reduced. This applies regardless of the input fuel used to generate the live steam; it could be coal, gas (via heat recovery steam generator), biomass or municipal waste.

Figure 5. Steam-based cogeneration applications



Power plant

Cogeneration District heat

Cogeneration Industrial application (topping)

Cogeneration Industrial application (bottoming)

Waste heat from condenser

Waste heat from condenser is reduced

Zero waste heat; all heat is useful

For internal combustion engines, the situation differs since there is no modification of the cycle as in the case of steam cycle. The "cogenerated" heat comes from engine cooling, oil cooling, and exhaust gases of the Otto cycle. However, this amount of heat recovered should be considered cogenerated heat and not waste heat, as the device was initially designed to provide heat at this useful temperature level. This it to make sure that the heat produced by devices designed for cogeneration purposes is not accounted as waste heat. This also applies for other technologies like fuel cells.

3.3 Cooling

Cooling systems extract heat from a space (for comfort) or a process (to reduce its temperature) and reject it to the outside environment (air, water or the ground). Waste heat and the need for cooling may be used to describe the same process. For example, condenser cooling (in a power generation cycle) is equivalent to waste heat rejection.

Cooling therefore presupposes the presence of heat that is not needed and is in excess of the desired temperature. Two basic cases when the need for cooling arises can be distinguished:

A) Presence of heat that is not the result of an intentional heat generation process (the heat originates from the outside environment);

B) Presence of heat that is the result of an intentional heat generation process (the heat originates from a process that produced more energy than needed, due to inefficiency).

Under Case A, the heat is the result of the presence in the environment of a higher temperature than needed. For example, during summer the temperature of the outside air can often be higher than the comfortable temperature for people; this is typically when space cooling is applied. Another example is when the temperature is too high to maintain the quality of a product such as food or medicine; this is when refrigeration is used.

Under Case B, a technically designed process uses energy to serve a specific purpose or energy end use (e.g. electricity or heat consumption), or the production of a product or service (e.g. steel, chemicals, textiles, food, computing capacity). In this case, the energy was intentionally produced but due to the inefficiencies of the process not all could be absorbed fully by the end use, product or service. It therefore needs to be removed. As was shown earlier in this report, this heat is identified as waste heat under EU legislation, specifically the recast RED and the EED.

The production of waste heat as a by-product may require some kind of removal from the energy generation unit (e.g. turbine), plant, factory or facility where it was produced. Sometimes this removal is done by simply dissipating the heat to the environment (passive cooling). Other times, there is a heat extraction device, such as a condenser linked to a turbine that removes the heat before it is dissipated (active cooling). An example is the cooling towers of power plants, which vent the waste heat removed by the condenser from the turbine to the outside air. The preferred way of removing waste heat is to use it, as described elsewhere in this report.

All types of use or recovery of waste heat are encouraged by the EED for the purpose of saving energy. A specific application of waste heat, its use for heating or cooling via DHC networks, is encouraged by the recast RED, after all reasonable internal recovery or efficiency measures have been exhausted.

When there is no way to avoid or recover waste heat, the need for cooling may arise. Cooling, other than passive cooling (letting the heat dissipate) requires energy input. In industrial processes, it often happens that heat is generated that later must be cooled, which also requires energy input.

Under Case A, cooling is used to remove heat that was not deliberately generated. However, as explained above, cooling generates cold by removing unwanted heat and transferring it away from a space (or product) to be cooled, generally to the environment. Cooling makes the space or product from which the heat is extracted colder, but on the other side the cooling process generates heat. The heat resulting from cooling is the sum of the removed or transferred plus the heat generated by the cooling device, which itself consumes energy. This heat is a by-product of the cooling process and therefore can be counted as waste heat. While it is generally dissipated to the environment, the preferred option would be to recover and use it, wherever a suitable application can be found.

In both Cases, there is heat that may need to be removed by cooling. However, cooling simply moves heat from one place to another, and in the case of active cooling adds some more heat. Since this heat is unwanted, cooling generates waste heat. In Case B, where the objective of cooling is to remove by-product heat, the priority is to avoid, reduce or recover this waste heat before applying cooling.

Cooling and the generation of waste heat thus can be described as the same process. For example, condenser cooling in a power generation cycle is equivalent to waste heat rejection.

For the purposes of this report, cooling is divided into two categories (Figure 6):

1. When the required temperature to be achieved by cooling is *above or at* ambient (T_0) then cooling can be done by simple "waste heat dissipation" (BOX A: $T_1 \rightarrow T_0$) (this is also known as free cooling);[8]
2. When the required temperature to be achieved by cooling is *below* the ambient (BOX B: $T_0 \rightarrow T_2$) (e.g. space cooling during hot summers or refrigeration) then there is a need for active cooling via a cooling generator.

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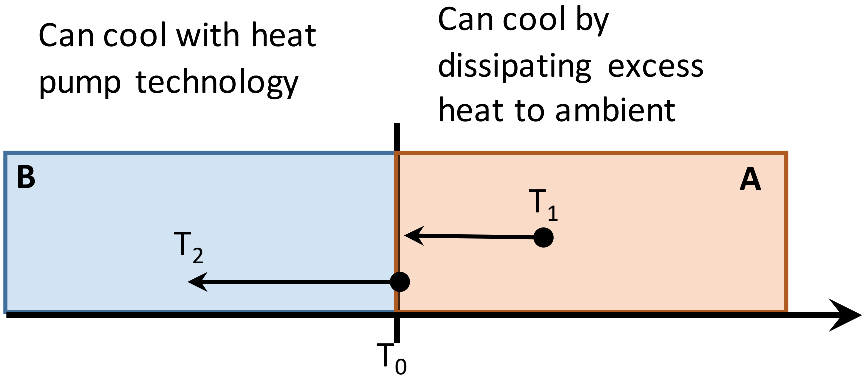
[8] In thermodynamics, ambient temperature usually means the *neutral* heat source (or dead state) with respect to which the usefulness of energy to produce work (exergy) is defined. At ambient temperature this is zero.

In other words, when there is an excess of energy in a space or process above ambient temperature then we can consider it waste heat, since this amount of energy may be valuable for other applications.

Figure 6. Two types of cooling depending on desired setpoint relative to ambient temperature



On the other hand, cooling systems of the second category, which need a "heat pump" technology to remove this amount of heat, also generate waste heat. Such refrigeration processes need to elevate the temperature of the cooling medium (refrigerant) by compressing it, then heat is released at the condenser where the medium has a temperature above ambient, which enables dissipation of heat to the outside. Afterwards, the coolant medium is expanded, which lowers its temperature below that of the process or space that requires cooling. This is the core principle of such cooling cycles. For this they need extra work (e.g. electricity). Heat rejected to ambient air (as waste heat) has a higher temperature than the energy removed (i.e. cooling demand) and has more quantity, due to the added electricity.

For example, in order to bring a room to a cooling setpoint temperature of 24ºC during a summer day, the heat rejected can be 55ºC. This waste heat stream, which is coming from the condensation of the refrigerant of the cooling thermodynamic cycle having a higher temperature than ambient temperature may be useful for various applications.

The cooling process therefore is another source of waste heat and when it is used, could be accounted for as an energy efficiency measure or under the recast RED as waste heat. Waste heat resulting from cooling in data centres is already exported to and used in DHC networks (see Table 8). This is not considered renewable cooling, to avoid double counting of energy flows.

4 Suggested approach for reporting waste heat and cold used in district networks

As explained earlier in this report, waste heat and cold used via DHC can be counted towards the DHC target under Article 24 of the recast RED, which is then carried into the calculation of the increase for the purposes of the general heating and cooling target under Article 23. In doing that, Member States must have verifiable reporting in place. This can be based on i) reporting by companies selling the waste heat or cold to DHC networks or ii) reporting by DHC networks that are buying those amounts and selling on to their customers as part of their overall network supply. In the latter case, Member States can build on the Eurostat DHC and cogeneration reporting template and national DHC statistics.

Each individual DHC network should be analysed to determine its shares of waste heat and renewables. Moreover, in order to determine whether a DHC network is efficient, the following criteria are used: 50% renewables, 50% waste heat, 75% cogeneration, or 50% of a combination of those.[9] Hence a detailed analysis of the sources is required, e.g. pinch analysis of an industrial waste heat source.

Table 2 summarises the proposed approach for Member States. For the power generation and tertiary sectors, heat streams are either waste heat or not, and should be accounted for in full or not at all.

Table 2. Calculation approach by sector and waste heat source under recast RED Articles 23 and 24

Sector	Sources	Approach
Industry	Anything that can be proven not to be "reasonably" recoverable	Justification is needed (e.g. pinch analysis)
Power generation	Output of condenser or gas turbine	Calculation is more straightforward (i.e. internal heat recovery is usually not applicable and stream is counted in full or not at all minus the energy needed to transport the waste heat)
Services	Active cooling or refrigeration systems (e.g. heat pumps) Passive cooling (e.g. data centres, power conversion) Other combustion activities (e.g. cremation)	
Wastewater	Wastewater treatment plants and pipes (but not sewage pipes)	
Other	Metro stations, etc.	

The industry sector should measure waste heat and cold using pinch analysis at site level wherever possible. This will show whether, or how much of, the stream could reasonably have been avoided through energy efficiency measures.

Pinch analysis is a rigorous, systematic methodology that can separate the streams of any site into total energy input needed, total energy output (including waste energy) and potential for process integration. It should be used wherever possible and is described in more detail in Annex C.

Pinch analysis is necessary because individual sites have to prove that all reasonable energy efficiency measures were implemented and that the waste heat truly is unavoidable, a consequence of the normal operation of the site, and would otherwise be dissipated. For a specific DHC network, waste heat is one of the important parameters that can be claimed for meeting the targets.

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[9] This stems from the definition of efficient DHC in Article 2(41) of the EED and Article 2(20) of the recast RED.

Individual industrial sites are so varied that sector averages will not suffice. Default values might be appropriate for small and medium-sized enterprises or ones with less than 10% of their energy demand in the form of heat, but Member States could obligate even those companies to perform a pinch analysis in cases where default values are not representative and actual values diverge significantly. Moreover, companies in that category may themselves prefer to carry out the pinch analysis for their site(s) if they deem the default value unrepresentative.

In other sectors, calculation may be more straightforward. For a data centre for example, the entire waste heat stream might be considered unavoidable. The heat to be dissipated from a data centre is, in general, fixed relative to the computing activity (defined by power usage effectiveness). That is, every watt of power for computing eventually becomes heat, and almost all of that can potentially be collected as waste heat. The overall energy consumption of the site could be reduced by using free cooling from a water body to reduce the need for active cooling, or by on-site recovery for an office building. However, the waste heat stream itself is considered to be already optimised. Newer server equipment or a more efficient algorithm would be outside the scope of this calculation because it would be effectively a different process.

We therefore suggest that the industry sector needs bottom-up reporting of site-specific calculations, collected in national waste heat and cold registries. In order to alleviate administrative burden, registries and reporting methods can be kept simple and only used where necessary. Nevertheless, inclusion of data on the characteristics of waste heat sources (e.g. capacity, temperature and availability), including from non-industrial sources such as data centres, would foster access to information and integrated urban planning (Codema, 2021).

5 Suggested approach for comprehensive assessments of waste heat potential

The identification of waste heat sources is a challenge because the required data is often unavailable or confidential, especially for smaller industries that are not within the EU Emissions Trading Scheme (EU-ETS) and not systematically registered (this is also the case for data centres and other unconventional waste heat sources) (AIT, 2020). Facilitating legislation might therefore be required. A related challenge is the exact location of the waste heat source: some geographical data are not detailed enough and the location often doesn't match the company's registered address.

Quantification of the characteristics of those waste heat sources is also a challenge. Historical data on temperatures are often not available due to the lack of sensors or data-logging equipment. And even when data exist, they could be considered commercially sensitive (AIT, 2020).

Estimation methods pose their own challenges as to the availability and accuracy of data. For example, some approaches correlate waste heat potential with publicly available company data on employee numbers, primary energy demand, industry sector, etc. Those correlations have a wide spread and thus low accuracy (AIT, 2020). These and other barriers are listed in Annex B.

For the purposes of comprehensive assessments, assumptions can be used for fractions of unavoidable waste heat from typical power plants, industrial sites, data centres, etc. If Member States choose this option, it is recommended that they provide opportunities for relevant companies and stakeholders to comment and integrate results of site-specific analysis.

Actual examples of off-site use (Table 3) and estimates of recovery potential (Table 4) show that the temperature of waste heat and cold and the fraction of it that is used vary significantly by sector. Tables such as these can be used by Member States in drafting their comprehensive assessments. The sEEnergies project (see Annex D) should also be seen as an important source of reference values in this regard.

Table 4 summarises the literature review on technical potentials contained in Annex D. Technical potential considers whether it is possible to extract heat from the carrier and whether there is any way of using it. The technical potential depends on the technologies considered, e.g. the required minimum temperature. In addition, a waste heat stream of a given medium and quality can be used only if there is a corresponding heating or cooling demand. It does not take into account economic constraints. Economic potential analyses whether or not it is profitable to exploit the technical potential identified, by employing a CBA as described in Article 14 of the EED.

Table 3. Temperatures, uses and waste heat and cold fractions by source (actual sites)

Source and (in parentheses) number of sites	**Temperature (°C)**		**Use**		**Fraction of waste heat or cold used (%)**	
	Typical value	**Range**	**Most common**	**Others**	**Typical value**	**Range**
Power generation (0)	-	-	-	-	-	-
Industry (13)	236	20-1 093	District heat	-	30	11-43
***Cement* (1)**	*300*	*250-350*	-	-	*11*	*11*
***Iron and steel* (2)**	*500*	*350-650*	*District heat*	-	*28*	*25-30*
***Other* (10)**	*200*	*20-1 093*	-	-	*39*	*34-43*

Other (25)	72	-1-800	District heat	-	67	1-100
Wastewater (5)	*15*	*12-27*	*District heat*	*Schools, Greenhouse, Hospital*	*89*	*77-100*
IT[1] (8)	*50*	*18-88*	*District heat*	*Greenhouse, Refrigeration, buildings*	*72*	*35-99*
Heat from cooling systems[2] (6)	*42*	*15-65*	*District heat*	-	*32*	*32*
Cooling system (1)	*-1*	*-1*	*District cooling*	-	-	-
Transmission and distribution[3] (2)	*39*	*35-43*	*District heat*	-	-	-
Cremation (1)	*800*	*800*	*District heat*	-	*91*	*91*
Transport infrastructure[4] (2)	*16*	*8-21*	*District heat*	-	*1*	*1*

[1] Data centres (air cooling systems; temperatures up to 60°C are possible with liquid cooling) and crypto-mining.
[2] Heat from district cooling, hospital dry-chillers, industry, large cold storage, and supermarket refrigeration.
[3] HVDC converter station and oil-cooled transformers.
[4] Full annual temperature interval present over a year in air ventilation shafts of metro station platforms.
Source: JRC based on various sources.

Table 4. Temperatures, uses and waste heat fractions by source (potentials estimates)

Sector	Temperature (°C)		Use		Fraction of waste heat used (%)	
	Typical value	**Range**	**Most common**	**Others**	**Typical value**	**Range**
Power generation	-	-		-	-	-
Industry	291	35-1 427	Power plant	District heat	13	0.3-50
Cement	*355*	*100-1 000*	*Power plant, District heat*	-	*12*	*1.5-25*
Iron and steel	*505*	*93-1 204*	*Power plant*	-	*19*	*1-44*
Other	*226*	*35-1 430*	*Power plant*	-	*11*	*0.3-50*
Other	29	5-60	District heat	-	65	65
Wastewater	*12*	*8-15*	-	-	-	-
IT[1]	*36*	*25-60*	*District heat*	-	*65*	*65*
Heat from cooling systems[2]	*34*	*25-40*	*District heat*	-	-	-
Transport infrastructure[3]	*20*	*5-35*	-	-	-	-

[1] Data centres (using air cooling systems; temperatures up to 60°C are possible with liquid cooling) and crypto-mining.
[2] Heat from district cooling, hospital dry-chillers, industry, large cold storage, and supermarket refrigeration.
[3] Full annual temperature interval present over a year in air ventilation shafts of metro station platforms.
Source: JRC based on various sources.

6 Reporting waste heat and cold to Eurostat

6.1.1 Background

Energy statistics are collected in Member States by national statistical offices. They verify and analyse national data and send them to Eurostat. Eurostat consolidates the data and ensures they are comparable, using a harmonised methodology. Eurostat also checks the data submitted, and the European Commission monitors overall progress.

Eurostat's energy balance methodology is based on physical energy content. The principle is that primary energy should be the first energy form in the production process for which various energy uses are practiced. For directly combustible energy products (e.g. coal, crude oil, gas, biomass, waste) it is their energy content. For products that are not directly combustible, this leads to the choice of heat as the primary energy form for nuclear, geothermal and solar thermal; and to electricity for solar photovoltaic, wind, hydro, tide, wave and ocean.

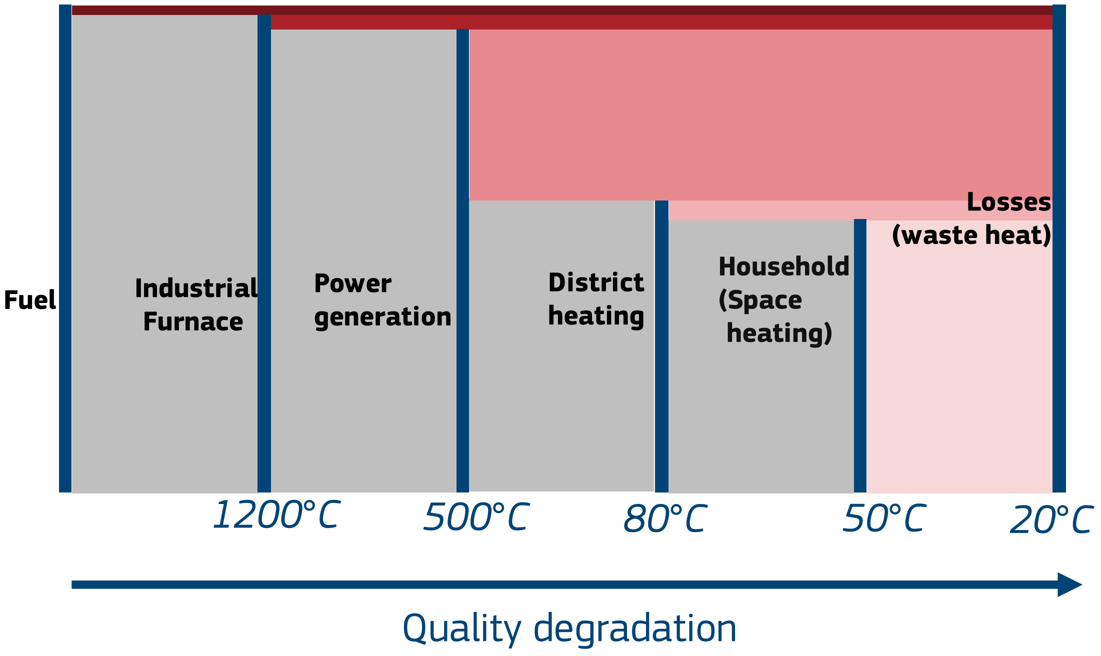
Primary energy is linked to final energy by a primary energy factor, which indicates how much primary energy is used to generate a unit of electricity or usable heat. The 2018 EED amended the primary energy factor for power generation from 2.5 to 2.1. In other words, it assumes that all power generation in the EU is 47.6% efficient rather than 40%. The increase is due to the growth of renewables in the energy system. The primary energy factor for all other fuels is 1.

