HEATLEAP
Valorising waste heat for enhanced energy efficiency

Waste Heat Recovery

Potentials, applications and recommendations for better policies

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Contents

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For more information about HEATLEAP see: https://heatleap-project.eu

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For more information see: https://cinea.ec.europa.eu/programmes/life_en

Introduction

Energy supply, energy affordability and mitigating environmental impact are at the centre of EU policy, investments and increasingly consumer concerns. Despite efforts to prioritise energy efficiency, significant potential remains unexplored when it comes to reducing energy waste across the entire energy value chain and making the best use out of the energy that we have available. Waste heat recovery and utilisation is a largely untapped energy efficiency resource, which presents important opportunities across many sectors and applications. To unlock this potential, policy must recognise its potential and promote all applications for waste heat recovery and utilisation for heat and/or power production, in both industry and district heating.

Most energy losses in energy conversion, industrial processes and energy consumption take the form of heat waste. There is a range of waste heat recovery methods and applications, depending on heat quality, proximity to a potential customer, specific customer needs, availability of the resource short, medium and long-term, as well as potential contractual constrains and requirements involved. Based on technical, commercial and local circumstances, waste heat may be used on-site or in district heating, in the form of heat and/or power.

Valorisation of waste heat and cascading its use can help decarbonise hard-to-abate industries and cities, thus delivering system integration locally and industrial symbiosis. Excess heat can become of the main sources for clean heat and power generation, thus playing a key role in the global decarbonisation path.

As demonstrated through the EU-funded HEATLEAP project[1], the benefits of waste heat recovery systems include:

- **Environmental benefits**: Waste heat recovery reduces greenhouse gases (GHG) and harmful emissions such as SOx and NOx, with benefits for the climate and air quality.
- **Socio-economic benefits**: Waste heat recovery helps boost the competitiveness of European industry and supports the decarbonisation of heat and power for local communities, businesses and public authorities.
- **Energy security**: Waste heat recovery reduces the dependence on fossil fuels, providing a reliable source of heat and/or power for surrounding consumers.
- **Reduction of energy cost**: Waste heat recovery secures a fixed price of energy for more than 20 years and the impact of energy cost increase is reduced.
- **European policy benefits**: Waste heat recovery is a crucial solution for Europe to achieve its climate and energy goals.

Given the amount of heat that is currently being wasted in Europe and worldwide, it is vital that national and EU policies prioritise the avoidance of heat waste and promote the cost-effective recovery of waste heat across all relevant applications.

[1] https://heatleap-project.eu/

The EU's Potential for Waste Heat Recovery

Europe has significant potential for excess heat recovery from power production, industry and commercial premises. The Heat Roadmap Europe project has estimated that **excess heat in the EU amounts to 245 Mtoe/year**, corresponding almost to the EU's total energy demand for heat and hot water in residential and service sector buildings[2].

Industrial processes

Industrial plants of energy intensive industries such as cement, glass, petrochemical, non-ferrous metals and steelmaking, dissipate between 30% and 60% of the overall energy consumed as heat dissipated into the atmosphere. Furthermore, most of the time, these flue gases must be cooled before being filtered and vented either with heat exchangers or by adding external air, which involve additional energy and/or water consumption.

Recovering this heat for either on-site use or for DHC supply could help improve energy efficiency of the site, reduce the carbon intensity per unit produced, reduce energy costs and/or generate new revenue streams.

Further studies have assessed the **technical potential for waste heat recovery from Europe's key industries by temperature level, estimated at around 300 TWh/year** (equivalent to 26 Mtoe)[3].

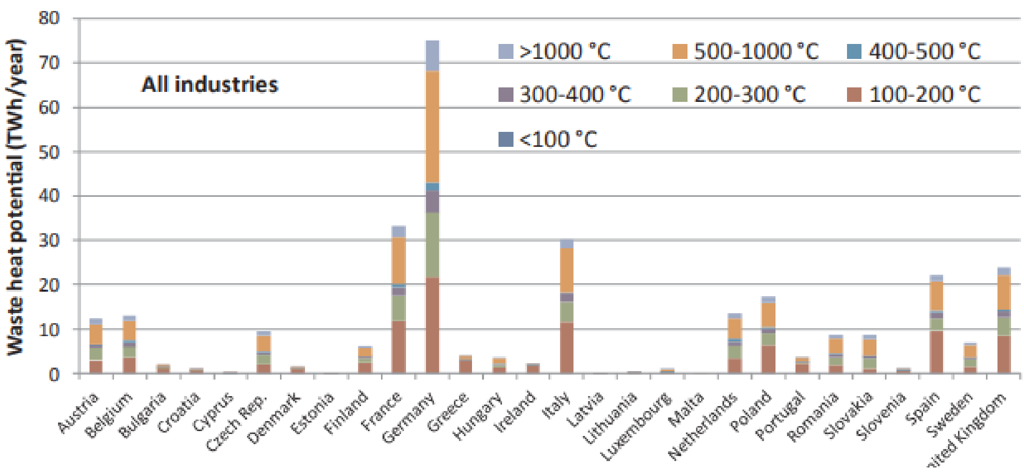

Figure 1: Waste heat potential in each EU country by temperature level and country (Source: Papapetrou et al, 2018)

Based on the identified potential for recoverable waste heat and the corresponding temperature levels, a recent analysis concluded that **at least 150 TWh per year of electricity could be generated by harvesting currently untapped thermal energy**, equivalent to the power consumed by 20 million citizens, the annual production of 19 nuclear power plants or the annual consumption of the Netherlands and Denmark combined[4].

