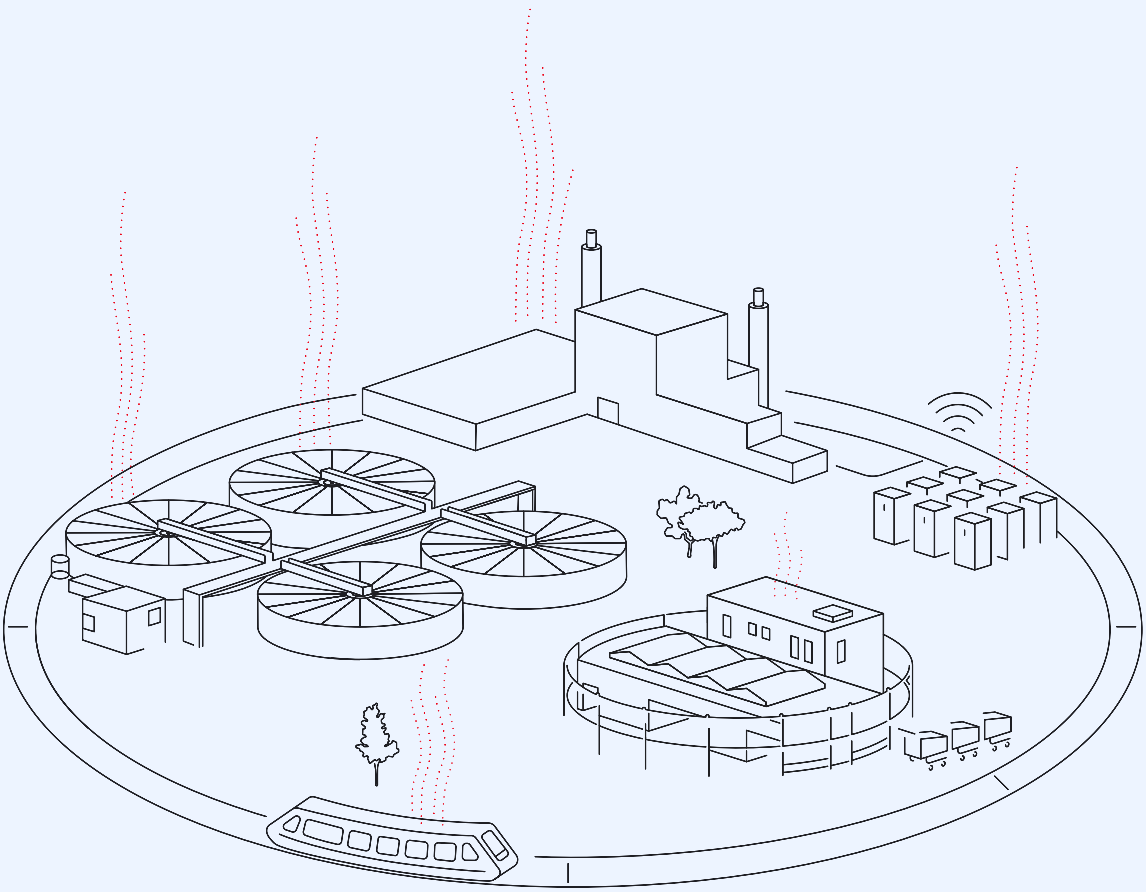
Waste heat

A competitive advantage for energy resilience, industrial growth, and decarbonization



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Brief

Drawing on empirical evidence and data from a range of credible sources, **Danfoss Impact Issue No. 9** shows how the world's supply of waste heat provides an incredible opportunity to decarbonize heating, increase industrial competitiveness, and boost energy system resilience. It highlights three pathways for waste heat recovery and reuse — on-site, microgrid, and district heating — presenting benefits, challenges, and credible, real-world cases for each.