The EU-wide energy efficiency target under the EED is expressed in both primary energy and final energy. When Member States choose to express their savings in primary energy, the primary energy factor converts final energy savings into primary energy, i.e. electricity savings can be multiplied by 2.1.

6.1.2 Waste heat and cold in the energy balances

Use of waste heat and cold is not easy to account for using the standard energy balances methodology because each time heat is reused it could be considered a "new" energy source. The same 100 MWh from a fuel could theoretically fire a furnace, produce electricity, supply a district heating network, and heat a household (Figure 7). This is because each of these end uses has a different minimum temperature requirement.

Figure 7. The cascade effect: energy and temperature by end use



Within a single industrial site, energy can be used several times at different temperature levels, thereby improving the site-level energy efficiency. If unavoidable waste heat produced as a by-product of an industrial or tertiary activity is used at another site, that would also be considered new energy and the primary energy factor would be 1.

In Eurostat's Energy balance guide (2019), waste heat is mentioned in two places:

- As a Transformation input, waste heat of energy processes is *not* to be reported under Derived heat for electricity production;
- As a Transformation output, recovered waste heat from industry sold to third parties *is* to be reported under Other sources, but electricity and derived heat produced from waste heat originating from energy-driven processes are excluded (production is reported under specific products).

Energy of low quality, such as waste heat, can either be used in a process with a correspondingly low quality requirement, or be reconverted (at a cost) to a more useful quality, an infinite number of times. Therefore, it is proposed to consider waste heat a new resource (i.e. a new flow of primary energy) each time it is used in a process to deliver an end-use energy service.

6.1.3 Other statistical reporting of waste heat and cold

A related JRC Technical Report (Filippidou et al., 2021) to this one discusses statistical reporting of renewable and waste heat in DHC networks in more detail. Among other potential areas for improvement, the report recognises waste heat as becoming more relevant, led by the current development of DHC networks and increasing suitability of waste heat sources. It notes that a clearer set of definitions are needed to harmonise accounting for both waste heat and DHC.

Waste heat and cold is indeed attracting greater interest from Member States, notably to achieve the average annual increase described in recast RED Article 23. Under Article 23(6), the contribution of the measures they employ should be measurable and verifiable. Member States may choose to require annual reporting of:

- Total amount of energy supplied for heating and cooling;
- Total amount of renewable energy for heating and cooling;
- Amount of waste heat and cold supplied for heating and cooling;
- Share of renewable energy and waste heat and cold in the total amount of energy for heating and cooling;
- Type of renewable energy source.

Waste heat and cold do not contribute to the overall renewables share and should therefore be reported separately. It can then be summed with the renewables share in heating and cooling for the purposes of the targets under Articles 23 and 24 of the recast RED.

In addition, the revision of Annex VIII of the EED and Article 15(7) of the recast RED made identification of the potential for the use of waste heat and cold in heating and cooling a mandatory element of the comprehensive assessments under Article 14 of the EED. Member States are encouraged to look at both efficient DHC and individual heating and cooling technologies.

7 Annex A Background on waste heat and cold

This Annex describes the landscape of waste heat and cold in more general terms, i.e. without judging its eligibility under the recast RED or EED. Waste heat or cold streams can be categorised by:

- medium (e.g. hot water or steam);
- quantity of energy;
- temperature.

A given quantity of 1 000°C heat has more value, i.e. can do more work, than the same quantity at 100°C. Carnot potential provides a more precise indication of whether waste heat could still perform technical work or, even better, be used for heat transfer. Thus, Carnot potential increases with temperature range.

Diffuse waste heat, e.g. from an uninsulated pipe, faulty insulation, opening, or natural cooling of products, cannot be directly reused. For waste heat and cold to be used therefore, it needs to be linked to a medium that can be recovered at a quantity and temperature close to that required for a given application. In order to identify usable waste heat and cold we need three elements:

- an accessible source;
- a recovery technology;
- a use or sink for the recovered energy.

Even when all three are in place, there are barriers to the utilisation of waste heat and cold that need to be overcome. This Annex discusses sources, technologies and uses, and Annex B describes barriers.

7.1 Sources

Sources of waste heat and cold are extremely varied and include power generation, industry, services (including data centres), and infrastructure (including wastewater treatment and metro stations).

Power plants burn fuel to generate electricity, with an efficiency typically between 30% and 50% depending on the technology and fuel (Codema, 2019). This process also generates high-temperature waste heat.

In Open Cycle Gas Turbines, the hot exhaust gas is vented to the atmosphere through a flue system. In Combined Cycle Gas Turbines, some heat is vented to the atmosphere via a flue and some is vented to the steam condenser.

Waste heat can also be recovered from exhaust gas cleaning systems (more commonly known as scrubbers) or power-to-X systems (e.g. electrolysers). There are also WtE facilities that burn municipal waste to produce steam for turbines to generate electricity; by-product waste heat can be recovered as a result of unavoidable inefficiency in such facilities (Box 4).

Box 4. Waste-to-energy, waste heat and the EU taxonomy

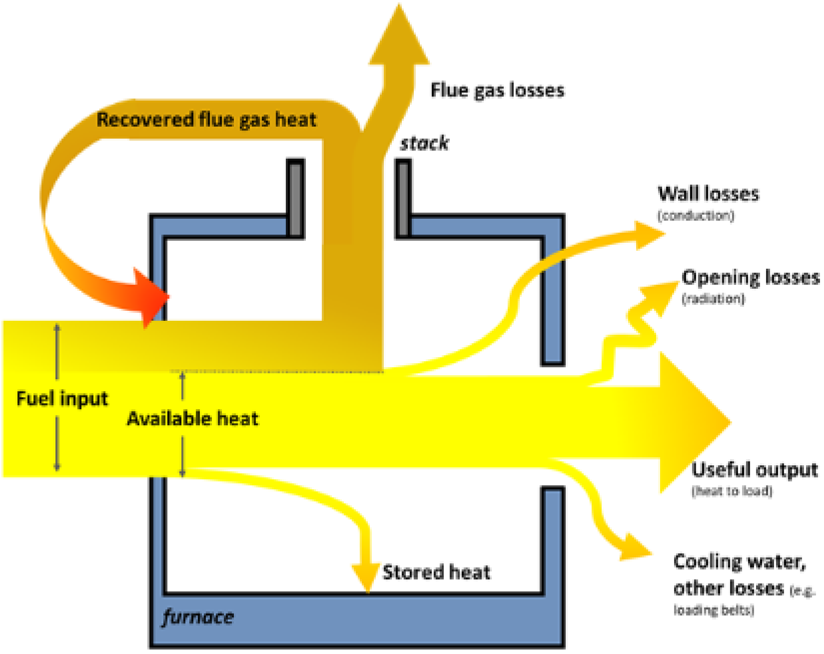
Both WtE and incineration (i.e. facilities without energy recovery) have been excluded from the technical report on EU taxonomy for sustainable activities because of their potential for lock-in and environmental impacts. A large portion of currently incinerated waste could instead be recycled, composted or reused. And even WtE represents a net increase in CO_2 emissions.

All recovery of waste heat, on the other hand, is eligible under the taxonomy "because the emissions from the underlying economic activity would be generated with or without the waste heat recovery system". It defines waste heat as "heat that is discarded by an existing industrial process".

Source: EU Technical Expert Group on Sustainable Finance, 2020.

Examples of waste heat sources from **industry** are combustion exhaust from furnaces (Figure 8 and Table 5); process off-gases; wastewater from washing, drying, boiling, cooking, baking or cooling processes; heat transfer from hot equipment surfaces; refrigeration systems; motors and compressors; the exhaust air from production halls; and heated products prior to storage or disposal.

Figure 8. Typical heat losses in industrial furnaces



Source: Adjusted from BCS (2008) by sEEnergies (2020).

Compressor air seems to be a particularly important source of waste heat potential. It accounts for around 12% of the energy costs of manufacturing processes – and up to 40% in some cases. 70-94% of compressor energy is recoverable (Atlas Copco, 2020).

Table 5. Typical temperature range and characteristics for industrial waste heat sources

Source	Temperature (ºC)
Furnace or heating system exhaust gases	316-1 093
Hot products	93-1 371
Gas (combustion) turbine exhaust gases	482-593
Reciprocating engines	
Exhaust gases (for gas fuels)	482-593
Jacket cooling water	5-93
Steam vents or leaks	121-316
Condensate	30-260
Compressor post-intercooler water	38-82

Source: Adapted from US DOE (2015) and DryFiciency (2020).

Energy-intensive industries including steel, cement, paper, glass and chemicals combine high flue gas temperatures, continuous operation and highly concentrated point sources, making waste heat from such plants in those sectors very attractive for district heating. In addition to the energy-intensive sectors, waste heat can be found everywhere from manufacturing to breweries to pharmaceuticals.

Despite this, and the availability of proven waste heat recovery technologies, waste heat from industry is rarely exploited in Europe (sEEnergies, 2020). In practice, a range of barriers need to be overcome (payback times, marketing of waste heat, etc.).

China has been much more successful in mainstreaming heat recovery technology; for instance in the cement sector, it has hundreds of installations compared to single digits in Europe (IFC and IIP, 2014). However, most if not all of those installations involve recovery for internal use rather than external.

In the **services** sector, examples of sources are data centres (Box 5), shopping centres that need to be cooled by chillers, air conditioners in office buildings, supermarket refrigeration systems and wholesale cold storage.

Box 5. Data centres

Data centres are a growing source of waste heat and could thus play a role in smart energy systems. Efforts are underway to power data centres with more renewable energy (though back-up power is still often provided by diesel), restrain their electricity consumption (including through digitalisation), and use the resulting heat. Currently even highly efficient data centres still vent significant amounts of heat. Whether or not heat is recovered for use off site, it must be removed to protect the equipment. The cooling system consumes 33-40% of data-centre energy.

Most currently operating data centres in Europe are equipped with air cooling systems, which means waste heat recovery temperatures in the range of 25-35ºC. For systems where servers are submerged in liquid coolant, temperatures up to 60°C are possible, and novel two-phase systems can provide temperatures up to 90°C. Other cooling solutions involve outdoor air, free cooling from nearby bodies of water, or evaporative cooling (uses less energy but a large quantity of water).

Sources: Various including ReUseHeat (2020).

Heat can be extracted from **wastewater** in the same way as from surface water. This usually takes place in the tertiary tanks of a wastewater treatment works via a heat exchanger connected to a heat pump.

Waste heat from **metro stations** comes from station platform and tunnel exhaust ventilation air shafts, i.e. air heated mainly from electricity used to drive the train carriages, from auxiliary systems, from heat dissipated upon braking as trains stop at a platform, and from humans themselves, all of which builds up underground over long periods. Heat is extracted at a heat pump evaporator surface before exiting into the surroundings (ReUseHeat, 2018). Such systems are in place in London, Paris,

In terms of variability, data centres and wastewater are notable in being largely constant on both daily and annual scales. Other buildings and infrastructure vary by time of day and season to a much greater degree (ReUseHeat, 2018).

Most of this discussion focuses on waste heat because it is much more common than **waste cold**. Waste cold would be a stream that is colder than ambient temperature and that needs to be dissipated or heated. The most significant example is waste cold recovered from gasification of Liquefied Natural Gas (LNG). There is also waste cold related to nitrogen in chemical industries. And a more common example that emits waste cold is heat pumps for heating. However, when it comes to heat pumps, confusion between ambient heat and renewable cooling needs to be avoided.

7.2 Recovery technologies

The main options for heat recovery are:

1. Direct on-site recovery using heat exchangers (a wide variety of systems used to transfer heat between fluids).
2. Direct recovery and upgrade via a heat pump. In some instances the temperature is not sufficient for the desired application.
3. Large-scale recovery in district heating systems. This could be either with a low-temperature network and distributed heat pumps, or a medium/high-temperature network and centralised heat pumps. Supply temperatures in 3rd generation district heating systems are on average above 80°C (ReUseHeat, 2018) but 4th generation systems operate at lower temperatures.
4. Waste heat-to-power: Heat can be expanded through a normal power generation cycle, using a steam turbine and water as the working fluid (Rankine cycle). This is also known as bottoming cycle cogeneration. If the temperature is lower than 250°C then usually a different fluid is used, one with a lower boiling point than water, such as a hydrocarbon, hydrofluorocarbon or ammonia; this is known as the Organic Rankine Cycle (ORC). The Kalina cycle is a Rankine cycle that uses a binary fluid pair (usually water and ammonia) as the working fluid, with the potential for higher efficiency (US DOE, 2015). A final variation of the Rankine cycle is the supercritical CO_2 cycle, which uses CO_2 instead of water or steam.

The medium and temperature of waste heat determine the recovery technology used:

Table 6. Commonly used waste heat recovery systems in industry by temperature range

Ultra-low temperature (<121°C)	Low temperature (121-316°C)	Medium temperature (316-649°C)	High temperature (649-871°C)	Ultra-high temperature (>871°C)
Shell and tube heat exchangers	Convection recuperator (metallic) of many different designs	Convection recuperator (metallic) of many different designs	Convection recuperator (metallic) – mostly tubular	Refractory (ceramic) regenerators
Plate heat exchangers	Finned tube heat exchanger (economisers)	Finned tube heat exchanger (economisers)	Radiation recuperator	Heat recovery boilers
Air heaters for waste heat from liquids	Shell and tube heat exchangers for water and liquid heating	Shell and tube heat exchangers for water and liquid heating	Regenerative burners	Regenerative burners
Heat pumps	Heat pumps	Self-recuperative burners	Heat recovery boilers	Radiation recuperator
HVAC applications (i.e. recirculation water heating or glycol-water recirculation	Direct contact water heaters	Waste heat boilers for steam or hot water condensate	Waste heat boilers including steam turbine-generator based power generation	Waste heat boilers including steam turbine-generator based power generation
Direct contact water heaters	Condensing water heaters or heat exchangers	Material (convection section) preheating	Material preheating	Material preheating
Non-metallic heat exchangers	Metallic heat wheel	Metallic heat wheel	Metallic heat wheels (regenerative system)	
		Heat pipes	Heat pipes	Heat pipes

Source: Adapted from US DOE, 2015; and Brough and Jouhara, 2020.

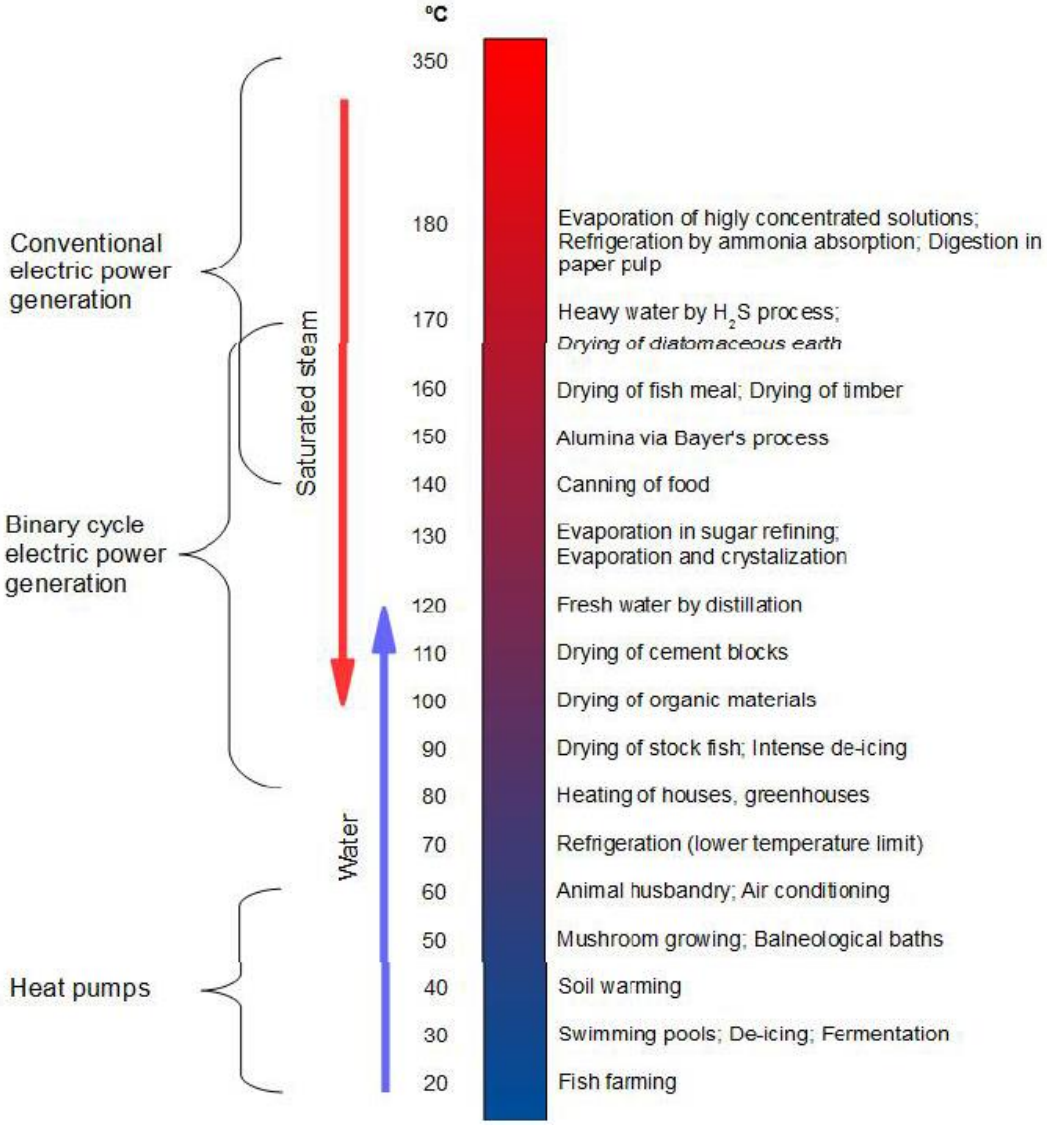
All energy conversions are associated with some heat loss, be it efficiency factors in motor drives, transfer losses in heat exchangers, or operational losses in heat pumps. Nevertheless, the efficiency of a normal heat exchanger that extracts waste heat from a process is almost 100%. Denser fluids have higher heat transfer coefficients, while fouling of heat exchangers can occur if the effluent stream is corrosive. Depending on the scale of analysis, such minor heat losses can be ignored (ReUseHeat, 2018).

7.3 Uses (Sinks)

The predominant use of waste heat is in DHC networks for home heating but it can also be used in industry, agriculture (greenhouses) or aquaculture. In contrast to other energy carriers that have standardised quality specifications, input heat has to match temperature and volume requirements of processes and other end uses. There are also logistical constraints like operating schedules and availability.