[2] Connolly, D., et al. (2013). Heat Roadmap Europe 2: Second Pre-Study for the EU27. Department of Development and Planning, Aalborg University, p. 54

[3] Papapetrou, et al. (2018). Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country. Applied Thermal Engineering. 138. 10.1016/j.applthermaleng.2018.04.043.

[4] Thermal Energy Harvesting Advocacy Group (TEHAG), 2022. Thermal Energy Harvesting - the Path to Tapping into a Large CO2-free European Power Source

Commercial premises, including data centres

To function properly, computers and servers require a high-quality environment equipped with systems that ventilate, dehumidify and cool. These systems add up to the high energy consumption of data centres, with estimations that data centres make up just over 1% of the world's total electricity use. The heat that gets generated by electricity input into IT-equipment is usually cooled off with the use of high energy[5]. Instead, it can be utilised in other parts of the building, or in a district hearing or cooling network nearby. In this case, the waste heat gets converted into a useful form, depending on its temperature.

Gas distribution system

Europe has an extensive gas distribution system, contributing to EU's energy mix by more than 25%. The pressure-reducing stations (PRS), used to reduce gas pressure from transmission pipelines to local networks, are the source of significant energy waste that is dissipated via expansion valves. This otherwise wasted mechanical energy can be recovered into electrical energy by means of gas expanders (e.g. GEX technology)[6].

The theoretical potential for **GEX deployment in the EU can be as high as 3.660 GWh of electricity production per year and potential investments volume of approximately 3.8 B€**[7]. Despite this large potential for GEX uptake, only few plants are currently in operation[8].

Power generation

At EU level, the waste heat due to energy conversion losses from power-only plants (198 Mtoe/year) exceeds the total heating and cooling demand of European buildings[9].

In Europe, the best-in-class conventional power plants have operational efficiencies in a range between 19.5% and 53%[10]. Meanwhile, more than 50% of the fuel used in power-only plants is wasted in conversion, transmission and distribution, mainly as heat discharged into the atmosphere.

By comparison, high efficiency cogeneration reaches total efficiencies between 75% and 95%, with losses being reduced to 5–25% of the energy input used[11] . Yet, the avoidance of waste heat in power generation via cogeneration, as elaborated on further below, remains largely untapped.

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[5] CELSIUS. Waste heat from data centres. P.1

[6] Davide Borelli1 , Francesco Devia1 , Ermanno Lo Cascio1 , Corrado Schenone∗,1, 2018. Energy recovery from natural gas pressure reduction stations: Integration with low temperature heat sources

[7] Estimate based on current gas consumption by country, considering Italy, Spain, France, Germany, the Netherlands, Belgium, Poland and Austria.

[8] HEATLEAP Project, 2020. GAS ESPANDER TECHNOLOGY (GEX)

[9] According to the latest Energy balance flow for the European Union Member States (2019) published by Eurostat.

[10] According to the Harmonised efficiency reference values for separate production of electricity stipulated in Annex I of the Commission Delegated Regulation (EU) 2015/2402. The values are based on net calorific value and standard atmospheric ISO conditions.