This paper also highlights technologies with significant energy- and emissions-reductions potential that remain underutilized today, despite being widely accessible and offering favorable payback times. In this paper, the terms "microgrid" and "industrial cluster" are often used interchangeably, as waste heat recovery and reuse technologies and processes are implemented similarly across both environments.

This Impact Paper is written primarily for industry leaders, policymakers, and energy system operators shaping how waste heat is produced and reused at scale to improve efficiency, competitiveness, and decarbonization.

The views expressed in this paper are those of Danfoss. Their completeness and accuracy should not be attributed to any other entities.

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Foreword

We cannot let waste heat become a wasted opportunity

Competitiveness, energy security, affordability, and decarbonization are not competing priorities. Increasingly, they depend on the same solutions. Yet around the world, governments and businesses continue to debate difficult choices based on the complex challenges the world is facing today such as geopolitical tensions, energy crises, climate change, and economic uncertainty. Should concerns of competitiveness override progress on industrial decarbonization? Should strategic investments in energy independence come before immediate relief for household energy bills? These are real economic and political debates occurring in boardrooms and legislatures every day.

It would be a failure to not recognize our ability to address these challenges simultaneously. They are deeply interconnected, and fortunately, so are many of the solutions. Today, proven technologies exist to strengthen competitiveness, improve energy resilience, reduce emissions, and lower costs at the same time.

This paper focuses on one of the largest and most overlooked opportunities: waste heat.

We've been engineering and implementing waste heat reuse solutions for decades. Whether in industry, wastewater treatment, or supermarkets, we've helped customers reduce their energy consumption, emissions, and operating costs with one of low hanging fruits available: the energy they've already purchased and used.

However, despite the progress we've seen, it's difficult to look past one glaring truth: there's more waste heat in the world today than ever before. In fact, by 2030 up to 55% of global energy will still be wasted as heat.[1] While many industries, energy system operators, and governments have realized the incredible economic and decarbonization potential of waste heat, it remains the world's largest untapped energy source.

Why is that? On the supply side, the answer lies in the rapid emergence and success of several energy-intensive industries. For example, as the economic and societal value of AI continues to increase, so does the demand for the data centers needed to process the complex algorithms they require. The question is no longer whether we build more data centers. The question is how we build them. Almost all of the electricity consumed by a data center is converted into heat. Too often, that heat is wasted. But through waste heat recovery and integration with local energy systems, data centers can become

> "While many key players have realized the incredible economic and decarbonization potential of waste heat, it remains the world's largest untapped energy source."

valuable assets that strengthen competitiveness, energy security, and resilience.

In other industries such as metals, chemicals, and manufacturing, the picture is the same. If captured and reused, this heat can become an incredible source of security and growth. But if it continues to go to waste, it will remain a burden to our energy systems, industries, and livelihoods.

There is also a demand-side issue. In some regions, unfavorable electricity-to-gas price ratios are hampering uptake. Waste heat reuse requires electric heating technologies such as heat pumps, and without policies that make electrification more attractive, the economic and decarbonization potential of waste heat will never be fully realized.

Despite these barriers, waste heat reuse is still a remarkably intuitive solution: rather than releasing perfectly good heat into thin air, just capture it and reuse it. That's why in the political dialogue we've seen a growing recognition of waste heat as a viable source of clean energy for industries and households alike. The next step is turning that recognition into action.

The good news is that waste heat reuse always reduces operating costs. By utilizing energy which has already been paid for, waste heat producers can increase energy efficiency while ensuring a rapid payback for heating electrification and decarbonization.

This paper provides clear pathways for industrial actors across sectors to identify, recover, and reuse waste heat, using proven and credible cases to demonstrate the potential. It also acknowledges the barriers for energy system operators and governments, proposing key actions to accelerate waste heat uptake.

We cannot let the growing political recognition of waste heat be overshadowed by perceived challenges that are addressable through smart planning and existing technology. Waste heat is one of our best opportunities to address competitiveness, decarbonization, and energy resilience. We must not let it go to waste.