Most waste heat from industry is at temperatures below 230°C but there are various applications even for such low temperature heat, including elsewhere in the industry sector (Figure 9). If the temperature is already high enough for a given use then only pumping power is needed, so the efficiency will be very high. If not, then heat pumps are used.

Figure 9. Lindal diagram of temperature ranges for possible uses of waste heat



Source: Gdansk University of Technology in Schuech et al., 2017.

Table 7 gives another indicative categorisation of heat and cold based on temperature level and lists common applications.

Table 7. Applications of heat by category

Category	Medium	Temperature (°C)	Common applications
High-grade heat	Direct heating via convection (flame-based), electric arc, oil-based, etc.	> 500	Steel, cement, glass
Medium-grade heat	High-pressure steam	150-500	Steam processes in chemical industry
Medium/low-grade heat	Medium-pressure steam	100-149	Steam processes in paper, food, chemical industry, etc.
Low-grade heat	Hot water	40-99	Space heating, processes in food industry, etc.
Cooling	Water	0-ambient	Space cooling, processes in food industry, etc.
Refrigeration	Refrigerant	< 0	Refrigeration in food, chemical industry
Low-grade heat	Hot water	40-99	Space heating, processes in food industry, etc.

Source: European Commission, 2019.

7.5 Examples

Table 8. Summary of data from 39 waste heat sites

Heat or cold source	Name	Waste heat temp. (°C)	Delivered temp. (°C)	Capacity (MW)	Delivered energy (MWh)	Energy reuse factor (%)	Technology	Heat pump COP	Link
Industry	Castelnuovo del Garda	40	63	1.32	-	-	Heat pump	4.4	http://hiref.it
Refinery	Port Arthur Steam Energy	1 093	-	-	-	-	Heat recovery boiler / Steam turbine	-	-
Cement	-	250-350	-	-	-	11	ORC	-	-
Steel	SIJ	-		4.5	8 000	25	Heat exchanger	-	www.sciencedirect.com/science/article/pii/S036054422031505X?via%3Dihub
	-	350-650	-	-	-	-	ORC	-	-
Glass	-	350-450	-	-	-	33.7	ORC	-	-
Plastics	Tønder	20	6-10	4.3 (gas) / 3.3 (electric)	36.1	39	Heat pump	2.16 (air), 2.9 (excess heat)	www.tonder-fjernvarme.dk
Packaging	Greiner Packaging	-	-	-	-	80	Oil-free screw compressors with water coolers	-	-
Paper-drying	Skjern Papirfabrik	43	-	9	47 000	-	Heat pump	6.9	www.skjernfjernvarme.dk, http://skjernpaper.com

Heat or cold source	Name	Waste heat temp. (ºC)	Delivered temp. (ºC)	Capacity (MW)	Delivered energy (MWh)	Energy reuse factor (%)	Technology	Heat pump COP	Link
Copper smelting	Hafencity East	90	-	18	160 000	-	-	-	-
Pump manufacturer	Grundfos and Bjerringbro Varmeværk	40	-	3.6	13 500	-	Heat pump	4.6	www.bjerringbro-varme.dk
Dairy	Arla	22-25	5	1.6	6 500	43	Heat pump	4.6	www.xn–rdkrsbro-fjernvarme-nxb98a.dk
Food and drink	CP Kelco	60	85	4-8	48 860	-	Vapor compression heat pump	-	https://waermepumpe-izw.de/wp-content/uploads/2020/05/Denmark-2019-2.pdf
District cooling	Copenhagen Markets	-1	-8	3.2	-	-	Refrigerator and heat pump	3.14	www.htf.dk
Hospital dry-chillers	Viborg	40	65	2.5	4 700 (most is in the three hottest months)	-	Heat pump	7.9	www.viborg-fjernvarme.dk
	Madrid demo	25-35	-	-	770	-	-	-	-
Large cold storage	Kopenhagen fur	-	70-90	1	6 000	-	Heat pump	5	www.glostrupforsyning.dk/varme
Supermarket refrigeration systems	Høruphav	65	-	-	-	-	There is ... no need for extra heat pumps to increase the temperatures	-	www.sonderborg-fjernvarme.dk, http://refrigerationandairconditioning.danfoss.com

Heat or cold source	Name	Waste heat temp. (ºC)	Delivered temp. (ºC)	Capacity (MW)	Delivered energy (MWh)	Energy reuse factor (%)	Technology	Heat pump COP	Link
	Lidl's Järvenpää distribution centre	-	-	-	700	-	-	-	www.fortum.com/media/2018/11/fortum-and-lidl-sign-agreement-utilise-excess-heat-open-district-heating-network
Shopping centre	Østerby	55	30	-	-	-	-	-	www.cooldh.eu/wp-content/uploads/2020/06/D4.2-Converting-%C3%98sterby-area-from-traditional-DH-to-LTDH.pdf
Metro system	London Underground	22 (summer), 28 (winter)	75	0.4-1	-	-	None or Air-to-water heat pump	-	http://celsiuscity.eu/, www.ehpcongress.org/wp-content/uploads/Henrique_LAGOEIRO_-_LONDON_SOUTH_BANK_UNIVERSITY.pdf
	Berlin	8-15	-	-	-	-	-	-	www.youtube.com/watch?v=0R9L8aTj_s4
Cremation	Aalborg crematory	800	120-140	-	530	91	-	-	-
Data centres	Val d'Europe	-	48-55	7.8	20 000	35	Heat exchangers and gas boiler	-	www.dalkia.fr
	Mäntsälä	40	85-87	4	20 000	35	Heat pump	4	www.nivos.fi

Heat or cold source	Name	Waste heat temp. (ºC)	Delivered temp. (ºC)	Capacity (MW)	Delivered energy (MWh)	Energy reuse factor (%)	Technology	Heat pump COP	Link
	Facebook Odense	-	-	-	100 000	-	Heat pump	-	www.ehpcongress.org/wp-content/uploads/Kim_WINTHER_-_FJERNVARME_FYN.pdf
	IBM Zurich Research Laboratory	50.0	-	-	-	85	-	-	www.treehugger.com/dean-technology/heat-your-home-withibms-waste-heat.html
	Quebecor	-	-	-	-	90	-	-	https://searchdatacenter.techtarget.com/news/1314324/Companies-reuse-data-center-waste-heat-to-improve-energy-efficiency
	Brunswick demo	18-25	70	0.3	1 750	-	Water-to-water heat pump	3.6	www.districtenergyaward.org/reuseheat-braunschweig-germany
Crypto-mining servers	BlockchainDome	-	-	-	-	Close to 100	Passive, Canadian Well	-	-
Wastewater	Sandvika	12	-	23	-	-	Heat pump	-	www.oslofjordvarme.no
	Rya Värmepumpverk	12	85	160	-	-	Heat pump	3	www.goteborgenergi.se
	Kalundborg	20-25	-	10	-	-	Heat pump	3.6-4.0	www.kalfor.dk

Heat or cold source	Name	Waste heat temp. (ºC)	Delivered temp. (ºC)	Capacity (MW)	Delivered energy (MWh)	Energy reuse factor (%)	Technology	Heat pump COP	Link
	Norfolk and Suffolk	-	-	70	-	-	Cogeneration and heat pumps	-	https://esb.ie/tns/press-centre/2019/2019/10/08/esb-provides-low-carbon-heat-solution-for-a-world-first-greenhouse-project-in-the-uk
Sump water from open-pit mining	Bergheim	27	85	0.865 (heat pump), 0.314 (cogeneration)	-	System efficiency (cogeneration and heat pump) 167%	Heat pump	3.04	-
Heat pumps, research facilities, wastewater	Saclay	48	-	37 (heating), 10 (cooling)	74 000 (heat), 25 000 (cooling)	31.5 (heat)	-	-	-
Oil-cooled transformers	UKPN	43	80	-	-	-	Heat pump	5	www.ehpcongress.org/wp-content/uploads/Jens_O._HANSEN.pdf
HVDC converter station	Endrup	35	68	-	-	-	Heat pump	6	https://energinet.dk, www.brammingfjernvarme.dk

Notes: Energy reuse factor is the percentage of the source site’s waste heat that is supplied to local heat consumers. COP = Coefficient of performance, defined as the ratio of the provided heating power to the electricity consumed.

8 Annex B: Barriers to the off-site use of waste heat and cold

There are barriers to utilisation of waste heat and cold on both the supply and demand sides. These include issues with contracts, temperature requirements and timing. Some of the legislative and regulatory barriers are discussed and addressed in this Technical Report. Other barriers will also be important to consider in reviews of the recast RED and EED.

As part of the Urban Agenda Energy Transition Partnership, the Austrian Institute of Technology, with the support of EH&P and stakeholders (waste heat sources, cities, researchers), identified barriers and best practices to boost waste heat recovery. The rest of this Annex is based on the resulting discussion paper (AIT, 2020). That paper also describes a range of solutions, including new heat pump technologies, low-temperature networks, long heat transport networks, heat-to-power, seasonal storage, district cooling, risk mitigation and other financial support, standardised contracts, and new business models. Of particular relevance to the content of this report are the proposals for "Equal treatment of waste heat sources and renewables" and "Promote the visibility and the use of the results of the EED Comprehensive Assessments".

8.1.1 General

Identification of waste heat sources:

- Often very little data is available or it can be confidential (e.g. for data centres);
- Unconventional waste heat sources or smaller industries are not systematically registered;
- The location of the waste heat source doesn't match that of the company;
- Businesses may not recognise that they are emitting a valuable heat source that could be used in a heat network.

Quantification of the waste heat source:

- Correlation factors have an inherent wide spread and thus little accuracy;
- Concrete measurements of waste heat quality, i.e. volumes and temperatures, are often not available;
- The data could reveal information on the production processes to competitors and thus are sometimes kept confidential.

Low interest and know-how of the waste heat owner for supplying waste heat:

- Waste heat utilisation is not a core business activity and, at best, a marginal source of revenue;
- Human resources, as well as available capital, are concentrated on primary activities;
- The extraction of waste heat might change the characteristics of the related processes or just be difficult to capture due to the design of the asset.

Suitable waste heat potentials might preferably be used within the company itself:

- Increasing motivation of companies to increase their energy efficiency via process-internal reuse of the waste heat (suitable heat pumps are becoming more available);
- Low-temperature waste heat can be used to satisfy room heating demand;
- Internal utilisation has a direct positive effect on the profitability of the company; also, the company can act independently from external stakeholders.

Low demand to utilise waste heat potential:

- Especially relevant for countries with low levels of DHC coverage;
- Securing supply from waste heat sources is difficult when demand is not guaranteed on a new or expanding network;
- Equally, getting consumers to commit to connect when the DHC network does not have the waste heat supply secured is a chicken-and-egg problem.

8.1.2 Technical

For many waste heat sources, one or more of the following technical challenges apply:

1. Temporal mismatch
    - Hourly, daily or seasonal mismatch to the heat demand;
    - Supply competition between waste heat and most renewable heat sources as well as waste incineration and other waste heat sources in summer time;
    - Instability of the waste heat supply might challenge the network controls.
2. Locational mismatch:
    - DHC network does not extend near the location of the waste heat source;
    - Limited network capacity for taking up and distributing the waste heat;
    - Larger industrial areas have widely distributed waste heat sources.
3. Quality mismatch:
    - The temperature is lower than in the DHC network it is supplying, especially for unconventional waste heat sources and "traditional" DHC networks;
    - Some waste heat sources have a relatively small volume or have a gaseous form or are contaminated.

However, those technical challenges, in general, can be solved and thus are mainly a question of additional investment (and in the case of heat pumps also operational costs).

8.1.3 Economic and financial

Long payback periods:

- High investment costs for installing the equipment for waste heat utilisation;
- Relatively low revenues for selling the heat, especially in summer time and in immature heat network markets;
- Low profitability over a long time frame for the investments and high risk due to possible future changes.

Limited standardisation of the waste heat utilisation:

- Individual and site-specific boundary conditions increase the effort required for planning, designing and operating the system;
- A higher number of stakeholders need to be involved, resulting in more contractual arrangements, complexity, and thus cost and time;
- Lack of standardised contracts, resulting in increased costs and the risk of omitting important clauses.

Missing long-term guarantees:

- Future availability and quality of the waste heat supply due to possible future improvements or changes to the process, product or service;

- The company might go bankrupt or move to other premises.

Requirement to install back-up facilities:

- For a significant waste heat supply, the network operator has to install back-up heating plants to cover the risk of unplanned interruptions in the waste heat supply;
- The DHC network operator might expect guaranteed supply security from the waste heat producer, leaving him with the requirements of additional investments into the back-up;
- If the waste heat extraction is providing important cooling services for the company, the installation of back-up cooling equipment might be required.

Diverging views on the value of the waste heat:

- DHC network operators try to minimise expenditures for waste heat supply;
- Private companies want to exploit their waste heat potential in monetary terms;
- Local and national governments may want to place a value on the avoided carbon from using waste heat.

Dependency on the electricity markets:

- For low-temperature waste heat, the use of a heat pump is required either at source or at a building or sub-station level;
- Uncertainty due to the future development of the average price and its volatility;
- The waste heat supply is usually difficult to control, thus the heat pump can only operate on the electricity market with additional effort, e.g. investing in waste heat storage.

Reduction of revenues in other areas:

- Waste heat from cogeneration is often available in large quantities;
- Competition with the supply of any other (waste) heat source.

Diverging view on amortisation time:

- Industrial companies require amortisation periods of 2-3 years;
- District heating companies have a long-term perspective and can accept amortisation periods of more than ten years, sometimes up to 20 years.

8.1.4 Legislative and regulatory

In general, there are no regulatory restrictions for the supply of waste heat into DHC networks, since virtually all waste heat supply situations are regulated using bilateral contracts between the DHC network operator or utility and the company "owning" the waste heat.

Specific regulations with regards to performance and safety for wastewater treatment plants, tunnels and metro stations, which are generally in public ownership and considered key infrastructure.

Unbalanced treatment of the different waste heat sources:

- In the RED, "waste heat and cold" is defined as: "... by-product in industrial or power generation installations, or in the tertiary sector...";
- Waste heat from sewage water is considered ambient energy;
- Waste heat from tunnels, metro systems and power-to-gas processes is not mentioned at all.

The term "unavoidable" used in the RED is difficult to define:

- Is this related to technical or economic feasibility?
- There is an uncertainty related to the future development of technologies (e.g. high temperature heat pumps) and energy prices (affecting economic feasibility);
- Resulting in insecurity when using the Directive as a basis for e.g. funding instruments.

No or very fragmented legal frameworks for driving waste heat recovery:

- Including limited standardised permit procedures;
- Uncertainty on the stability of regulative boundary conditions;
- Increasing lack of legal clarity and uncertainty for waste heat utilisation.

Support for fossil fuels, other (competing) renewable heat sources and cogeneration:

- Unfavourable primary energy and CO_2 factors for waste heat;
- Unequal distributed subsidies for electricity use in heat pumps;
- Costs for the use of fossil fuels might have an impact on the utilisation of waste heat sources from processes using fossil fuels.

8.1.5 Societal and cognitive

Little awareness of the potential of waste heat utilisation at national level:

- Waste heat, especially from unconventional sources, is not being consistently considered;
- Electricity-centred view of the energy system means heat is not sufficiently valued in the energy system;
- Modelling tools are not considering the full potential of waste heat;
- National assessments of efficient DHC potentials do not consider all waste heat sources properly.

It is difficult to sell waste heat as a "green" product to end users and customers:

- District heating sometimes still has a "fossil-fuel" perception;
- Waste heat as an environmentally friendly heat source might be questioned if the related processes are driven by fossil fuels and this is why waste heat needs to be better explained and understood;
- Integrating waste heat might result in extra costs that are difficult to justify passing on to the customer.

In contrast, the electricity sector offers green products and services for similar prices to non-green energy, and there is a clear commitment and pathways for 100% renewable electricity.

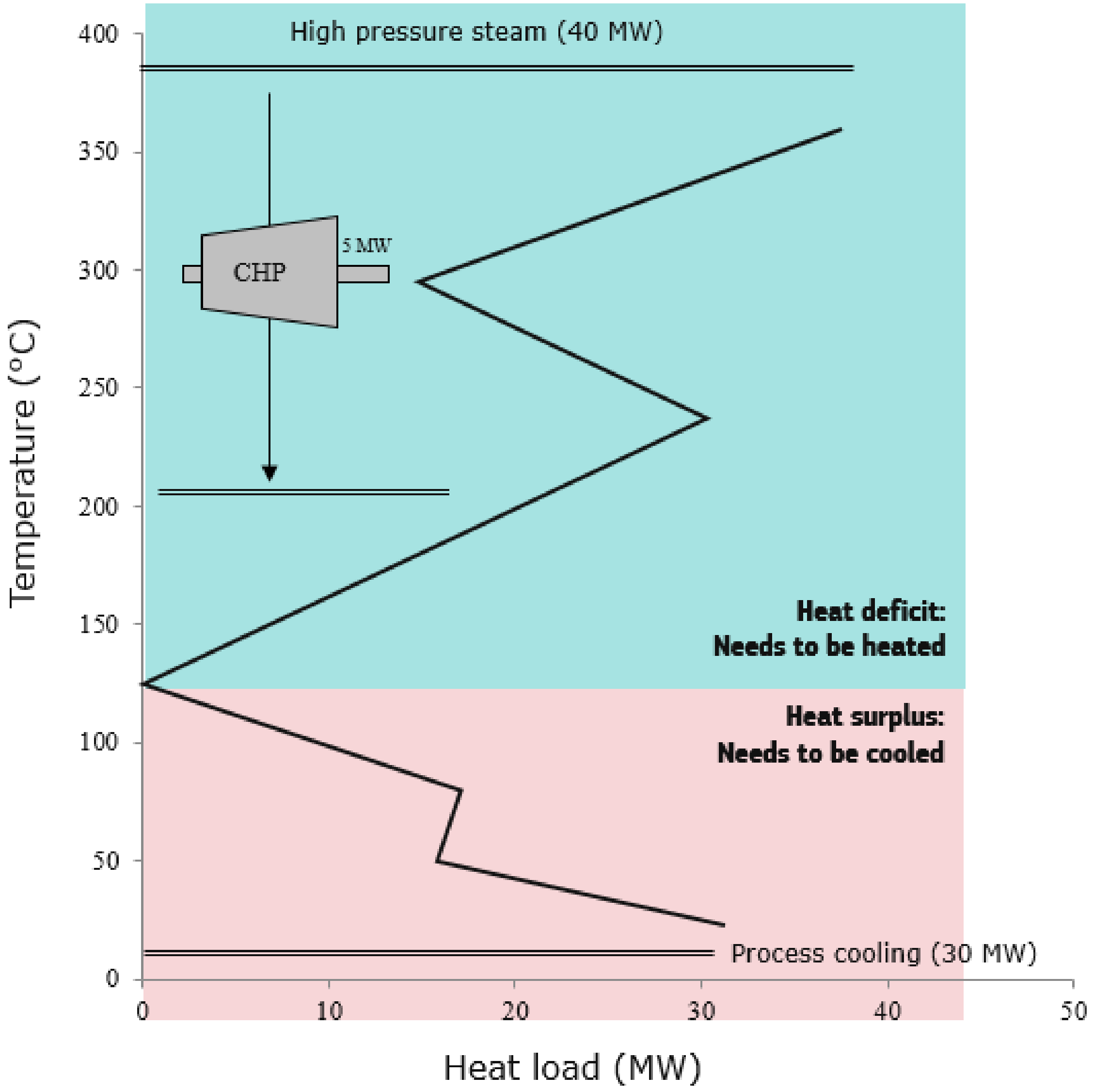
9 Annex C: Pinch analysis in the industry sector

The best way for an industrial site to prove it has exhausted all reasonable energy efficiency and heat recovery options is through pinch analysis. Pinch analysis has been in widespread use in industry for a long time. It is a way of quantifying the avoidable and unavoidable shares of industrial waste heat for a particular site, by calculating:

- Usable waste heat potential for off-site use;
- Potential for installation of heat engines (cogeneration);
- Potential for installation of heat pumps for internal recovery of energy.