[11] EPA, CHP. Waste heat to power systems. P.1

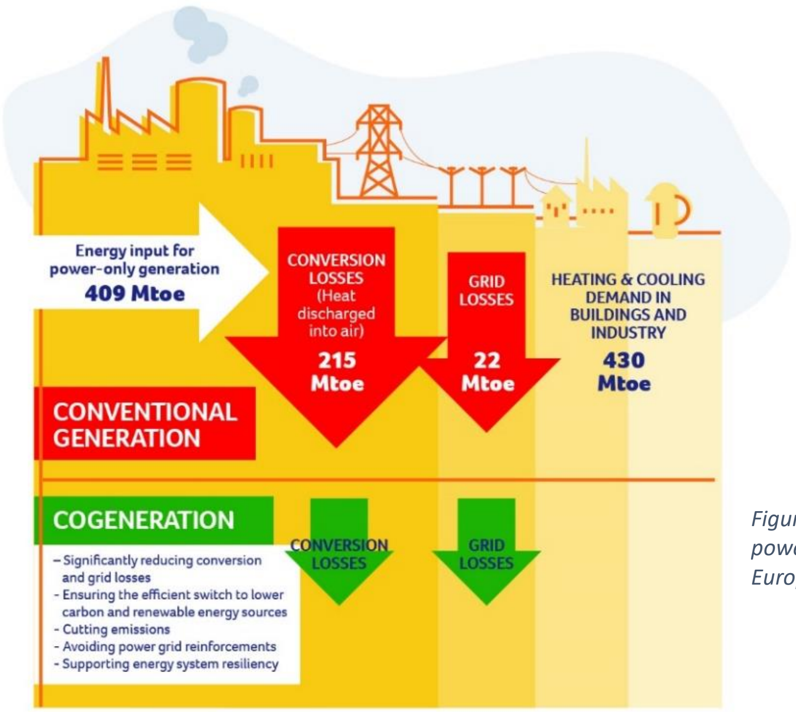


Figure 2: Aggregated heat losses from power-only plants in EU (Source: COGEN Europe based on Eurostat, 2021)

Waste Heat Recovery Applications and Case Studies

Depending on a range of factors, waste heat recovery can be implemented in different sectors and across a diverse array of applications and technologies[12]**.** Recovered waste heat can be used to cover demand for heat, power or both heat and power, either consumed on-site or distributed via energy grids – local district heating and electricity networks.

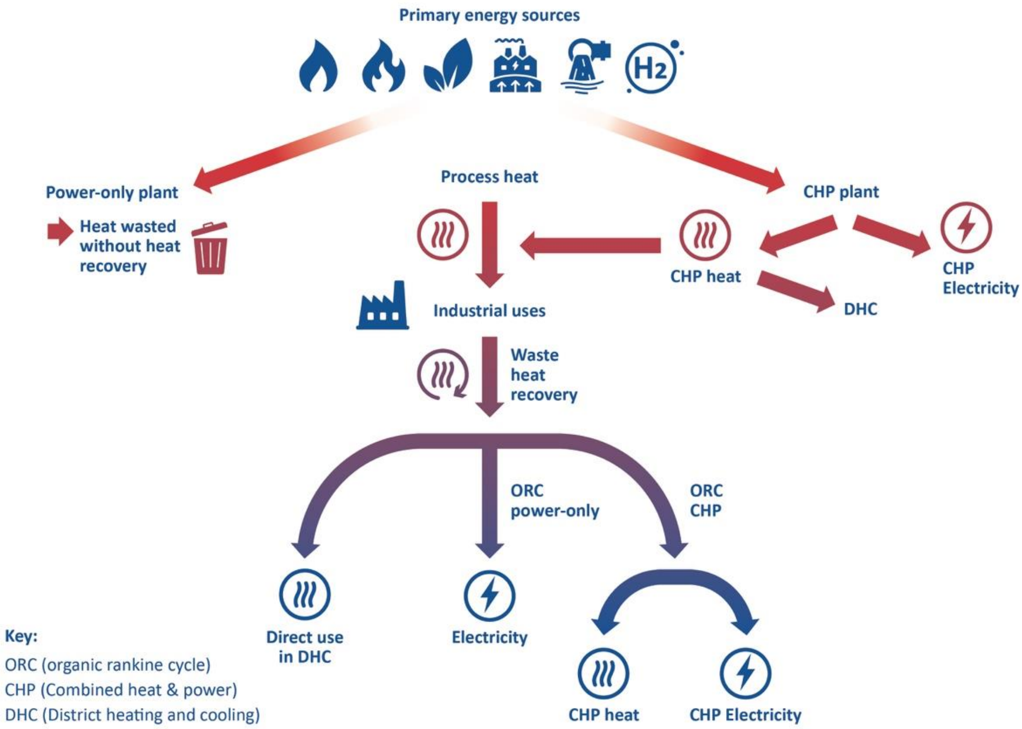


Figure 3: Overview of key waste heat sources and applications

Case 1. Thermal use of waste heat in district heating

DHC represents over 10.000 heat networks in Europe, covering 13% of the heat market and supplying more than 60 million citizens. From 13% today, DHC could supply from 30% to 50% of EU heat demand by 2050.

In urban areas, the smart integration of waste heat sources available in cities into district heating networks offers a remarkable opportunity to achieve more efficient energy use, reducing or completely displacing fossil fuel use.

Figure 4: Direct use of industrial waste heat in DHC

[12] E. Garofalo et al.: Waste Heat to Power: Technologies, Current Applications, and Future Potential. P.1

Case 2. Waste heat recovery for electricity (and heat) generation

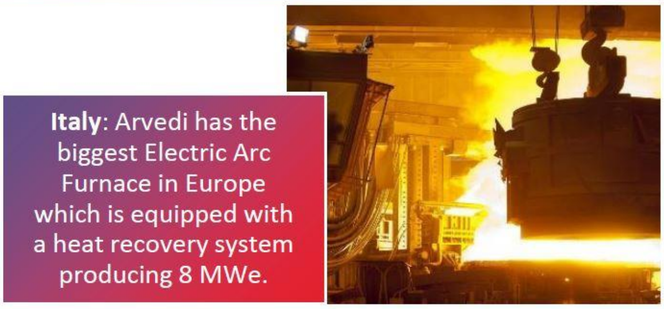
In addition to direct use of waste heat in DHC, there are cases when waste heat recovery is better suited for power and/or heat production. Waste heat valorisation in industrial processes can be achieved through Organic Rankine Cycle (ORC) technology in several configurations[13]:

- ***Waste heat recovery by ORC (power-only configuration)***: Waste heat from industrial process can be valorised to generate power. The electricity produced can be used on-site or it can be sold to the grid.
- ***Waste heat recovery by ORC-CHP (cogeneration configuration)***: Waste heat from industrial process can also be designed to work in cogeneration mode (ORC-CHP) to maximise energy efficiency and match seasonality of heat and power demand. Outputs for this configuration are electricity and heat, which can be used either on-site or delivered to nearby consumers via district heating.

Producing electricity from waste heat could be an important source of carbon-free dispatchable power, which will have increasing value in power system resiliency and security of supply.

Case 2.1 Power-only configuration utilising industrial waste heat

Figure 5: Application for waste heat for electricity generation



[13] Turboden. Comments to JRC Technical Report "Defining and accounting for waste heat and cold"

Case 2.2.1 Power-only Configuration via Gas Expander technology

In view of the important role of the gas distribution network and its high potential in terms of efficiency improvement, Gas Expander (GEX) technology was recently developed in Europe[14]. GEX uses the energy that would otherwise be lost through throttling valves: the natural gas pressure drop becomes the "driving force" to produce electrical power. GEX is capable to produce electric power in order of 150 kWe-2MWe with an efficiency above 65%.

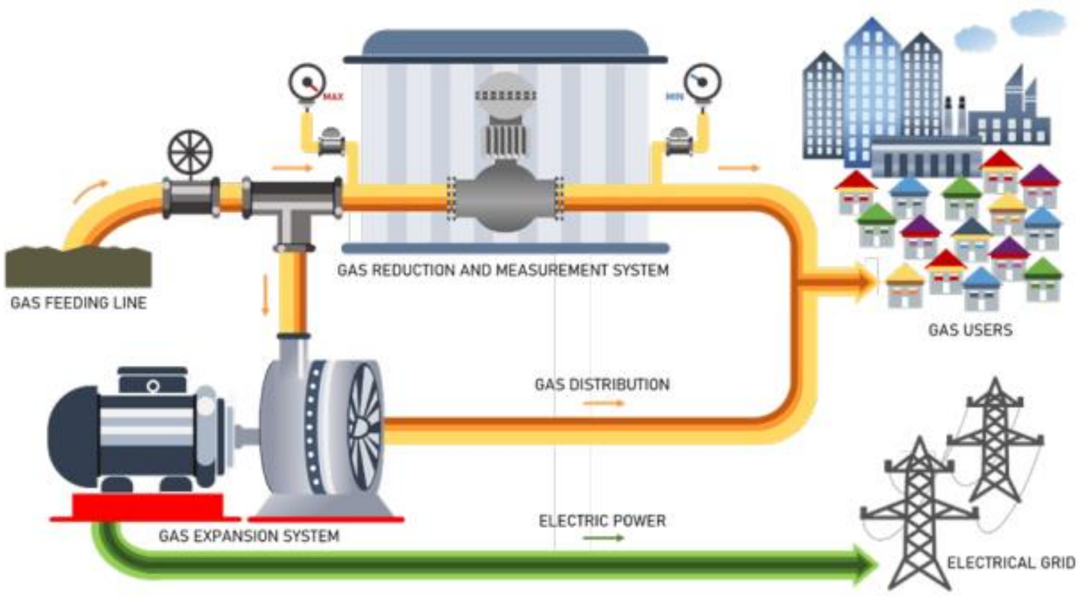


Figure 6: How Gas Expander Technology Works

In case the electricity produced by the GEX cannot be used effectively either as captive consumption of the PRS or dispatched to the grid; it could be used to produce green hydrogen via electrolysers as well as through ORC technology.

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[14] https://www.turboden.com/

Case 2.2.2 Power-only Configuration via Gas Compressor Station

Across Europe's extensive gas transmission and distribution network, gas compressor stations are required every 100-200 km to maintain adequate gas pressure via gas turbines. Around Europe, more than 7,500 MW gas turbines installed in gas compressor stations generate a relevant amount of waste heat. Since these stations are not usually placed near busy urban areas, the best valorisation of the waste heat is to convert it into electricity via ORC technology for grid feed-in. Estimates show that potential 1.3 GWe can be installed in Europe gas plants, with electricity generation of up to 10.43 TWh per year, consequently avoiding 3.7 million tons of GHG, according to the "Thermal Energy Harvesting – version 1.0" paper[15].