Kristian Strand
President, Danfoss Climate Solutions

Waste heat is one of our best opportunities to address competitiveness, decarbonization, and energy resilience.

Only got 2 minutes?

1 **Waste heat is the world's largest untapped energy source**

Two-thirds of global energy was wasted in the form of heat in 2024[2] and up to 55% of energy is still expected to be wasted by 2030.[3] Capture and reuse of this waste heat has the potential to replace fossil-based energy sources, significantly boosting economic and industrial resilience while decarbonizing our energy systems.

2 **On-site reuse is the quickest and most competitive pathway for many waste heat producers**

By capturing waste heat from one process within a facility to heat water, space, and other industrial processes in that same facility, companies can save significantly on energy bills while reducing emissions. Through on-site reuse, one aluminum manufacturer in Denmark is projected to eliminate 205,600 m^3 of gas usage per year, resulting in an annual CO_2 emission reduction of 407 tons (see on-site reuse case on p. 12).

3 **Data centers can become reliable contributors of waste heat to energy systems**

Data centers are one sector with significant waste heat supply but nearly zero on-site demand. Typically operating 24/7/365, they can serve as a constant source of waste heat to nearby off-takers through microgrids or district heating systems. The move to high-performance computing data centers with liquid cooling — the future of data center design — significantly increases both the amount of heat available and the quality of that heat, thereby increasing the economics for heat reuse. In one Chinese industrial microgrid, waste heat provided by two data centers is expected to reduce annual energy use by 1.1 million kWh while cutting CO_2 emissions by an estimated 1,659 tons per year (see microgrid reuse case on p. 17).

4 **Waste heat can feasibly cover over 30% of Germany's district heating demand**

There is a clear untapped potential to decarbonize heating on a large scale in many cities. In the EU, Germany alone accounts for more than 20% of the total industrial waste heat recovery potential.[4] New Danfoss analysis of the German district heating networks shows that over 30% of its district heating demand can be feasibly covered by existing industrial waste heat emitters (see district heating case on p. 20).

Chapter 1

Waste heat — the world's largest untapped energy source

What is waste heat?

Every day, all over the world, energy is consumed on an industrial scale in facilities such as supermarkets, metro systems, factories, and wastewater treatment plants. Much of this energy is directly converted into work or useful heat, powering our societies and providing essential goods, services, and economic livelihoods. But much of it is not. In fact, in 2024, nearly two-thirds of global energy was wasted in the form of heat.[5] This is because any energy which is not directly converted into work or useful heat is an inefficiency in the energy conversion or use process and thereby lost as waste heat. Just think of the warmth behind a fridge or the heat from a laptop, but on a global scale and in much more energy-intensive processes.

Today, most of this heat is simply released into the atmosphere. This wasted energy yields lost energy and environmental value and missed revenue potential. But it doesn't have to. In fact, the technology already exists to recover and reuse this waste heat to heat homes, businesses, and industrial processes. However, doing so requires an understanding of where waste heat is produced, how it can be reused, and what it can help societies achieve. This paper provides insights into exactly those topics.

How much waste heat is there?

As stated, nearly two-thirds of all energy globally is wasted as heat.[6] What does this look like regionally? In the European Union (EU), the current total waste heat sources amount to approximately 1,200 TWh, a number which is expected to grow to 1,517 TWh by 2050 — enough to cover the EU's future heat demand in buildings.[7] To put this into another perspective, Paris consumes 32 TWh of electricity annually, meaning that the energy Europe wastes as heat every year is comparable to the electricity needed to power Paris for over 48 years.[8] In 2021, China's waste heat amounted to 13,889 TWh, with about 60% of these waste heat sources located within 10 km of urban areas.[9] In 2023, US waste heat amounted to 18,028 TWh,[10] nearly three times the country's heating demand of 6,389 TWh.[11] In short, the picture looks similar across the globe: enough heat is being wasted through existing energy processes to cover heating demand.