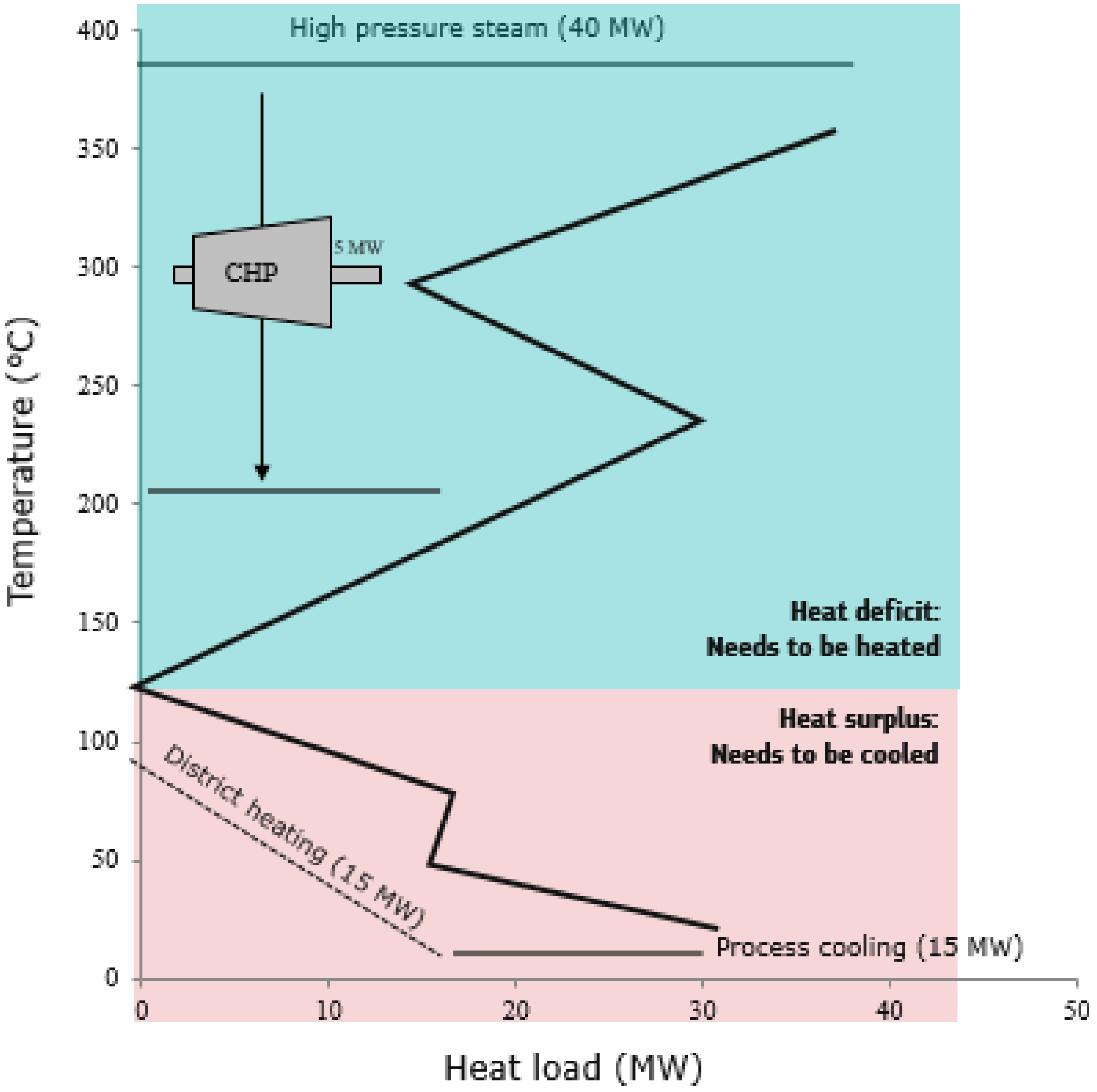
In a pinch analysis, the heat surplus area is the heat that a given industrial site needs to vent to the environment. If it cannot reasonably be avoided, we refer to this as waste heat. It needs to be cooled or sent for use off site. In Figure 10, all this waste heat is cooled by an external utility (process cooling).

Figure 10. Pinch analysis of an industrial site (heat load and temperature) – with cooling only



In Figure 11, this waste heat is recovered and sent to a district heating network. As a result, the remaining process cooling requirement is reduced to 15 MW from 30 MW.

Figure 11. Pinch analysis of an industrial site (heat load and temperature) – with cooling and off-site use



The waste heat merit order will thus depend on the site but the following rule of thumb applies:

- Internal (heat recovery)
    1. Carry out energy efficiency measures, e.g. insulation;
    2. Use heat directly (only requires piping or ducting, usually within the same process);
    3. Use a heat exchanger for on-site heat transfer;
    4. Use an absorption or adsorption chiller to provide cooling services on site;
    5. Upgrade heat for use on site using a heat pump;
    6. Generate electricity, i.e. cogeneration through ORC.
- External (waste heat)
    7. Export heat for direct use off site;
    8. Export heat for use off site and upgrade it via heat pump.

In general, avoidable heat shouldn't be used for a secondary application since it could discourage investment to improve energy efficiency (Bendig et al., 2013). In some cases it might be justified to use avoidable waste heat in order to reach the target temperature for district heating if there is a large amount of unavoidable waste heat at a plant but its temperature is too low for district heating; that depends on local demand for district heating and the alternatives for producing it.

A final point to bear in mind is that the definition of "reasonable" energy efficiency measures evolves over time. Therefore, site-specific analyses will need to be updated periodically, or at least when the design of the plant changes.

10 Annex D: Waste heat potentials literature

Significant efforts have been made to estimate (and map) waste heat potentials, especially in recent years. This section presents several examples of methodologies and results in chronological order. The research is mainly based on officially available data such as power plants in the EU-ETS. The surveys and estimates of waste heat potential are summarised in Tables 9 and 10. As far as possible, we have aligned them with the definition of waste heat and cold used in this report, retaining the more conservative number where relevant.

Table 9. Summary of estimates of waste heat potential in the EU by sector and country (TWh)

Sector	AT	BE	BG	CY	CZ	DE	DK	EE	EL	ES	FI	FR	HR	HU	IE	IT	LT	LU	LV	MT	NL	PL	PT	RO	SE	SI	SK	EU
Total																												3 139
Power generation	18	44	45	7	80	550	29	20	77	127	50	66	6	30	25	244	6	3	1	4	102	224	21	49	23	10	11	1 869
WtE	6	4	0	0	2	45	6	0	0	4	1	25	0	1	0.0	12	0	0.0	0	0	13	0	3	0	9	0	0.0	131
Industry	24	4-39	5	1	17	35-132	1-4	1	17	65	25	9-110	5-8	0.9	1-4	5-95	6	1	1	0	6-47	46	17	21	30	1	13	261-735
Other																												344

Sources: D’Appolonia, 2015; Persson, 2015; Brueckner et al., 2016; Papapetrou et al., 2018; ReUseHeat, 2018; Bianchi et al., 2019; Codema, 2019, Ademe et al., 2019; sEEnergies, 2020.
Note: Rows and columns do not sum because multiple sources are used.

Table 10. Characteristics of selected studies of waste heat potential

Study	Year	Geography	Sectors	Map
Spie-Batignolles	1982	EU countries, regions	Refining, chemicals, steel	N
McKenna and Norman	2010	EU	EU-ETS	N
Energetics	2012	United States	Industry	N
Heat Roadmap Europe and Peta	Since 2012	14 European countries	Power generation, incineration, industry, metro stations, wastewater	Y
Gustafsson	2013	Sweden	Pulp and paper, coke, refining, chemicals, steel	N
Brueckner et al.	2014	European countries, regions	Industry	N
D’Appolonia	2015	EU	Cement, glass, steel, petrochemicals	N
United States Department of Energy	2015	United States	Industry	N
Persson	2015	EU	Power generation, industry	N
Papapetrou et al.	2018	EU	Industry	N

ReUseHeat	2018	EU	Data centres, metro stations, service sector buildings, wastewater treatment	Y
Bianchi et al.	2019	EU	Industry	N
Codema	2019	South Dublin	Data centres, industry (wastewater), cold storage, transformers	N
sEEnergies	2020	EU	Industry	Y
Cornelis	2020	EU	Iron and steel, non-metallic minerals, petrochemicals and pharma, non-ferrous metals, food and beverages	N
Energy & Industry Geography Lab	Forthcoming	EU	Power generation, transformers, coal mines, industry, transport infrastructure, data centres	Y

10.1 Spie-Batignolles (1982)

10.1.1 Methodology

The aim of this study was to determine the waste heat potentially recoverable from the oil-refining industry, the chemical industry and the steel industry in order to supply district heating networks throughout the (then) European Economic Community.

For each industrial location considered, the amount of heat potentially recoverable was assessed in relation to the processing or production capacities of the unit in question.

For each potential source of industrial waste heat, a maximum network length (the "economic distance") was evaluated using a simplified technical-economic model. The economic criterion used was a payback period of seven years.

Within the area thus defined around the industrial location, centralised heating requirements were analysed either on the basis of the installed power of collective boilerhouses or on the basis of population density. The most promising examples concerned urban areas that already had a heat distribution network.

10.1.2 Results

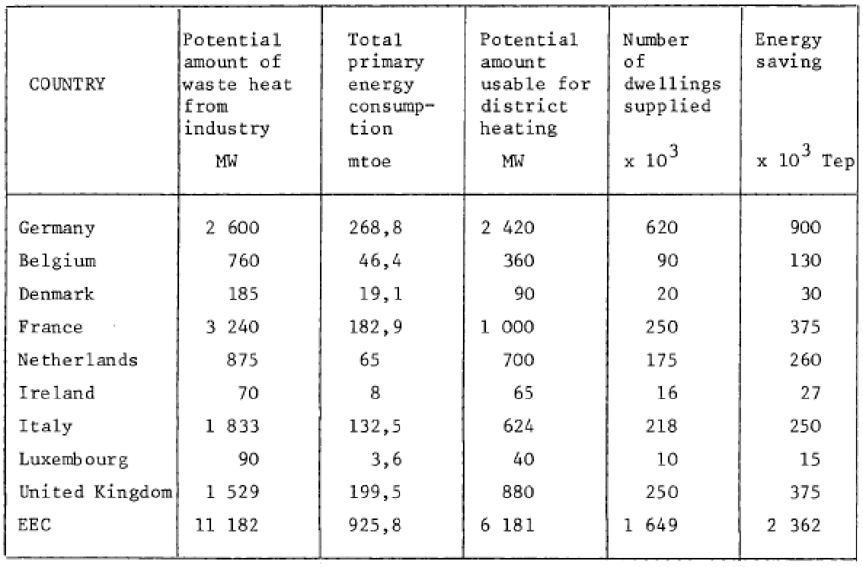
In the industries considered, at least 2.4 million toe could be saved in this way by making use of waste heat in order to heat over 1.7 million dwellings.

The amount of heat that may be recovered in integrated steelworks over the entire production process, i.e. from coking plant to rolling mill, is between 120 and 135 megacalories (Mcal) per tonne of finished product depending on the type of casting:

- Coking plants: Heat recovery potential between 12 and 15 Mcal per tonne of coal processed (i.e. 2.5-3% of the plant's energy consumption).
- Sintering of ore: 20 Mcal per tonne of ore.
- Blast furnaces: 20 Mcal per tonne of cast iron produced.
- Steelworks: Where the combustion is incomplete, the estimated heat recovery potential for these converters is 30 Mcal per tonne of steel (in the form of hot water in the temperature range 100-130°C).
- Electric steel plants: Heat recovery from the waste gases is possible only in large plants and is estimated at 25-30 Mcal per tonne of steel.
- Rolling mills: Average quantities of recoverable heat range from 45 to 55 Mcal per tonne for ingot casting and from 30 to 35 Mcal per tonne for continuous casting.

The study also provides estimates for oil refining, petrochemicals, ammonia, nitric acid, ammonium nitrates, urea-sulphuric acid, methanol and oxygen.

Table 11. Potential amounts of waste heat from industry usable for district heating



COUNTRY	Potential amount of waste heat from industry MW	Total primary energy consumption mtoe	Potential amount usable for district heating MW	Number of dwellings supplied x 10^3	Energy saving x 10^3 Tep
Germany	2 600	268,8	2 420	620	900
Belgium	760	46,4	360	90	130
Denmark	185	19,1	90	20	30
France	3 240	182,9	1 000	250	375
Netherlands	875	65	700	175	260
Ireland	70	8	65	16	27
Italy	1 833	132,5	624	218	250
Luxembourg	90	3,6	40	10	15
United Kingdom	1 529	199,5	880	250	375
EEC	11 182	925,8	6 181	1 649	2 362

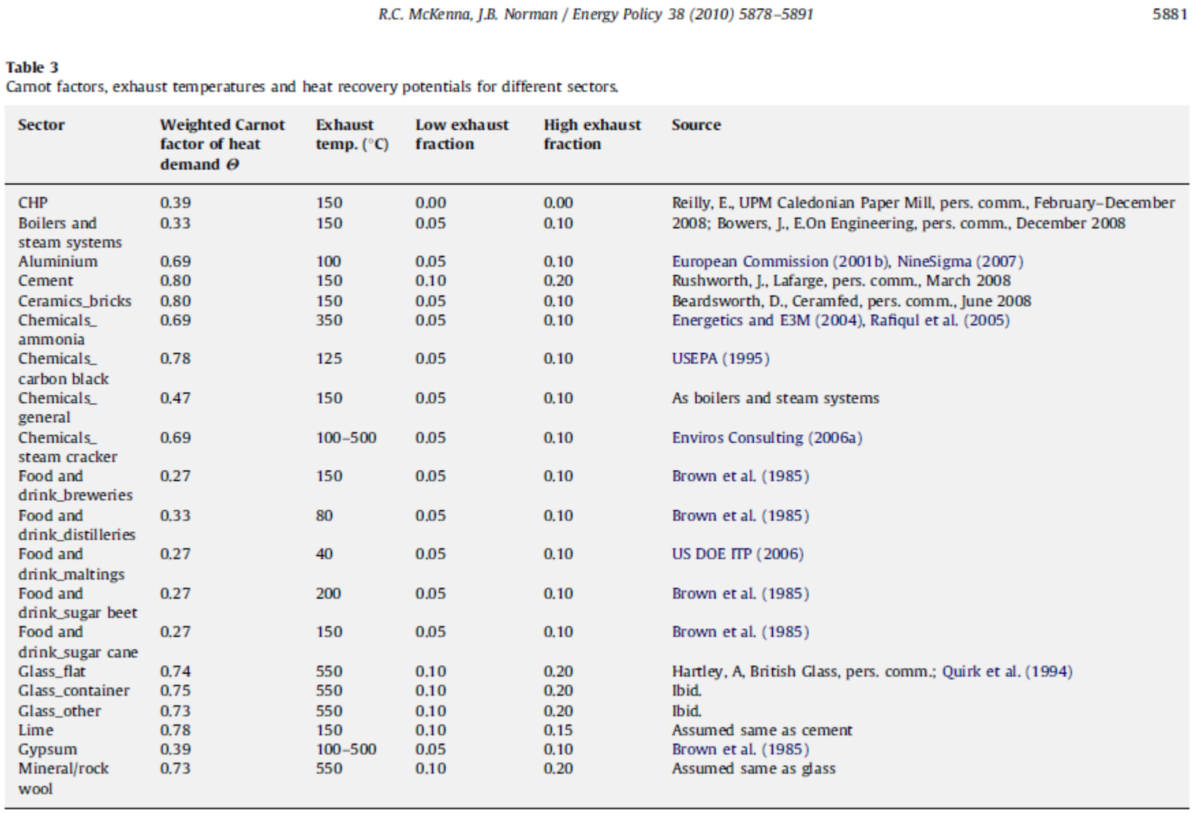
Source: Spie-Batignolles, 1982.

10.2 McKenna and Norman (2010)

McKenna and Norman take conservative estimates from literature for the fraction of input energy that is released at the exhaust and assume that 50% of this energy is recoverable. Where data is not readily available for the exhaust fraction or it is not clear what process is occurring at a particular site, the range for the exhaust fraction is estimated at 5-10%. This is intended to represent even the most efficient boilers, and therefore reflects marginal improvements widely considered possible. The input energy is then back-calculated at site level from the amount of emissions using data from the EU-ETS.

The assumed temperature demand profiles, exhaust temperatures and sources for these data are presented in Table 12. The temperature demand profile is based on an estimate of the fraction of heat used for each sector within five temperature bands: below 100, 100-500, 500-1 000, 1 000-1 500 and above 1 500°C. For temperatures above 1 500°C, a mid-point temperature of 1 800°C was used. Multiplying the Carnot factor for each temperature demand by the proportion of heat use in each band yields the weighted overall Carnot factors shown. These estimates are based on background studies of industries and relevant literature such as the BREFs.

Table 12. Carnot factors, exhaust temperatures and heat recovery potentials by sector



R.C. McKenna, J.B. Norman / Energy Policy 38 (2010) 5878–5891 5881

Table 3
Carnot factors, exhaust temperatures and heat recovery potentials for different sectors.