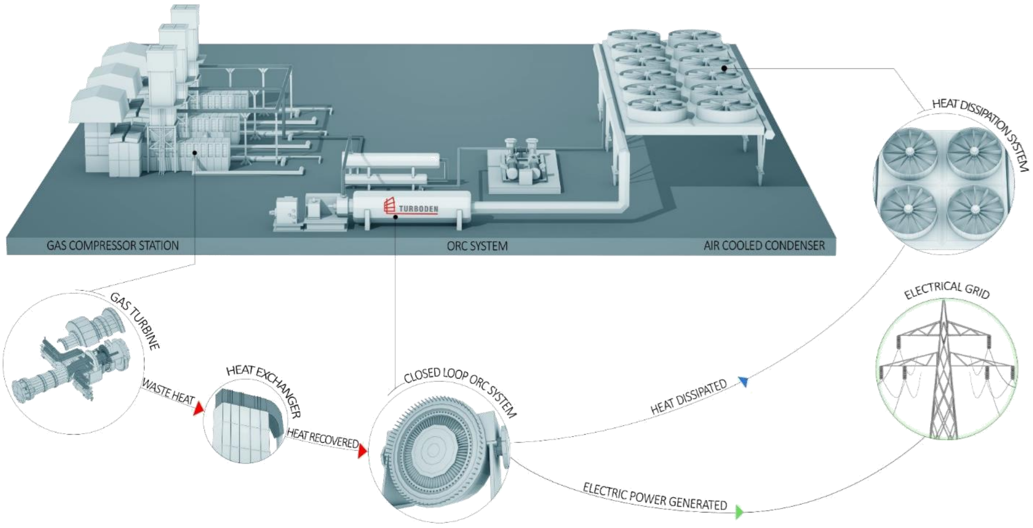
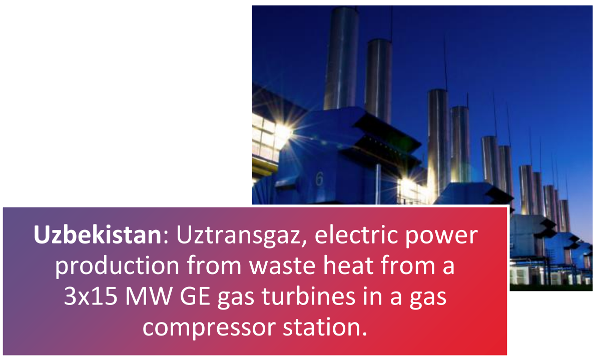
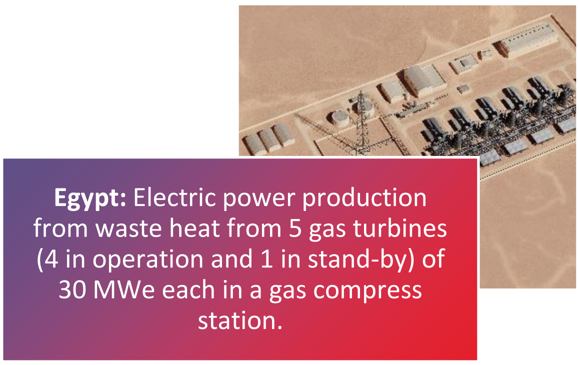


Figure 7: How ORC Works in a Gas Compressor Station





[15] https://kcorc.org/media/medialibrary/2022/05/Thermal_Energy_Harvesting_-_the_Path_to_Tapping_into_a_Large_CO2-free_European_Power_Source.pdf

Case 2.3 Combined Heat & Power Configurations (CHP)

Cogeneration (combined heat and power or CHP) is a key energy efficiency technology, which is linked to the concept of waste heat recovery and utilisation in different ways. CHP is generally defined as the simultaneous generation of heat and power from a thermal energy source (e.g. gas, biomass, hydrogen, geothermal).

CHP avoids waste heat in thermal power production: CHP is generally understood as a more efficient conversion solution that produces electricity from any available fuel and captures the heat that would otherwise be wasted via power-only production. In locations where there is sufficient demand of both electricity and heat, such as large cities, implementing CHP is an optimal solution because of its superior energy efficiency and reliability. The alternative of sourcing waste heat from nearby sources and producing dispatchable electricity via power-only plants (which further generate waste heat) may lead to a less efficient and more costly outcome.

CHP can use waste heat as a source: ORC technology working in cogeneration mode can produce both electricity and capture the remaining heat, whenever there is heat demand nearby (e.g. seasonal heating demand or hot water). This further improves the efficiency benefits of implementing ORC solutions to recover waste heat.