Sector	Weighted Carnot factor of heat demand Θ	Exhaust temp. (°C)	Low exhaust fraction	High exhaust fraction	Source
CHP	0.39	150	0.00	0.00	Reilly, E., UPM Caledonian Paper Mill, pers. comm., February–December 2008; Bowers, J., E.On Engineering, pers. comm., December 2008
Boilers and steam systems	0.33	150	0.05	0.10	
Aluminium	0.69	100	0.05	0.10	European Commission (2001b), NineSigma (2007)
Cement	0.80	150	0.10	0.20	Rushworth, J., Lafarge, pers. comm., March 2008
Ceramics_bricks	0.80	150	0.05	0.10	Beardsworth, D., Ceramfed, pers. comm., June 2008
Chemicals_ ammonia	0.69	350	0.05	0.10	Energetics and E3M (2004), Rafiqul et al. (2005)
Chemicals_ carbon black	0.78	125	0.05	0.10	USEPA (1995)
Chemicals_ general	0.47	150	0.05	0.10	As boilers and steam systems
Chemicals_ steam cracker	0.69	100–500	0.05	0.10	Enviros Consulting (2006a)
Food and drink_breweries	0.27	150	0.05	0.10	Brown et al. (1985)
Food and drink_distilleries	0.33	80	0.05	0.10	Brown et al. (1985)
Food and drink_maltings	0.27	40	0.05	0.10	US DOE ITP (2006)
Food and drink_sugar beet	0.27	200	0.05	0.10	Brown et al. (1985)
Food and drink_sugar cane	0.27	150	0.05	0.10	Brown et al. (1985)
Glass_flat	0.74	550	0.10	0.20	Hartley, A, British Glass, pers. comm.; Quirk et al. (1994)
Glass_container	0.75	550	0.10	0.20	Ibid.
Glass_other	0.73	550	0.10	0.20	Ibid.
Lime	0.78	150	0.10	0.15	Assumed same as cement
Gypsum	0.39	100–500	0.05	0.10	Brown et al. (1985)
Mineral/rock wool	0.73	550	0.10	0.20	Assumed same as glass

Source: McKenna and Norman, 2010.

Heat obtained from exothermic reactions (i.e. other than combustion of fuels) is not considered. Examples include the production of nitric and sulphuric acids and most polymerisation reactions. In such cases there may even be a net heat yield from the reaction, whereby the heat is typically used elsewhere in the plant, which will be characterised by a high degree of energy integration.

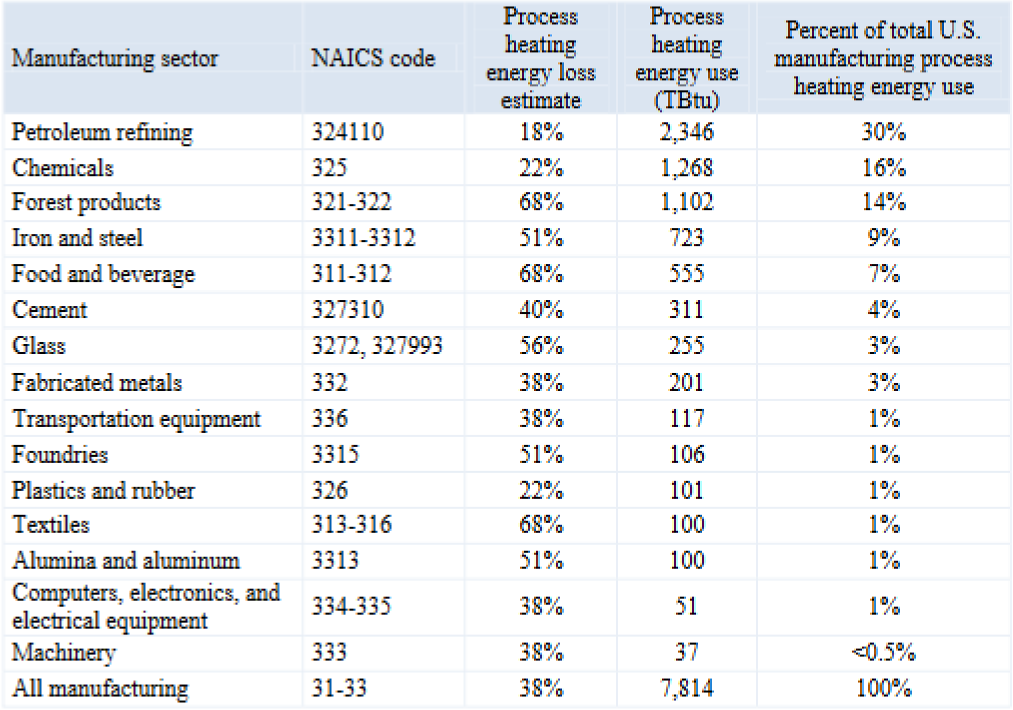
McKenna and Norman also provide sector-specific methodologies for aluminium, chemicals, ammonia, chlorine, ethylene, other major chemicals, iron and steel, and lime.

10.3 Energetics (2012)

The Manufacturing Energy and Carbon Footprints describe manufacturing energy use and loss and associated greenhouse gas emissions for fuel, electricity and steam use in the United States. Each footprint consists of an overview of the sector's total primary energy flow including off-site energy and associated generation and transmission losses, and a more detailed breakdown of the on-site energy by end use.

Process heating loss estimates were derived for seven manufacturing sectors, representing 84% of manufacturing process heating energy use (Table 13).

Table 13. Process heating energy loss in the manufacturing sector of the United States



Manufacturing sector	NAICS code	Process heating energy loss estimate	Process heating energy use (TBtu)	Percent of total U.S. manufacturing process heating energy use
Petroleum refining	324110	18%	2,346	30%
Chemicals	325	22%	1,268	16%
Forest products	321-322	68%	1,102	14%
Iron and steel	3311-3312	51%	723	9%
Food and beverage	311-312	68%	555	7%
Cement	327310	40%	311	4%
Glass	3272, 327993	56%	255	3%
Fabricated metals	332	38%	201	3%
Transportation equipment	336	38%	117	1%
Foundries	3315	51%	106	1%
Plastics and rubber	326	22%	101	1%
Textiles	313-316	68%	100	1%
Alumina and aluminum	3313	51%	100	1%
Computers, electronics, and electrical equipment	334-335	38%	51	1%
Machinery	333	38%	37	<0.5%
All manufacturing	31-33	38%	7,814	100%

10.4 Heat Roadmap Europe and the Pan-European Thermal Atlas (since 2012)

Heat Roadmap Europe is a series of projects covering 14 European countries: Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Spain, Sweden and the United Kingdom. Its outputs include quantification of heating and cooling demand, the Pan-European Thermal Atlas (Peta[10]), and the first ever quantification of the waste heat volumes available from power plants, waste incineration, and industry in Europe.

Peta maps waste heat from industry using the emissions database of the European Environment Agency. Recently, metro stations and wastewater sources from the ReUseHeat project (see below) have been added.

10.5 Gustafsson (2013)

10.5.1 Methodology

Data on how much waste heat industries supply to the district heating network, and how much fuel they use, were collected from Statistiska Centralbyrån (Statistics Sweden). From these data, the ratio of delivered waste heat to fuel use was calculated for each industry sector. By collecting data on total fuel use in each sector (even plants that currently do not deliver waste heat to a district heating network) a theoretical potential for waste heat was calculated by multiplying the fuel use by the ratio. The theoretical potential was then adjusted based on contacts with companies and other sources of today's waste heat supplies.

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[10] See https://heatroadmap.eu/peta4/.

Table 14. Calculated ratios of waste heat per fuel use per year (upper), and potentials for district heating export (MW, lower)

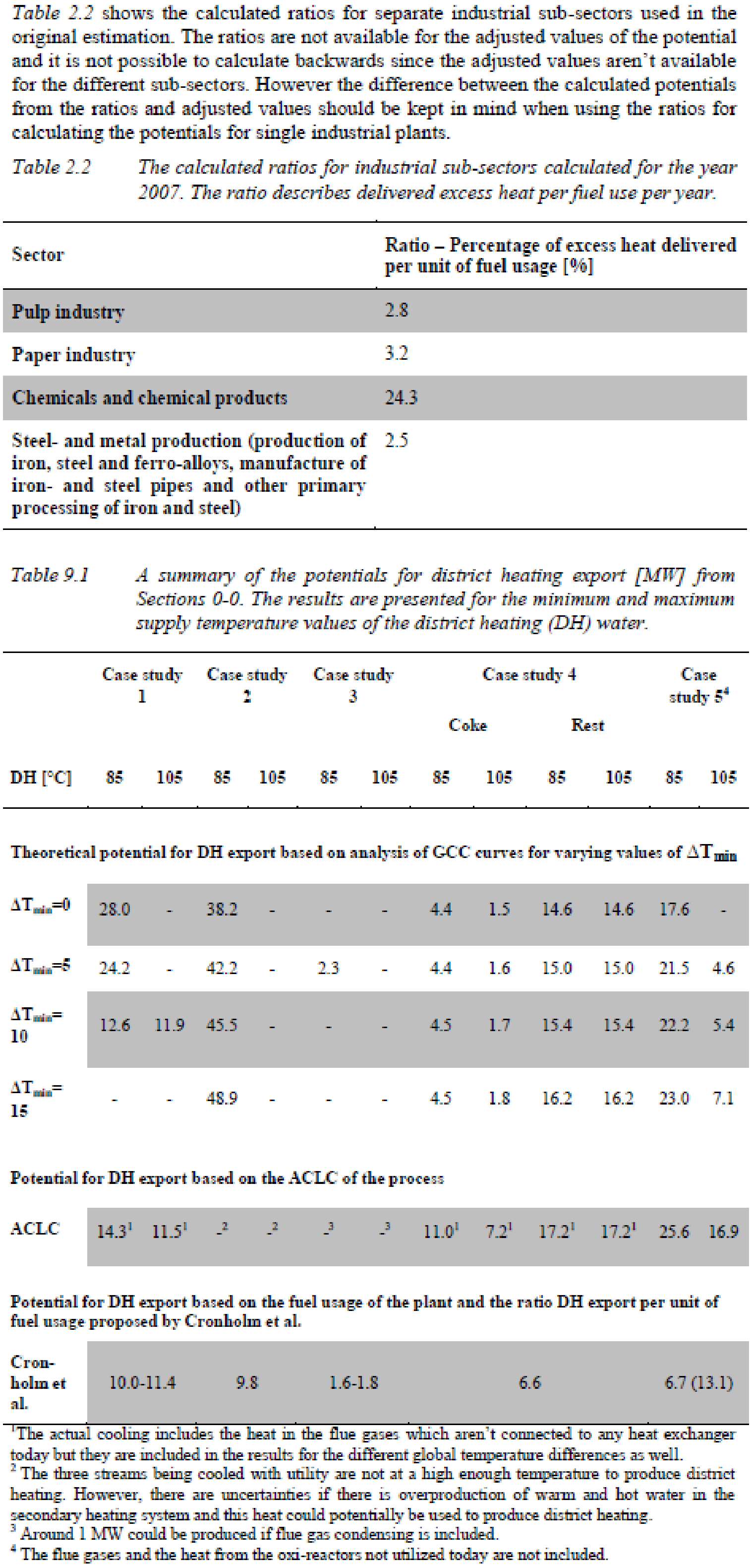

Table 2.2 shows the calculated ratios for separate industrial sub-sectors used in the original estimation. The ratios are not available for the adjusted values of the potential and it is not possible to calculate backwards since the adjusted values aren't available for the different sub-sectors. However the difference between the calculated potentials from the ratios and adjusted values should be kept in mind when using the ratios for calculating the potentials for single industrial plants.

Table 2.2 The calculated ratios for industrial sub-sectors calculated for the year 2007. The ratio describes delivered excess heat per fuel use per year.

Sector	Ratio – Percentage of excess heat delivered per unit of fuel usage [%]
Pulp industry	2.8
Paper industry	3.2
Chemicals and chemical products	24.3
Steel- and metal production (production of iron, steel and ferro-alloys, manufacture of iron- and steel pipes and other primary processing of iron and steel)	2.5

Table 9.1 A summary of the potentials for district heating export [MW] from Sections 0-0. The results are presented for the minimum and maximum supply temperature values of the district heating (DH) water.

	Case study 1		**Case study 2**		**Case study 3**		**Case study 4**				**Case study 5[4]**	
							Coke		**Rest**			
DH [°C]	**85**	**105**	**85**	**105**	**85**	**105**	**85**	**105**	**85**	**105**	**85**	**105**
Theoretical potential for DH export based on analysis of GCC curves for varying values of ΔT_{min}												
$\Delta T_{min}=0$	28.0	-	38.2	-	-	-	4.4	1.5	14.6	14.6	17.6	-
$\Delta T_{min}=5$	24.2	-	42.2	-	2.3	-	4.4	1.6	15.0	15.0	21.5	4.6
$\Delta T_{min}=10$	12.6	11.9	45.5	-	-	-	4.5	1.7	15.4	15.4	22.2	5.4
$\Delta T_{min}=15$	-	-	48.9	-	-	-	4.5	1.8	16.2	16.2	23.0	7.1
Potential for DH export based on the ACLC of the process												
ACLC	14.3[1]	11.5[1]	-[2]	-[2]	-[3]	-[3]	11.0[1]	7.2[1]	17.2[1]	17.2[1]	25.6	16.9
Potential for DH export based on the fuel usage of the plant and the ratio DH export per unit of fuel usage proposed by Cronholm et al.												
Cronholm et al.	10.0-11.4		9.8		1.6-1.8		6.6				6.7 (13.1)	

[1] The actual cooling includes the heat in the flue gases which aren't connected to any heat exchanger today but they are included in the results for the different global temperature differences as well.

[2] The three streams being cooled with utility are not at a high enough temperature to produce district heating. However, there are uncertainties if there is overproduction of warm and hot water in the secondary heating system and this heat could potentially be used to produce district heating.

[3] Around 1 MW could be produced if flue gas condensing is included.

[4] The flue gases and the heat from the oxi-reactors not utilized today are not included.

Source: Gustafsson, 2013.

10.5.2 Results

The calculated theoretical potential for all industrial plants in Sweden is 6.3 TWh/year and the adjusted potential is 6.2-7.9 TWh/year. The total amount of waste heat currently delivered is 4.1 TWh/year.

Table 15. Delivered excess heat, theoretical potential and adjusted theoretical potential by sector (GWh/year)

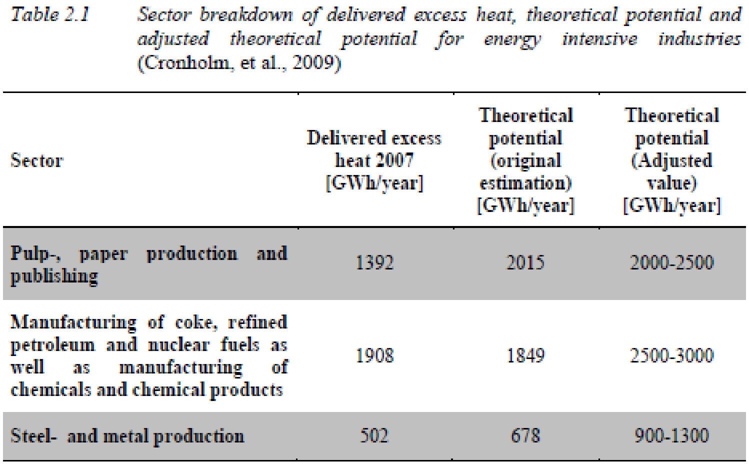

Table 2.1 *Sector breakdown of delivered excess heat, theoretical potential and adjusted theoretical potential for energy intensive industries* (Cronholm, et al., 2009)

Sector	Delivered excess heat 2007 [GWh/year]	Theoretical potential (original estimation) [GWh/year]	Theoretical potential (Adjusted value) [GWh/year]
Pulp-, paper production and publishing	1392	2015	2000-2500
Manufacturing of coke, refined petroleum and nuclear fuels as well as manufacturing of chemicals and chemical products	1908	1849	2500-3000
Steel- and metal production	502	678	900-1300

Source: Gustafsson, 2013.

10.6 Brueckner et al. (2014)

This paper categorises and compares different methods to estimate the waste heat of industrial production within a region. The resulting waste heat potential ranges between 5 and 30% of the energy demand of the region. For example:

- Basque country: 51x106 GJ/year or 14 TWh/year. Most of this potential (23%) is in the 80-120°C temperature range, second-most (21%) above 1.200°C, and 19% between 400 and 800°C.
- Baden-Württemberg: approximately 8 TWh/year (1 267 GWh/year < 100°C, 215 GWh/year at 100-500°C, 6 645 GWh/year > 500°C).

For Germany in total, a 2010 estimation based on energy factors from various studies found a waste heat potential of 88 TWh/year above 140°C and 44 TWh/y in the 60-140°C range.

An EH&P estimate applied energy factors from a Swedish study to 32 other European countries. For example, from oil refineries 0.6% of the input energy can be retrieved as waste heat; for paper 2.4%, in the chemical industry 12.2%, and in the mineral sector 2.9%. The total waste heat potential was estimated as 1 106 PJ/year or 307 TWh/year. This was economically feasible potential.

10.7 D'Appolonia (2015)

The TASIO Horizon 2020 project created a new generation of direct heat exchange technology for commercial ORC systems and evaluated energy recovery potential in the cement, glass, steel and petrochemical sectors.[11] The estimated theoretical potential is about 2.5 GW, or almost 20 TWh of electricity.

In the cement sector, the clinker cooler section was found to be a suitable source of waste heat, at a temperature of 250-350°C (Figure 12).

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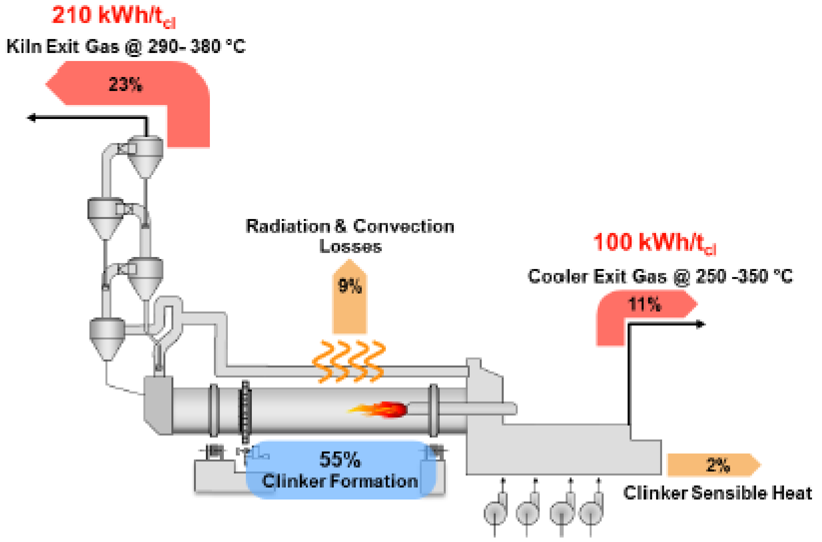
[11] Information on this and other EU-funded research in the area of industrial waste heat can be found at https://cordis.europa.eu/article/id/422033-waste-heat-valorisation.

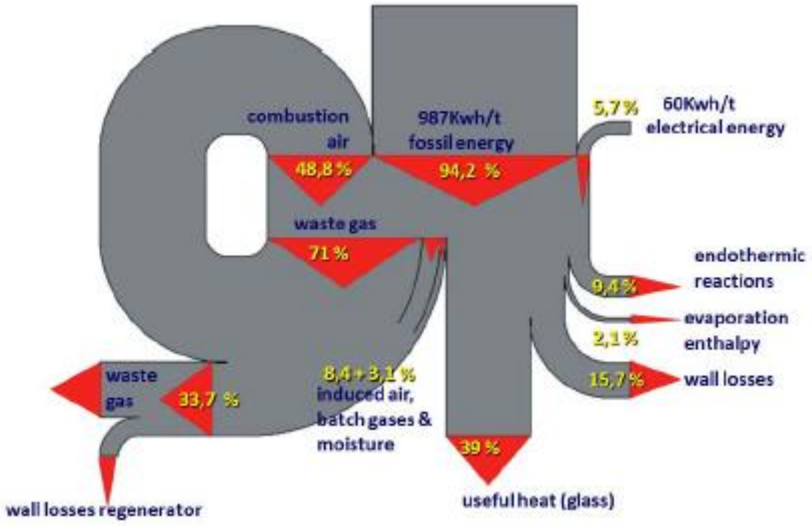
Figure 12. Energy flow chart of the clinker production section of a cement plant



Source: TASIO, 2015.

In the glass sector, the main source of waste heat would be the exhaust gases of the melting furnace, at 350-450°C (Figure 13).

Figure 13. Energy flow chart of a fired glass furnace



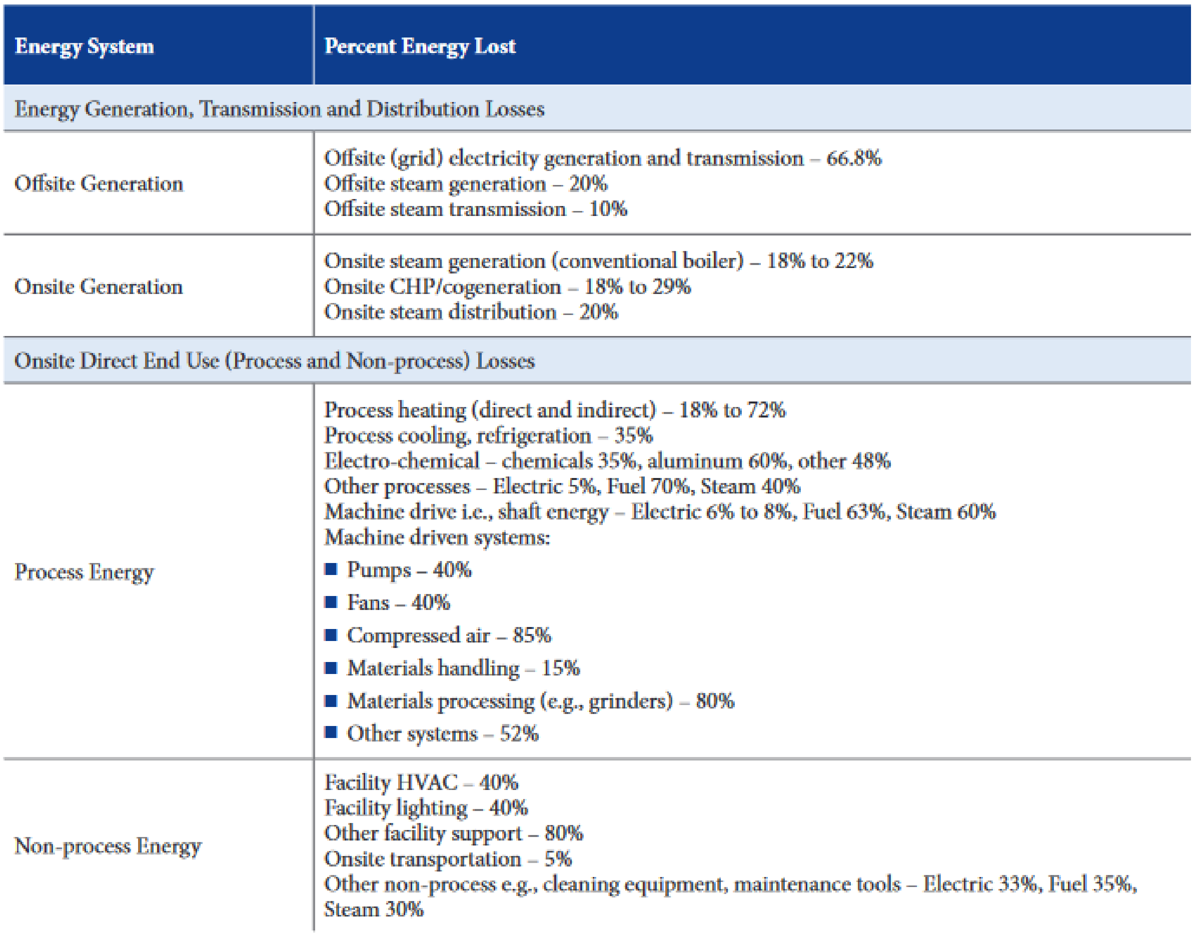
Source: TASIO, 2015.

There are two possible sources of waste heat from the steel sector: electric-arc furnaces and rolling mill or reheating furnaces. The latter have a waste heat temperature of 350-650°C.

10.8 United States Department of Energy (2015)

This Technology Assessment cites the report *Energy Use, Loss, and Opportunities Analysis*, which estimates energy losses by use area in manufacturing facilities. The report evaluated process systems and indicated that the major energy losses take place in process heaters (steam and direct heaters), motor-driven systems (compressed air, pumps and fans), and steam generation systems. More efficient systems can avoid some of these losses.

Table 16. Energy losses by energy-consuming system in manufacturing facilities



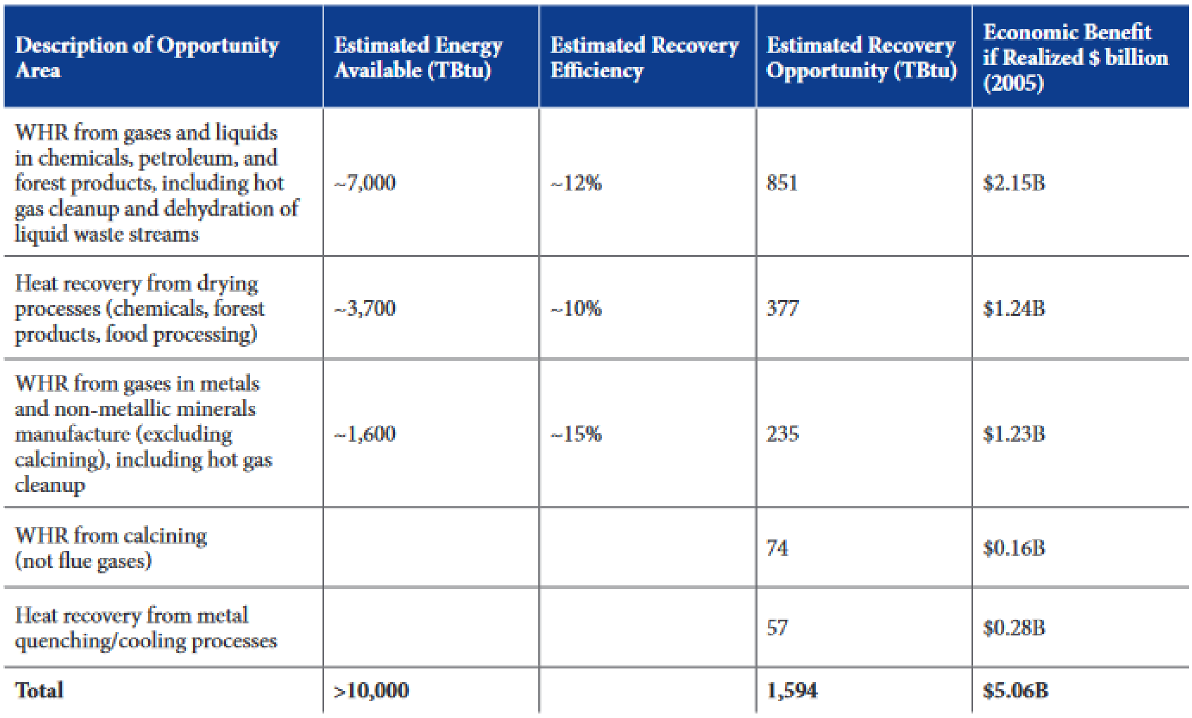
Energy System	Percent Energy Lost
Energy Generation, Transmission and Distribution Losses	
Offsite Generation	Offsite (grid) electricity generation and transmission – 66.8% Offsite steam generation – 20% Offsite steam transmission – 10%
Onsite Generation	Onsite steam generation (conventional boiler) – 18% to 22% Onsite CHP/cogeneration – 18% to 29% Onsite steam distribution – 20%
Onsite Direct End Use (Process and Non-process) Losses	
Process Energy	Process heating (direct and indirect) – 18% to 72% Process cooling, refrigeration – 35% Electro-chemical – chemicals 35%, aluminum 60%, other 48% Other processes – Electric 5%, Fuel 70%, Steam 40% Machine drive i.e., shaft energy – Electric 6% to 8%, Fuel 63%, Steam 60% Machine driven systems: ■ Pumps – 40% ■ Fans – 40% ■ Compressed air – 85% ■ Materials handling – 15% ■ Materials processing (e.g., grinders) – 80% ■ Other systems – 52%
Non-process Energy	Facility HVAC – 40% Facility lighting – 40% Other facility support – 80% Onsite transportation – 5% Other non-process e.g., cleaning equipment, maintenance tools – Electric 33%, Fuel 35%, Steam 30%

Source: US DOE, 2015.

Note that energy losses do not equate to recoverable energy. There are technical and economic limits to the recovery potential of those losses.

Another report cited, *Opportunity Analysis for Recovering Energy from Industrial Waste Heat and Emissions*, quantified the total waste heat opportunity in the manufacturing sector. It determined the amount of energy in industrial emissions and identified technology opportunities for capturing and redeploying it.

Table 17. Waste heat recovery opportunities



Description of Opportunity Area	Estimated Energy Available (TBtu)	Estimated Recovery Efficiency	Estimated Recovery Opportunity (TBtu)	Economic Benefit if Realized $ billion (2005)
WHR from gases and liquids in chemicals, petroleum, and forest products, including hot gas cleanup and dehydration of liquid waste streams	~7,000	~12%	851	$2.15B
Heat recovery from drying processes (chemicals, forest products, food processing)	~3,700	~10%	377	$1.24B
WHR from gases in metals and non-metallic minerals manufacture (excluding calcining), including hot gas cleanup	~1,600	~15%	235	$1.23B
WHR from calcining (not flue gases)			74	$0.16B
Heat recovery from metal quenching/cooling processes			57	$0.28B
Total	**>10,000**		**1,594**	**$5.06B**

Source: US DOE, 2015.

10.9 Persson (2015)

The STRATEGO project estimated that around 26.2 EJ of primary energy was supplied to 2 712 energy and industry sector facilities in EU-28 in 2010. A theoretical waste heat potential of 11.3 EJ is estimated to have been vented from these activities during that year. Waste heat activities in industrial sectors dominate the selection in terms of number of facilities, while main activity thermal power generation plants constitute the majority of annual waste heat volumes.

10.10 EnEff:Wärme:NENIA (2015-2018)

As part of the project EnEff:Wärme:NENIA, a comprehensive geodata bank was drawn up, featuring more than 4 700 industrial sites with specific details of energy use and the resultant theoretically usable heat quantities of around 63 TWh/year – differentiated by temperature, humidity, pollutant load and temporal availability. The declarations of airborne emissions from manufacturing companies in accordance with the 11th Federal Emissions Control Act, supplementary data from the E-PRTR database, and independent research into thermally relevant electricity inputs were collated to create the database.

In addition, six case studies in industrial companies and a questionnaire-based survey of around 40 other companies generated extensive empirical input on data validation and the recording of technical, economic and organisational barriers with regard to external waste heat utilisation. These were incorporated into policy recommendations.

A nationwide GIS model (Heat Map2.0) was developed for high-resolution spatial mapping of heating demand in residential and non-residential buildings, based on ifeu's GEMOD building model. In conjunction with models for the spatial mapping of existing district heating supply areas and other feasible heat network potential areas, a comprehensive nationwide comparison of waste heat supply and heat sink potential was carried out for the first time to determine the technically and economically feasible potential of industrial waste heat in heating networks.

The results show that in many companies, significant externally available waste heat quantities are available and can be exploited economically (80-90% in the low/medium temperature range). This can be attributed in part to the positive spatial correlation between waste heat supply and heat sink potential: much of the technical waste heat potential is located less than 1 000 metres from adequate heat sinks that can be supplied from the grid (ifeu, 2018).

10.11 Brueckner et al. (2016)

This paper presents the first bottom-up approach for estimating the industrial waste heat potential in Germany. An algorithm to evaluate and test the mandatory emissions reporting data from German companies was developed. Next, around 81 000 datasets were evaluated to calculate a conservative and lower boundary value for industrial waste heat. Based on the collected data, the waste heat volume was evaluated as 127 PJ/year (35 TWh/year) or 13% of industrial fuel consumption. Results were used to derive missing data.

10.12 CE-HEAT (2016-2019)

The CE-HEAT project was funded under the Interreg CENTRAL EUROPE Programme. Its outputs included a manual for the estimation of regional waste heat potential, and another for cadastre (map) development. The following waste heat conversion factors were used (CE-HEAT, 2019):

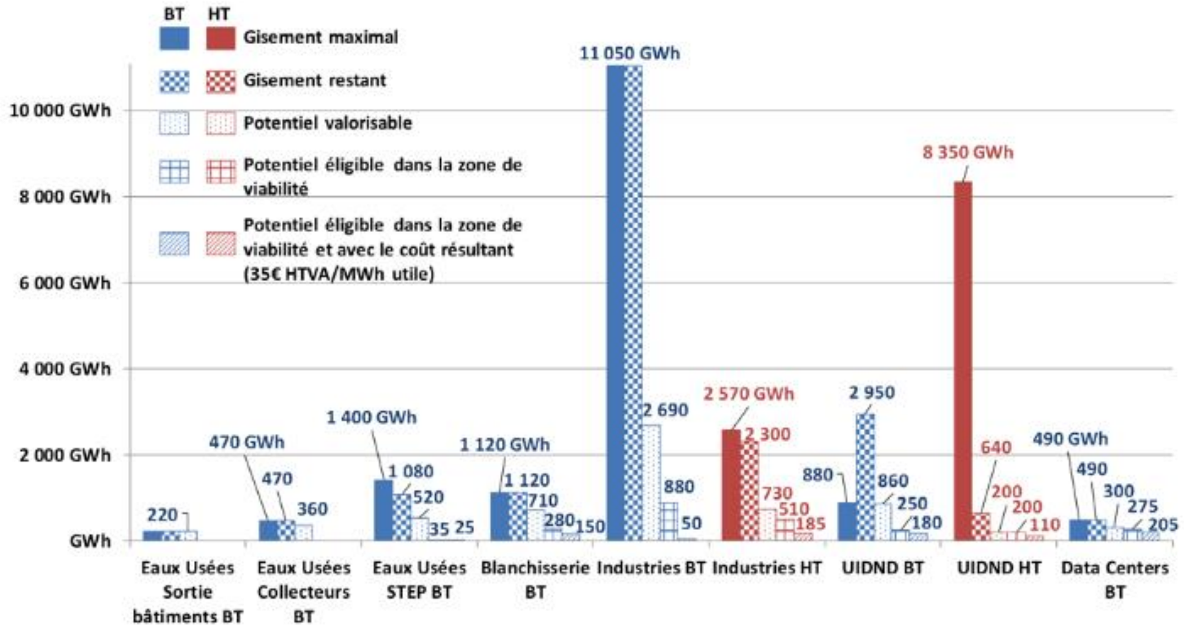
- 15% waste heat share of total energy consumption in manufacturing of food products, beverages and tobacco;
- 20% waste heat share of total energy consumption in manufacturing of paper and paper products;
- 8% waste heat share of total energy consumption in the temperature range between 60 and 140°C, and 4% in the temperature range less than 60°C, in manufacturing of chemicals and chemical products;
- 3% waste heat share of total energy consumption in the temperature range between 60 and 140°C, and 1.5% less than 60°C, in manufacturing of rubber and plastic products;
- 40% waste heat share of total energy consumption in manufacturing of other non-metallic mineral products (glass, brick etc.);
- 30% waste heat share of total energy consumption between 60 and 140°C, and 15% less than 60°C, in manufacturing of basic metals;
-
- 3% waste heat share of total energy consumption between 60 and 140°C, and 1.5% less than 60°C, in manufacturing of fabricated metal products;
- 3% waste heat share of total energy consumption between 60 and 140°C and 1.5% in the temperature range lower than 60°C in manufacturing of machinery and equipment;
- 3% waste heat share of the total energy consumption between 60 and 140°C, and 1.5% less than 60°C, in manufacturing of motor vehicles and transport equipment.

10.13 Ademe (2017)

This study assessed the waste heat potential in the Ile-de-France region. The region has a significant resource in this area: up to 26 000 GWh, with a majority from the industry sector and incineration. Taking into account demand constraints, i.e. proximity of potential users to producers of waste heat, reduces the potential considerably however, to 6 500 GW. Moreover, applying economic criteria results in a potential of 900 GWh from around

30 projects, matching each producer with one or several users. Figure 14 below illustrates the disparity across source-types and between theoretical resource and economic potential.

Figure 14. Waste heat resource, potential and economic potential by source and temperature



Notes: BT = Low temperature (<90°C); HT = High temperature; HTVA = Excluding Value-Added Tax; UIDND = Incineration.

Source: Ademe, 2017.

10.14 Papapetrou et al. (2018)

10.14.1 Methodology

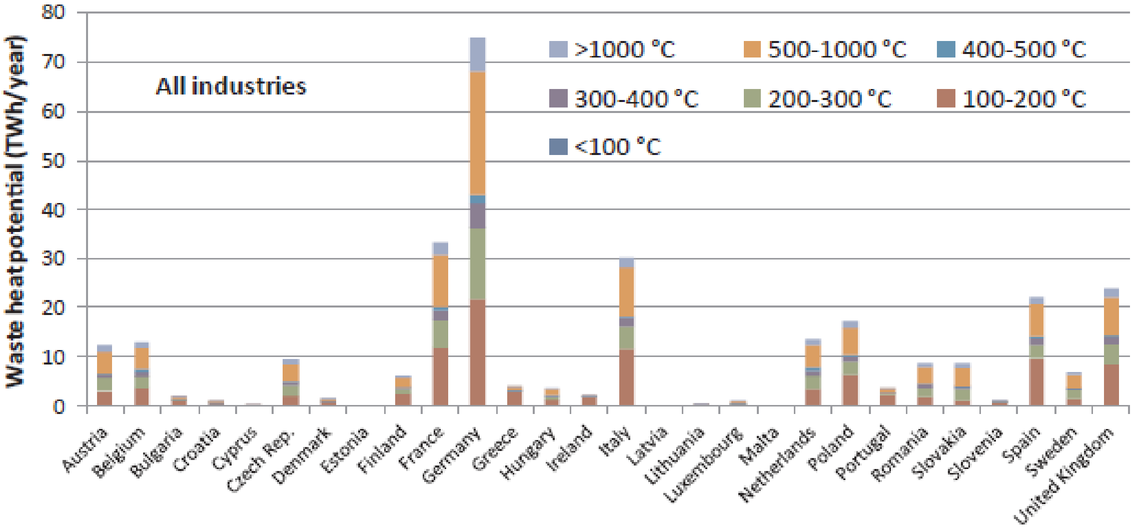
This work examines industrial waste heat in EU countries, focusing on the amount that can be recovered and exploited, referred to as technical potential. The methodology is based on waste heat fractions derived from a detailed study of UK industry during 2000–2003.