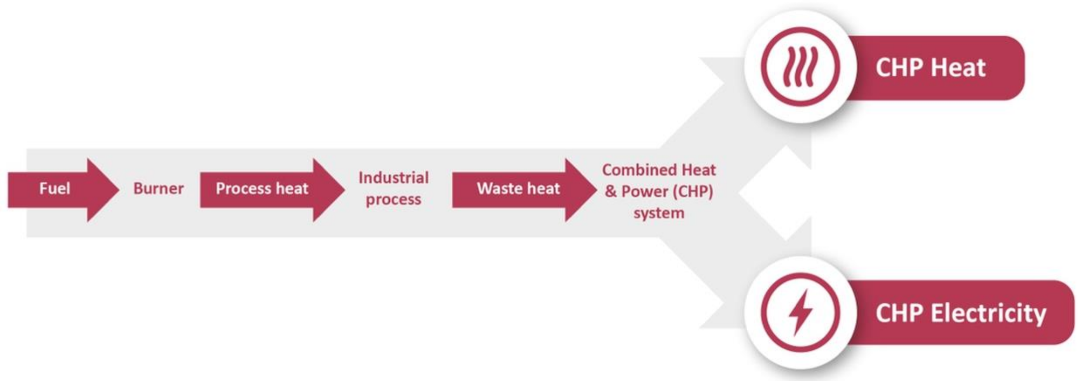


Figure 8: Use of waste heat in CHP application to efficiently produce heat and power

CHP can be a source of waste heat: An additional variation of the CHP application is represented by cases where a CHP system will generate power and process heat for an industrial site. Adding an ORC solution or simply capturing the waste heat for direct use in DHC could bring further efficiency benefits.

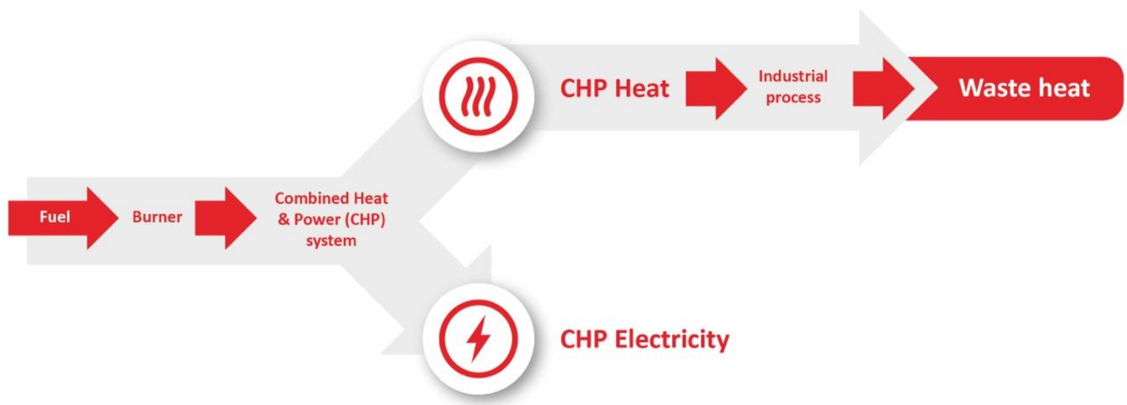


Figure 9: Application for waste heat via CHP combustion

Poland, Szlachęcin:
Veolia integrates waste heat from a waste water treatment facility, a large heat pump and a cogeneration facility to provide environmentally friendly heat and electricity to a local community. The innovative solution is a heat recovery system of waste recovery supported by a cogeneration facility.

Italy, Brescia: iRecovery project for steelmaker ORI Martin to recover the exhaust gases coming from the steel production and to exploit them for generating heat and electricity. Thanks to the cogeneration project 2,000 families receive heat for their homes during winter and 700 families power their homes with the generated electricity.

Waste Heat in EU legislation

Waste heat recovery is recognised in high level EU strategies and policies as an energy efficiency measure, a source of clean heat and a "*more circular energy system, with energy efficiency at its core*".

An EU-wide definition for waste heat was recently introduced in the Renewable Energy Directive, covering the direct use of waste heat in district heating applications.

EU "WASTE HEAT" DEFINITION

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.

RED III, Article 2 (9)