The waste heat fractions are calculated for each main industry sector and temperature level. The methodology first takes into account the different levels of energy efficiency in each EU country. Second, the fractions are adjusted for the year 2015, using energy intensity trends for each country and sector.

10.14.2 Results

The main result is the estimation of total waste heat potential in the EU at about 300 TWh/year, with one third below 200°C, another 25% in the range 200–500°C and the rest above 500°C (mostly 500–1 000°C).

Figure 15. Technical waste heat potential from industry by country and temperature



Source: Papapetrou et al., 2018.

Table 18. Selected indicators for five energy-intensive sectors

	<100°C	100-200°C	200-300°C	300-400°C	400-500°C	500-1 000°C	>1 000°C
Non-ferrous metals	0	22	0	0	0	0	0
Non-metallic minerals	0	17.19	0	1.45	0	7.66	0
Chemical and petrochemical	0	0.97	0	0.34	1.89	0	0
Food and beverage	0.63	6.34	0	0	0	0	0
Paper, pulp and printing	0	19.73	0	0	0	0	0
Iron and steel	0	0	10.04	2.78	0	14.88	4.6
Other	0	0.59	0	0	0	0	0

Source: Papapetrou et al., 2018.

10.15 ReUseHeat (2018)

This report assesses the EU-28 urban waste heat recovery potential from four unconventional (i.e. temperatures well below 50°C) sources: data centres, metro stations, service sector buildings, and wastewater treatment plants. In all, potentials are modelled and spatially mapped for 26 400 unique activities. Two new concepts are applied: available waste heat and accessible waste heat. In so doing, total potentials are distinguished from practical utilisation potentials, and the count is reduced to 6 800 unique facilities. All those facilities are located inside or within 2 km of urban district heating areas.

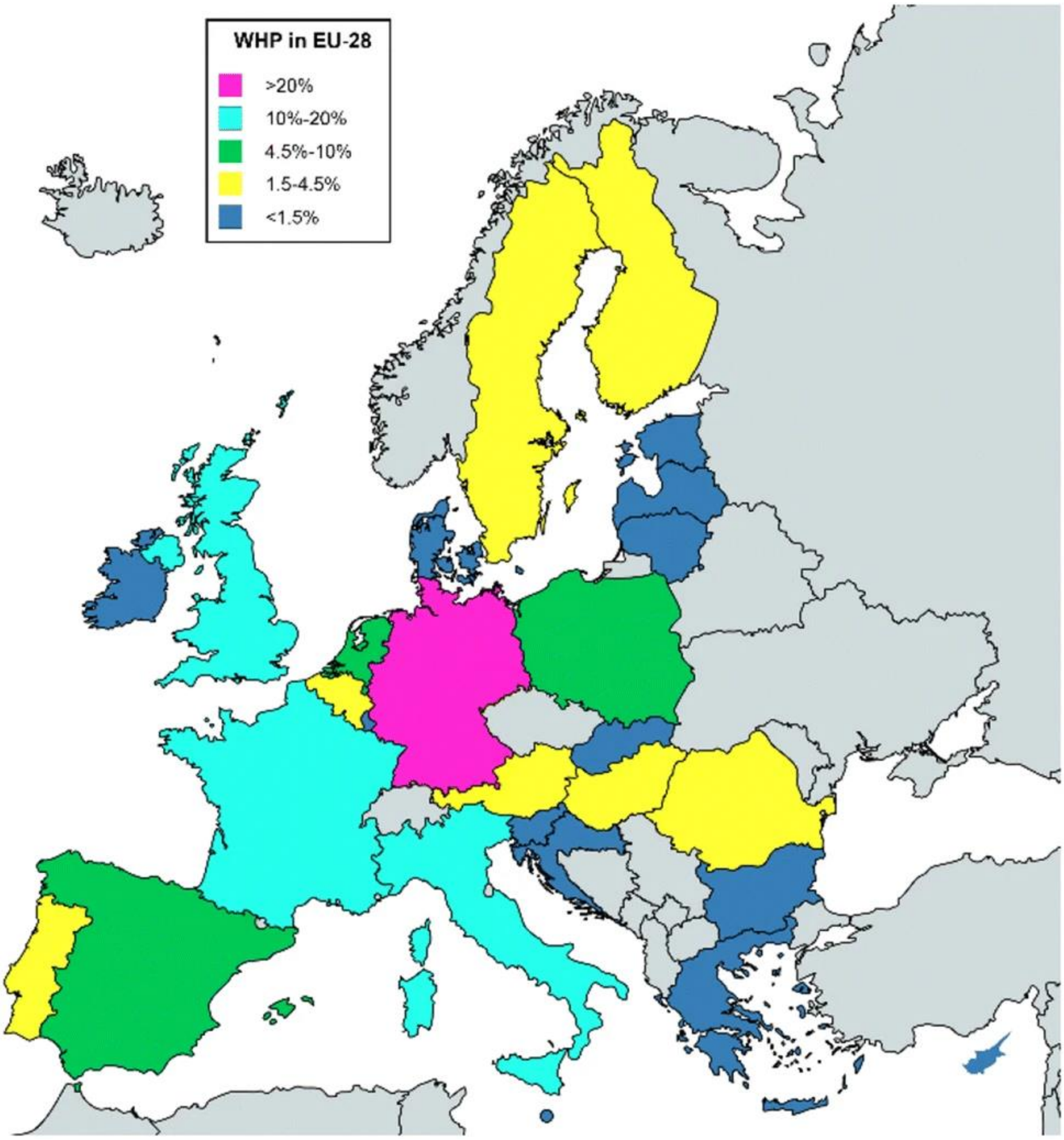
For the total count of activities, waste heat potential is assessed at 1.6 EJ per year. For those facilities with potential for practical utilisation, the *available* potential is 0.8 EJ per year, which corresponds to an *accessible* potential of 1.24 EJ annually.

This distinction is based on two dimensions. First, the waste heat sources considered are all so-called low-temperature sources, which depend on heat pump applications. The second dimension is spatial correlation to heat distribution infrastructure.

10.16 Bianchi et al. (2019)

This study revisits the waste heat recovery potential of EU industry through a methodology that takes into consideration the temperature levels of the process. It addresses both theoretical and Carnot potentials, by country and sub-sector (Figure 16). The potential is high, of the order of 300 TWh/year, even though the estimate is considered more conservative than Papapetrou et al. (2018) for example.

Figure 16. Share of waste heat potential from industry by Member State

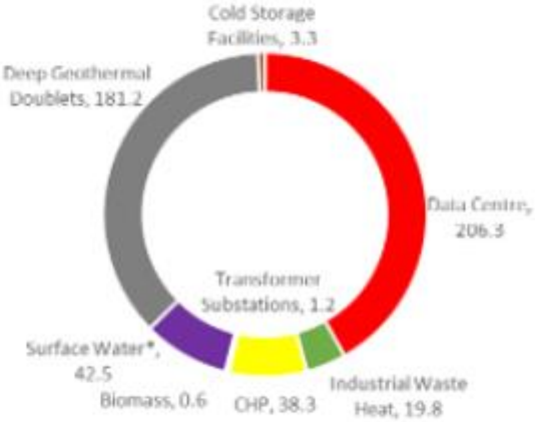


Note: Total value = 920 TWh theoretical, 279 TWh Carnot.
Source: Bianchi et al., 2018.

10.17 Codema (2019)

In south Dublin, the heat source with the greatest capacity is data centres, with enough heat to supply the peak demand of 70 000 dwellings.

Figure 17. Capacity (MW) by heat source in south Dublin



* This estimate is quite conservative and could be in excess of ten times higher under different assumptions.
Source: Codema, 2019.

Details of individual industrial processes were not available so waste heat potential was taken as being the heat vented to the sewage system. Maximum sewer water flow rates (m^3/hour) and maximum sewer water temperatures were taken from industrial facilities' Industrial Emissions licence documentation, available from the national Environmental Protection Agency (EPA).

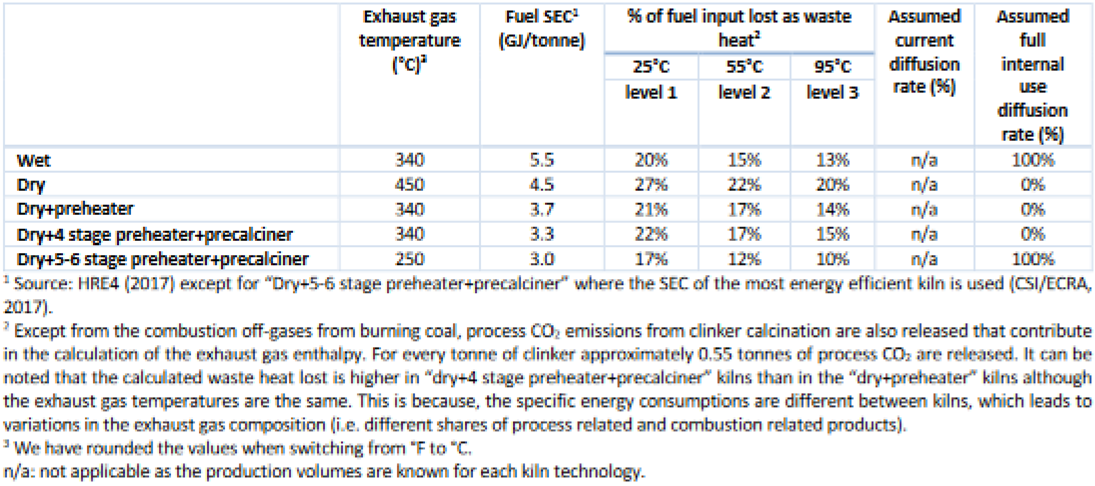
For wastewater, waste heat capacity estimates were based on annual average temperatures for tertiary tanks of similar treatment sites and the typical flow rate (m^3/day) was taken from EPA licence data. The maximum temperature reduction of the effluent was assumed based on technical constraints such as the temperature below which issues with freezing on the evaporator of the heat pump may occur.

10.18 sEEnergies (2020)

10.18.1 Methodology

sEEnergies is a Horizon 2020 project that analyses the available waste heat from heavy industry in Europe and assesses its suitability for use in district heating. It uses GIS mapping of 1 608 industrial sites in Europe combined with a process-specific assessment of their waste heat potential. The heat sources are then matched with data on heat demand density and district heating networks.

Table 19. Estimated exhaust gas waste heat losses from cement kilns



	Exhaust gas temperature (°C)[3]	Fuel SEC[1] (GJ/tonne)	% of fuel input lost as waste heat[2]			Assumed current diffusion rate (%)	Assumed full internal use diffusion rate (%)
			25°C level 1	55°C level 2	95°C level 3		
Wet	340	5.5	20%	15%	13%	n/a	100%
Dry	450	4.5	27%	22%	20%	n/a	0%
Dry+preheater	340	3.7	21%	17%	14%	n/a	0%
Dry+4 stage preheater+precalciner	340	3.3	22%	17%	15%	n/a	0%
Dry+5-6 stage preheater+precalciner	250	3.0	17%	12%	10%	n/a	100%

[1] Source: HRE4 (2017) except for "Dry+5-6 stage preheater+precalciner" where the SEC of the most energy efficient kiln is used (CSI/ECRA, 2017).

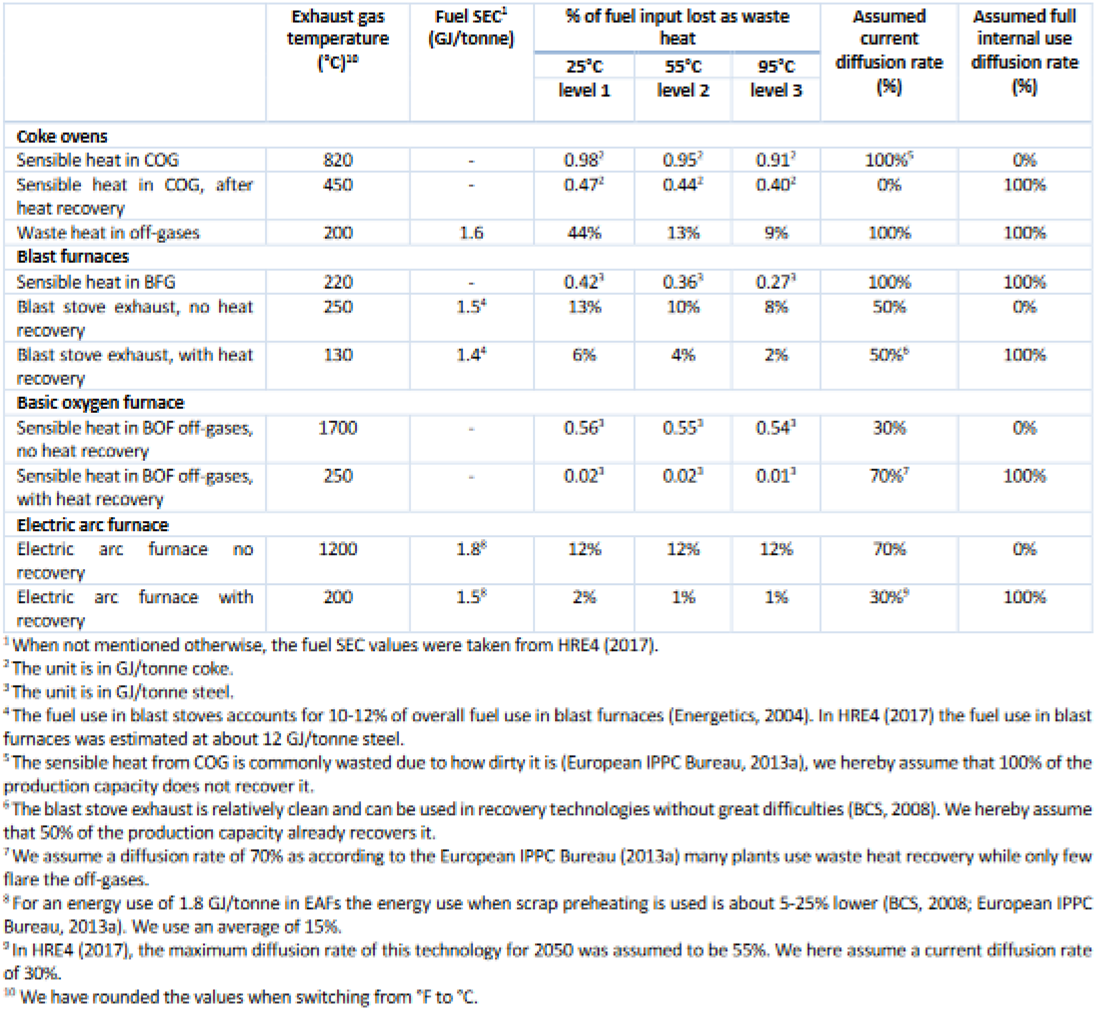
[2] Except from the combustion off-gases from burning coal, process CO_2 emissions from clinker calcination are also released that contribute in the calculation of the exhaust gas enthalpy. For every tonne of clinker approximately 0.55 tonnes of process CO_2 are released. It can be noted that the calculated waste heat lost is higher in "dry+4 stage preheater+precalciner" kilns than in the "dry+preheater" kilns although the exhaust gas temperatures are the same. This is because, the specific energy consumptions are different between kilns, which leads to variations in the exhaust gas composition (i.e. different shares of process related and combustion related products).

[3] We have rounded the values when switching from °F to °C.

n/a: not applicable as the production volumes are known for each kiln technology.

Source: sEEnergies, 2020.

Table 20. Estimated exhaust gas waste heat losses from the iron and steel sector



	Exhaust gas temperature (°C)[10]	Fuel SEC[1] (GJ/tonne)	% of fuel input lost as waste heat			Assumed current diffusion rate (%)	Assumed full internal use diffusion rate (%)
			25°C level 1	55°C level 2	95°C level 3		
Coke ovens							
Sensible heat in COG	820	-	0.98[2]	0.95[2]	0.91[2]	100%[5]	0%
Sensible heat in COG, after heat recovery	450	-	0.47[2]	0.44[2]	0.40[2]	0%	100%
Waste heat in off-gases	200	1.6	44%	13%	9%	100%	100%
Blast furnaces							
Sensible heat in BFG	220	-	0.42[3]	0.36[3]	0.27[3]	100%	100%
Blast stove exhaust, no heat recovery	250	1.5[4]	13%	10%	8%	50%	0%
Blast stove exhaust, with heat recovery	130	1.4[4]	6%	4%	2%	50%[6]	100%
Basic oxygen furnace							
Sensible heat in BOF off-gases, no heat recovery	1700	-	0.56[3]	0.55[3]	0.54[3]	30%	0%
Sensible heat in BOF off-gases, with heat recovery	250	-	0.02[3]	0.02[3]	0.01[3]	70%[7]	100%
Electric arc furnace							
Electric arc furnace no recovery	1200	1.8[8]	12%	12%	12%	70%	0%
Electric arc furnace with recovery	200	1.5[8]	2%	1%	1%	30%[9]	100%

[1] When not mentioned otherwise, the fuel SEC values were taken from HRE4 (2017).

[2] The unit is in GJ/tonne coke.

[3] The unit is in GJ/tonne steel.

[4] The fuel use in blast stoves accounts for 10-12% of overall fuel use in blast furnaces (Energetics, 2004). In HRE4 (2017) the fuel use in blast furnaces was estimated at about 12 GJ/tonne steel.

[5] The sensible heat from COG is commonly wasted due to how dirty it is (European IPPC Bureau, 2013a), we hereby assume that 100% of the production capacity does not recover it.

[6] The blast stove exhaust is relatively clean and can be used in recovery technologies without great difficulties (BCS, 2008). We hereby assume that 50% of the production capacity already recovers it.

[7] We assume a diffusion rate of 70% as according to the European IPPC Bureau (2013a) many plants use waste heat recovery while only few flare the off-gases.

[8] For an energy use of 1.8 GJ/tonne in EAFs the energy use when scrap preheating is used is about 5-25% lower (BCS, 2008; European IPPC Bureau, 2013a). We use an average of 15%.

[9] In HRE4 (2017), the maximum diffusion rate of this technology for 2050 was assumed to be 55%. We here assume a current diffusion rate of 30%.

[10] We have rounded the values when switching from °F to °C.

Source: sEEnergies, 2020.

Other industry sectors analysed in this way are glass, aluminium, pulp and paper, chemicals and refineries. The bottom-up approach underestimates the available potential because it focuses on the largest point sources, major processes and flue gases. It should also be considered that some of the waste heat might be used internally instead.

Another task of the sEEnergies project creates a dataset of industrial sites. For the estimation of georeferenced waste heat potentials from industrial processes, the following data for each industrial site are required:

- coordinates or at least the address of the site,[12]
- industrial subsector together with production processes, or in some cases sufficient information on the manufactured goods, and
- annual production data or at least production capacity.

Other datasets of georeferenced waste heat potentials calculate waste heat potential only based on the emissions intensity of the sites, using pollution registries like the EU-ETS and the European Pollutant Release and Transfer Register (E-PRTR, prtr.eea.europa.eu). The sEEnergies methodology allows a more precise calculation and has three major advantages:

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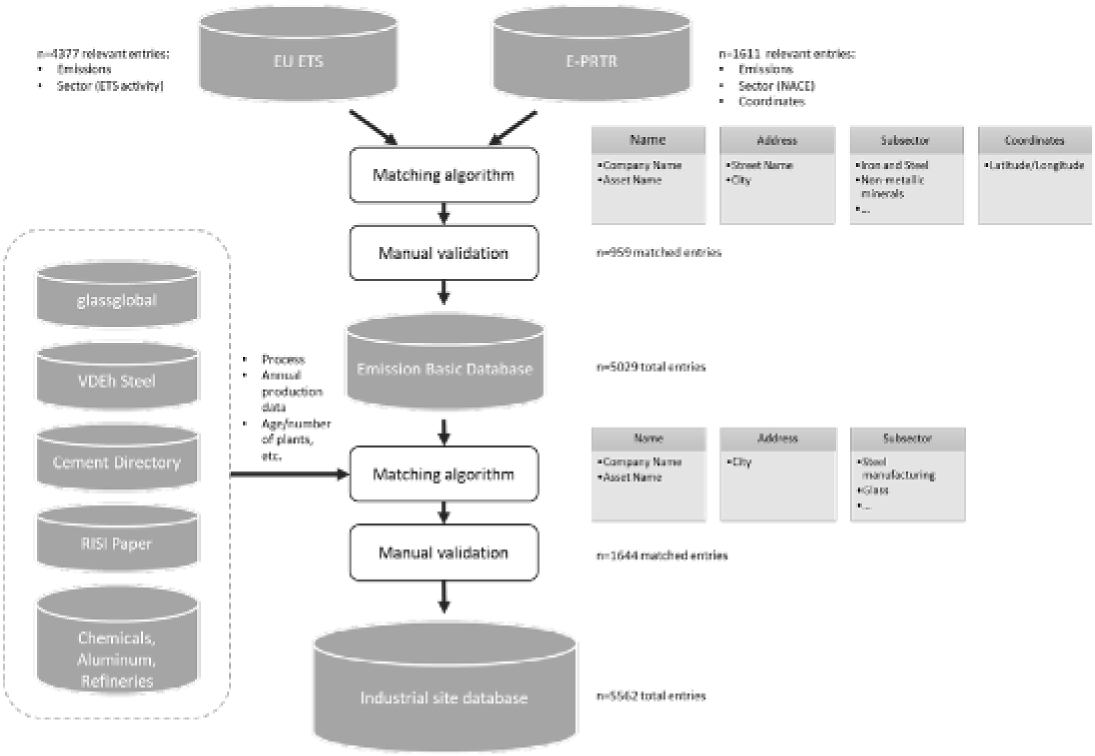
[12] The GIS map can be accessed at: https://euf.maps.arcgis.com/apps/webappviewer/index.html?id=43888b15ffd7409d8e544ad83b3a59a6.

- Adds data on the physical production of each site in tonnes of e.g. steel (whereas other studies use CO_2 emissions). Production allows a much more precise estimation of energy needs and waste heat availability than CO_2 emissions.
- Adds information on the specific product or process (whereas other studies only identify the sector). Specific information on the process or product allows detailed estimation of exhaust gas temperature and thus resulting waste heat potential.
- Adds additional sites that are not included in the E-PRTR or the EU-ETS, in particular smaller sites e.g. in the pulp and paper industry.

Figure 18. Data flow for establishing the georeferenced industrial site database



Source: sEEnergies, 2020.

In concluding, the project report underlines that there is still some waste heat potential that remains outside the scope. In particular this includes:

- smaller industrial facilities;
- activities with comparably lower energy demand (e.g. furnaces in downstream steel or other metals processing, and products from the ceramics, bricks, chemical products and food sectors);
- non-industrial activities with low temperature heat demand like wastewater treatment plants, metro stations or data centres;
- waste heat sources beyond the losses from exhaust gases, such as solid and liquid streams, cooling water, and radiation and conduction heat losses.

10.18.2 Results

The results show a potential of 425 PJ of industrial waste heat available at 95°C, with 960 PJ available at 25°C. This is about 4% and 9% respectively of industrial final energy consumption in 2015.

Matching this potential with a GIS analysis of heat demand densities and district heating systems reveals that 151 PJ of waste heat could be used within a 10 km range at 95°C, which is compatible with most district heating systems. As district heat today has final energy consumption of 1 945 PJ, this means that about 8% of district heating in EU-28 could be supplied by waste heat from energy-intensive industries.

If district heating networks were expanded, they could use almost all the available waste heat from the industrial sites analysed. 98% of these are within 10 km, allowing the exploitation of 415 PJ of heat at 95°C.

In future, 4th generation district heating could more than double that exploitable waste heat potential, to 940 PJ (25°C). This low-temperature heat could either be used in cold district heating systems with decentralised heat pumps, or in large centralised heat pumps to supply district heating systems at higher temperatures. However, the analysis also shows that industrial waste heat alone will not be sufficient, and the biggest heat source for district heating will need to be renewable energy (except possibly in highly industrialised areas).

10.19 Cornelis (2020)

This study looks at five energy-intensive sectors in the EU and makes recommendations, including the creation of a market for waste heat from industry. Waste heat potential is estimated at: 2.5-12% for iron and steel; 1.7-21% for non-metallic minerals; 16-24.3% for (petro)chemicals and pharma; 11.2-15% for non-ferrous metals; and 8.6-51% for food and beverages.

10.20 Hotmaps

The Hotmaps project funded under Horizon 2020 has developed a heating and cooling mapping and planning toolbox (www.hotmaps.eu). The toolbox is open source and provides default data for EU-28 at national and local levels. It includes integration of industrial waste heat.

The industrial site database contains more than 5 000 georeferenced industrial sites of energy-intensive industry sectors published, together with GHG-emissions, production capacity, fuel demand and waste heat potentials in three temperature ranges (Hotmaps, 2020).

10.21 The Energy & Industry Geography Lab (2021)

The High-Level Group on Energy-Intensive Industries (EIIs) developed an Industrial Transformation Masterplan for the implementation of EIIs' transition towards a climate-neutral and circular EU economy by 2050. One of the key priorities of the Masterplan is the "Mapping of energy and non-energy infrastructure and supply, underpinned by technologies for industrial transformation in support of climate-neutral industry". The Energy & Industry Geography Lab (EIGL) is being developed by JRC in response, in co-operation with DG GROW of the European Commission.

The EIGL will consist of a data inventory and an online WebGIS platform to display data, charts and maps in an interactive, easy-to-use interface. The database should include settlements, power plants, electricity substations, coal mines, EII facilities, transport infrastructure, resources and data centres inter alia. It is being launched in 2021.

11 Annex E: Other possible accounting applications

11.1 Green Public Procurement of data centres

There are so many existing and planned data centres that public acceptance is becoming an issue, which may encourage authorities to set (and operators to accept) conditions regarding energy use. In Dublin and Barcelona for example, local authorities have begun to set waste heat recovery (or at least readiness for such recovery) as a condition for granting planning consent for data centre construction or expansion (Codema, 2019). In the Netherlands, district heating companies have to get a quality certificate, checked by an independent bureau, they have to report on their sustainability, and the city carries out checks as part of the construction permit (Bosselaar and de Regt, 2020).

Policy at EU level could help make sure this happens more often. Indeed, the new digital strategy for the EU proposed by the European Commission in 2020 says that "Data centres and telecommunications will need to become more energy efficient, reuse waste energy, and use more renewable energy sources. They can and should become climate neutral by 2030" (European Commission, 2020b).

A recent European Commission Working Paper on GPP for data centres includes a preference for "products/services that ensure waste heat reuse, e.g. in building or district heating networks", and the concepts of "waste heat reuse" and "waste heat reuse readiness" (European Commission, 2020c). For example, for construction of a new data centre, expansion of existing building with new data centre and server room infrastructure, or consolidation of existing server rooms or data centres into new or existing data centres:

- **Waste heat reuse**
    - The criterion should be adapted to the local availability of district heating systems and networks, which may include heat reuse on the same site. It is recommended that a comprehensive technical specification be set if there is ready access.
    - The data centre must be connected to and supply [percentage to be specified by the contracting authority]% of the data centre's waste heat expressed as the energy reuse factor (ERF) to local heat consumers.
    - The ERF must be calculated for each facility according to EN 50600-4-6:2020 or an equivalent standard.
- *Verification:*
    - The tenderer must provide calculations and design engineering drawings for the heat reuse systems and connection. Evidence of contractual arrangements or letters of intent must be obtained from the network operator.
    - The contracting authority reserves the right to request a report of a suitable third-party audit of the data centre to verify implementation of this criterion.
    - A third-party verification of the ERF can be accepted as evidence.
    - Third-party verified energy management systems (based on ISO 50001) or environmental management systems (based on EMAS or ISO 14001) reporting the calculated ERF can also be accepted.
- **Waste heat reuse readiness**
    - It is recommended that this technical specification only be set if there is ready demand on or near site for the heat or if the public authority has identified a clear planned or potential opportunity on or near the site.

    - The data centre or server room must provide for routings for future heat transfer pipework or other layout features to fit, or facilitate retrofitting of, a facility water system reaching each row of server rack so that liquid cooling of these could easily be retrofitted at a later stage.

- *Verification:*
    - The tenderer must provide design engineering drawings showing that a facility water system with branches to each row of server row will be fitted or that the layout is so designed that it could be easily retrofitted.
    - The contracting authority reserves the right to request a report of a suitable third-party audit of the data centre to verify implementation of this criterion.

11.2 Guarantees of Origin

Guarantees of Origin are a credit-based chain of custody system that is already widely used in the EU to guarantee the source of electricity is renewable. Article 14 of the EED requires Member States to set up a system that can ensure Guarantees of Origin of electricity produced from high-efficiency cogeneration. The recast RED extended the scope of Guarantees of Origin to hydrogen and mandated CEN/CENELEC to review the relevant European standard (Ecos, 2020).

Article 19 of the recast RED does not refer specifically to waste heat but the approach is starting to be applied to heat and with appropriate certification could even distinguish waste heat based on renewable input from that based on fossil input. This is the case since 2013 in the Netherlands, with waste heat being supplied by Vattenfall with certificates provided by CertiQ for example (Think Geoenergy, 2020).

11.3 Carbon credits

Under the Clean Development Mechanism of the United Nations Framework Convention on Climate Change, many projects were developed to implement waste heat recovery, in particular in China. These projects were mostly if not all for internal heat recovery, and there is a methodology for establishing that waste heat recovery would not otherwise have been implemented (Oeko-Institut et al., 2016).

In Europe, the issuing of EU-ETS credits for heat supplied by eligible installations has been suggested to improve the economic viability of waste heat supply by the industry sector (Cornelis, 2020).

11.4 Energy Portfolio Standards

The most commonly implemented portfolio standards are renewable portfolio standards (RPS), although there is increasing discussion about Energy Efficiency Resource Standards. An RPS requires electricity providers to supply a specified minimum share from eligible renewable energy sources.

In the United States, Colorado, Nevada and North Dakota include recycled energy or energy recovery processes as eligible technologies within their RPS. Cogeneration is included under each of these definitions, but the most common type of cogeneration, which recovers otherwise lost energy from a process whose primary purpose is electricity generation, is excluded in each case (US EPA, 2009).

12 Annex F: Draft guidance and recommendations on waste heat under the Renewable Energy Directive

Recast RED Article 2(9) defines waste heat and cold as "unavoidable heat or cold generated as by-product in industrial or power generation installations, or in the tertiary sector, which would be dissipated unused in air or water without access to a district heating or cooling system, where a cogeneration process has been used or will be used or where cogeneration is not feasible". Note that this definition does not depend on the fuel mix of the source, whether biomass, renewable electricity or fossil fuels.

Only unavoidable losses are counted as waste heat. An unavoidable waste stream cannot be reduced through energy efficiency measures or recovered and used inside the same facility. It can only be used by sending it off site or expanding the facility to include new processes. Before considering off-site use, the technical and economic feasibility of applying energy efficiency options and on-site use has to be analysed, and all "reasonable" efficiency measures must be implemented first. In the longer term therefore, advances in Best Available Technology (affecting the definition of what is "reasonably" unavoidable) will affect the availability of waste heat for sale.

Waste heat and cold must be a by-product, i.e. not the intended purpose of the system but an inevitable result:

a) Importantly, the originally designed heat production from a heat or cogeneration plant cannot be considered waste heat, though unavoidable waste heat from such a plant can. Also, only the heat from the condenser can be counted as waste heat; the heat stream before the condenser does not qualify as waste heat. Note that this guidance applies even where cogeneration has been installed in order to use waste heat from another process.

b) Waste heat from a metro system can be considered a by-product of transport activity; waste heat from a mining operation can be considered a by-product of mining activity. However, waste heat from the mine water left over in a disused mine would not be considered waste heat (because the activity in question has ceased) but could be considered a kind of ambient heat instead. Geothermal energy that takes advantage of such infrastructure should also be accounted for separately.

c) Heat from wastewater can be accounted for as waste heat as long as it is a by-product of the treatment activity. However, heat from sewage is considered ambient heat and therefore renewable but not waste heat. It would not be feasible to account separately for the share of sewage heat that is a by-product of industry.

Without a district heating or cooling network, waste heat would be dissipated. While end uses (or sinks) are not specified, the definition implies that only DHC networks of one kind or another are recognised under the recast RED. According to Article 2(19) of the recast RED, "district heating" or "district cooling" means the distribution of thermal energy in the form of steam, hot water or chilled liquids, from central or decentralised sources of production through a network to multiple buildings or sites, for the use of space or process heating or cooling.

a) The consumption must be off site, i.e. by a different economic entity. For example, using heat from a production facility for an office building belonging to the same company would be internal recovery rather than waste heat.

b) Waste heat must be sold. There are situations where waste heat is provided free of charge, for example during summer months. Waste heat, or any other form of energy, provided free of charge is not accounted for in energy statistics however.

c) Waste heat must go to a heat network of some kind, i.e. more than one customer and more than one building or site. Supply of heat to one building only is excluded from DHC and therefore from the definition of waste heat under the recast RED. Situations where only one customer is connected should not be reported either. In other words, "closed" industrial networks are excluded.

Row 9 of the Eurostat DHC questionnaire covers heat recovery units recovering heat from chemical and other processes (e.g. other industrial processes, manufacturing, data centres, metro systems, or any other process). Only units that recover heat in order to use it for district heating, and if this surplus heat would otherwise have been dissipated unused into the air or water, are to be reported there. Heat produced by cogeneration plants is not to be reported.

Waste heat that cannot be avoided or used on site, which is then ~~sold~~ sent for use off site, **can be counted towards the targets for renewable heating and cooling** (Article 23) **and renewable DHC** (Article 24):

a) Under **Article 23**(1), Member States have to endeavour to increase the share of renewables in heating and cooling by an indicative 1.3 percentage points as an annual average for the periods 2021 to 2025 and 2026 to 2030 compared to 2020, in terms of final energy consumption. Achievements prior to 2020 cannot be counted.

b) Under Article 23(2), waste heat and cold can supply a maximum of 40% of the average annual increase. Use of waste heat and cold to meet the heating and cooling target is optional for Member States that do not have significant DHC, because waste heat and cold are only eligible if used in DHC. Even Member States where such infrastructure has been developed can opt out from using waste heat and cold to meet the heating and cooling and DHC targets.

c) If the share of renewables in heating and cooling is greater than 60% in 2020, the average annual increase is deemed to be fulfilled automatically. This rewards early effort and reflects the wide range of maturity of renewable heating across Member States.

d) The Directive also rewards renewable shares of heating and cooling that are less than 60% but still high. If the share of renewables in heating and cooling is less than 60% but greater than 50%, half of the annual increase is fulfilled. In other words, the required increase is only 0.65 percentage points if such a Member State chooses to use waste heat and cold to achieve it.

e) The flexibility to use waste heat and cold is intended to improve the overall efficiency of the energy system and to encourage the development of efficient DHC, which is also a major enabler of the use of decentralised renewables. The reduced- or zero-increase requirements are intended to reward early efforts and to recognise that at high shares of renewable heat, further increases become progressively more difficult.

f) Under **Article 24**(4), Member States have to endeavour to increase the share of energy from renewables and waste heat and cold in DHC by at least one percentage point as an annual average for the periods 2021 to 2025 and 2026 to 2030, compared to 2020 and expressed in terms of final energy consumption. Member States can choose instead to implement third-party access to DHC networks for suppliers of renewable and waste heat and cold, as well as from high-efficiency cogeneration; such access is currently blocked in many cases.

g) Article 24(10) contains exemptions for Member States where the national share of DHC is less than 2%, where the share of DHC increases to above 2% by developing new efficient DHC (as set out in National Energy and Climate Plans), and where efficient DHC or small systems make up 90% of the DHC market. Efficient DHC includes networks based on high-efficiency cogeneration and those for which a plan exists to become efficient by 31 December 2025. Small DHC systems are less than 20 MW.

The eligibility of waste heat and cold does not depend on the fuel mix of the source. Any waste heat can be used to meet the heating and cooling sector target or the DHC sub-sector target, whether it comes from biomass, renewable electricity or fossil fuels.

Waste heat and cold do not count towards the overall EU renewable energy target of 32% under Article 3(1) of the recast RED. The eligibility of a waste heat and cold stream for the targets under Articles 23 and 24 does not render it renewable in a broader sense. This is analogous to the sectoral transport target, which can be met using non-renewable (e.g. waste-based) fuels that do not count towards the overall EU renewables target either.

In summary, heat or cold used externally that could not be used internally is considered equivalent to renewable energy under Articles 23 and 24 of the recast RED but does not count towards the overall EU renewables target or national renewable energy contributions. It also does not count as renewable energy in the context of renewable energy levels in buildings (Article 15(4)), even though it can be delivered through DHC networks along with renewables.

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List of abbreviations and definitions

BREF	Best Available Techniques Reference Document
CBA	Cost-Benefit Analysis
CO_2	carbon dioxide
COP	Coefficient of performance
DHC	district heating and cooling, district heating or cooling
eceee	European Council for an Energy Efficient Economy
EED	Energy Efficiency Directive
EH&P	Euroheat & Power
EHPA	European Heat Pump Association
EPA	Environmental Protection Agency
ERF	Energy reuse factor
EUR	euros
GIS	Geographical Information Systems
JRC	Joint Research Centre of the European Commission
LNG	Liquefied Natural Gas
Mcal	Megacalories
MW	megawatt
MWh	megawatt-hour
RED	Renewable Energy Directive
toe	tonnes of oil-equivalent
US DOE	United States Department of Energy
US EPA	United States Environmental Protection Agency
WtE	Waste-to-Energy

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KJ-NA-30869-EN-N

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of the European Union

doi:10.2760/73253
ISBN 978-92-76-42588-5