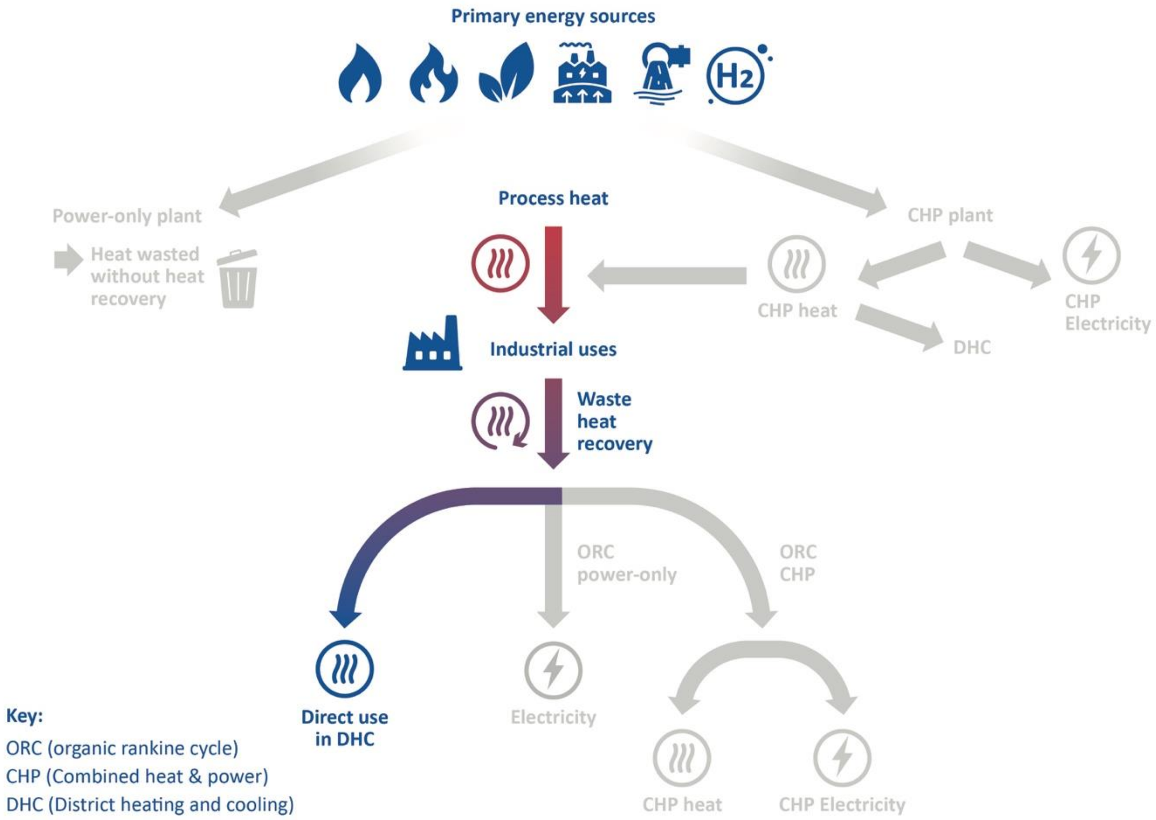


Figure 10: Waste heat recovery pathway captured in EU definition

As shown in the overview below, other EU legislation and provisions appear to prioritise the direct use of waste heat from industrial and commercial applications in district heating. This approach limits unlocking the full potential of waste heat, as long as other feasible applications do not get visibility or receive sufficient support.

Direct waste heat use in DHC

- ✓ Waste heat used directly in DHC is recognised as a clean heat source, contributing to the renewable heat obligation (RED III, Recital 27, Article 1).
- ✓ Waste heat used directly in DHC is recognised as a clean source for "efficient DHC", as an alternative to renewable heat sources, with binding requirements and milestones until 2050 (EED recast, Article 24.1).
- ✓ Waste heat used to produce heat and cool (for DHC) is recognised in EU Taxonomy as a climate mitigation measure and green investment (EU Taxonomy Delegated Act, Annex I, Section 4.25).
- ✓ The EU definition for "waste heat" refers to the portion of waste heat supplied directly to DHC (RED II, Article 2(9)).

Waste heat use in power-only applications

✓ Waste heat recovery is encouraged for facilities with substantial energy inputs (EED recast, Recital 80).

✗ The EU definition for "waste heat" refers to the portion of waste heat supplied directly to DHC, but excludes the use of waste heat for power and/or heat production (RED II, Article 2(9)).

✗ Member States are required to estimate waste heat potential as part of heating and cooling assessments and introduce measures to encourage the deployment of waste heat recovery installations, including in the industrial sector. Yet, no specific measures or recognition is provided for systems converting waste heat to power (EED recast, Article 23.4, Annex IX).

✗ Industrial installations above 8 MW are required to carry out a cost-benefits analysis (CBA) on the utilisation of waste heat on-site or off-site. Yet, no binding action to implement the results of the CBA and no link is made to energy audits for industry (EED recast, Article 24.4.b).

Waste heat in CHP applications

✓ CHP is recognised as a more efficient alternative to power-only generation due to the avoidance of waste heat (EED recast, Recitals 80, 81 & Article 24.4.a).

✗ However, no binding measures are introduced for the widespread implementation of CHP instead of less efficient power-only generation.

✗ Waste heat is recognised as a source for CHP plants (EED recast, Annex II). Yet, only waste heat supplied directly to a DHC (not via CHP) is considered as a clean heat source for "efficient DHC" beyond 2045.

✗ CHP using waste heat is not recognised as a climate neutral solution and green investment in EU Taxonomy (Taxonomy Climate Delegated Act)

Policy recommendations to unlock waste heat potentials

Despite the high-level recognition of waste heat across EU legislation, the definitions and provisions pertaining to waste heat are not sufficient to capture the full potential of waste heat recovery and does not cover the entire range of applications.

Best practices implemented by industry today showcase a range of feasible applications for waste heat recovery, which deserve better policy recognition to be scaled up. As demonstrated in this paper, waste heat can be used directly in DHC, but also for power production on-site or for grid feed-in. Moreover, not all waste heat sources have been identified and mapped for their potential valorisation (e.g. gas compression stations).

Policy principles for effective waste heat valorisation

Comprehensive definitions

- Harmonise waste heat definitions to capture all sources and uses of waste heat

>> Energy Efficiency Directive, Renewable Energy Directive

Assess full potential

- As part of integrated energy systems' planning

>> Heating & Cooling Assessments/Local Plans (EED), National Climate and Energy Plans (Energy Union & Climate Change Regulation), System Adequacy Assessments and Flexibility Assessments (Electricity Regulation/ Electricity Market Design)

Recognise all sources and applications

- Adopt policy measures giving visibility to the entire range of waste heat recovery solutions

>> Energy Efficiency Directive, Renewable Energy Directive, EU Taxonomy, Net-zero Industry Act

Promote and support

- Full range of waste heat applications

>> Energy Efficiency Directive (EED), Renewable Energy Directive (RED), EU Taxonomy , Net-zero Industry Act, State Aid

Policy recommendation 1: Harmonise waste heat definitions to cover all relevant applications

Energy Efficiency Directive/Renewable Energy Directive

➔ The waste heat definition must be encompassing enough to cover all relevant and feasible waste heat applications, namely (Energy Efficiency Directive/Renewable Energy Directive):
- Direct waste heat use in district heating
- Electricity production from waste heat
- Electricity and heat production from waste heat in cogeneration mode

Justification: *There is a valuable opportunity and urgent need to clarify and harmonise the definitions of waste heat and cold across EU legislation, especially between the Energy Efficiency Directive (EED) and the Renewable Energy Directive. A broader "waste heat" definition capturing all applications and sources expands the role that waste heat recovery can play in EU's decarbonisation pathways.*
As shown above, EU legislation provides a narrow definition limited to the waste heat which can only be used in DHC applications in RED III. Further references to "waste heat" in other legislation refer either to the broader use of waste heat (e.g. EED, Article 23, Annex IX) or exclusively to its use in DHC (e.g. EED, Article 24, EU Taxonomy). This creates uncertainty among both industry and policymakers aiming to implement the legislation. Moreover, it risks excluding large volumes of untapped waste heat potential from energy and climate plans and eventually Europe's energy mix.

Policy recommendation 2: Recognise all waste heat sources and applications in energy and climate plans and assessments

National Energy and Climate Plans

➔ Encourage Member States and relevant local authorities to include all waste heat potentials in their upcoming NECPs and heating and cooling assessments/local plans (Governance of Energy Union and Climate Action Regulation), such as: waste heat from industry, gas distribution systems, commercial premises and power sector.

Power System Adequacy and Flexibility Assessments

➔ Consider power generation from waste heat sources as a carbon-free source of flexibility, as part of system adequacy and flexibility assessments (Electricity Market Design/Reform).

Justification: *Given the limited scope of the RED III definition for waste heat recovery and the fact that only waste heat in DHC counts towards very concrete targets, there is a risk that other relevant uses or sources are overlooked in long term energy and climate plans. This will further limit the visibility of those potentials and contributions to overall energy and climate targets.*

Policy recommendation 3: Support and promote waste heat as a clean energy resource in EU legislation

Due to the incomplete "waste heat" definition in RED II, references to it in other EU legislation results in the exclusion of important waste heat applications from support schemes, funding and clean energy accounting.

EU Taxonomy

- ➔ Recognise waste heat to power and/or heat applications in EU Taxonomy as a clean energy source and green investment.

Justification: *Waste heat is reported in the EU Taxonomy as one of the carbon-free opportunity but only partially related to the production of heat/cool only. Waste heat to Power (WH2P) solutions are still missing in Taxonomy's Delegated Act. This paper therefore recommends an amendment to the Taxonomy Delegated Act to consider all applications of waste heat utilisation: Annex II, activity 4.25: "Production of heat/cool using waste heat" to "Production of heat/cool* ***and/or power*** *using waste heat".*

EU ETS

- ➔ Recognise waste heat recovery from industrial processes for power generation eligible for free allocation.

Justification*: Despite considerable advantages for climate and sustainability, waste heat and waste gases from industrial processes are not eligible for free allocation in the Emission Trading System when valorised to generate electricity*.

About the project

Low-grade heat waste (around 70 °C) is often widely present in various energy intensive industries. However, it is difficult to valorise using conventional technologies (e.g. Organic Ranking Cycles). Conversely, some innovative technologies (Waste Heat Recovery System-WHRS) are emerging and can provide further energy improvements and CO_2 savings.

The HEATLEAP project aims to demonstrate the environmental and economic benefits of waste heat recovery systems such as large heat pumps in energy intensive industries and gas expanders in gas distribution networks by testing these technologies at real scale. By recovering heat that would otherwise be wasted, we can increase energy efficiency, reduce emissions and energy costs, thereby making the industrial and utility sectors more competitive.

Partners

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