This begs the question of where the heat is coming from. Nearly every sector is responsible for a certain degree of waste heat production, but several industries stand as outliers simply by virtue of their energy intensity and critical role within the global economy. For example, heavy industries such as chemicals, steel, and cement employ many high-temperature processes, which generate significant amounts of waste heat as a by-product. We also see major waste heat production in other forms of critical infrastructure, such as data centers, wastewater treatment plants, and urban transportation systems. While gains in efficiency are critical in preventing this waste across all these sectors, the speed is not yet at scale; by 2030, up to 55% of global energy will still be wasted as heat.[12] This highlights that waste heat will remain one of the world's largest untapped energy sources well into the future.

Why does it matter?

Heating is one of the most widespread and energy-intensive processes in the global energy system. In Europe, for example, heating and cooling accounts for roughly

half of total final energy demand, with over 70% of that energy being provided by burning fossil fuels.[13, 14] Any opportunity to meet this demand with already-existing waste heat pushes us towards affordable, sustainable, and strategic energy efficiency with the opportunity for massive economic savings. In 2023, at least 3,100 TWh of waste heat globally went uncaptured, and recovery could provide annual global savings of up to EUR 140 billion.[15]

However, it is not just about meeting heating demand. Waste heat can also provide significant progress on key political, economic, and societal priorities — namely, industrial competitiveness, decarbonization, electrification, and energy resilience.

The case for **competitive decarbonization** is straightforward: reusing waste heat means reducing fossil fuel consumption, which would otherwise occur to meet heat demand. When paired with heating electrification, this elimination is total and the reuse becomes about improving efficiency, competitiveness, affordability, and resilience. This translates not only into reduced emissions but also reduced energy cost. Even after installing heat recovery and reuse technologies, payback times are often less than three years (see on-site and microgrid cases in Chapter 2).

Waste heat can also speed up progress on **electrification and renewables targets**. Electric technologies such as heat pumps are often needed to boost waste heat to a usable temperature. In other words, by reusing waste heat, we are electrifying heating processes. However, this electrification push faces a structural challenge: in many markets, electricity remains disproportionately expensive relative to gas, undermining the economic case for switching. To see more rapid progress, this must be addressed through policies which are more favorable to electrification, eliminating country-specific subsidies on gas and taxes on electricity. On renewables, the enablement of waste heat to contribute to national renewable energy targets is becoming more common, as evidenced by the EU considering waste heat a form of renewable energy when it is unavoidable.[16] When the heat recovery is part of a heating electrification and the retrofit is paired with installation of on-site renewables to offset increased electricity use, the impact on meeting renewable goals is amplified.

Finally, **energy security** is a rising concern across the globe, especially as geopolitical instability continues to expose vulnerabilities in energy supply chains and regional dependencies on fossil fuels. The EU serves as a prominent example, having faced significant disruption due to its strong dependency on Russian gas imports. Despite recent successful efforts to reduce consumption of Russian gas, the EU is still deeply dependent on gas imports. In 2025, the EU obtained 12% of its total gas imports from Russia,[17] a decrease from its 45% dependency in 2022.[18] Still, the US accounted for 58% of LNG imports to help bridge the gap.[19] This essentially means that the EU hasn't reduced its dependency on imports but simply shifted it to another exporter. In 2025, 30% of EU households were heated using gas, leaving the bloc exposed to the price volatility and political risks that come with dependence on any foreign supplier. Waste heat has the potential to not only help EU break free from gas, but to significantly boost economic and industrial resilience. Of course, this is not just an EU phenomenon: regardless of region, increasing the share of waste heat in the heating mix shields industries and households alike from price shocks that occur in the wake of global energy crises.

As humanity navigates ongoing economic, energy, and climate crises, the reuse of energy that has already been produced and purchased is one of the simplest ways to save money while providing more resilient and sustainable energy systems.

How does it work?

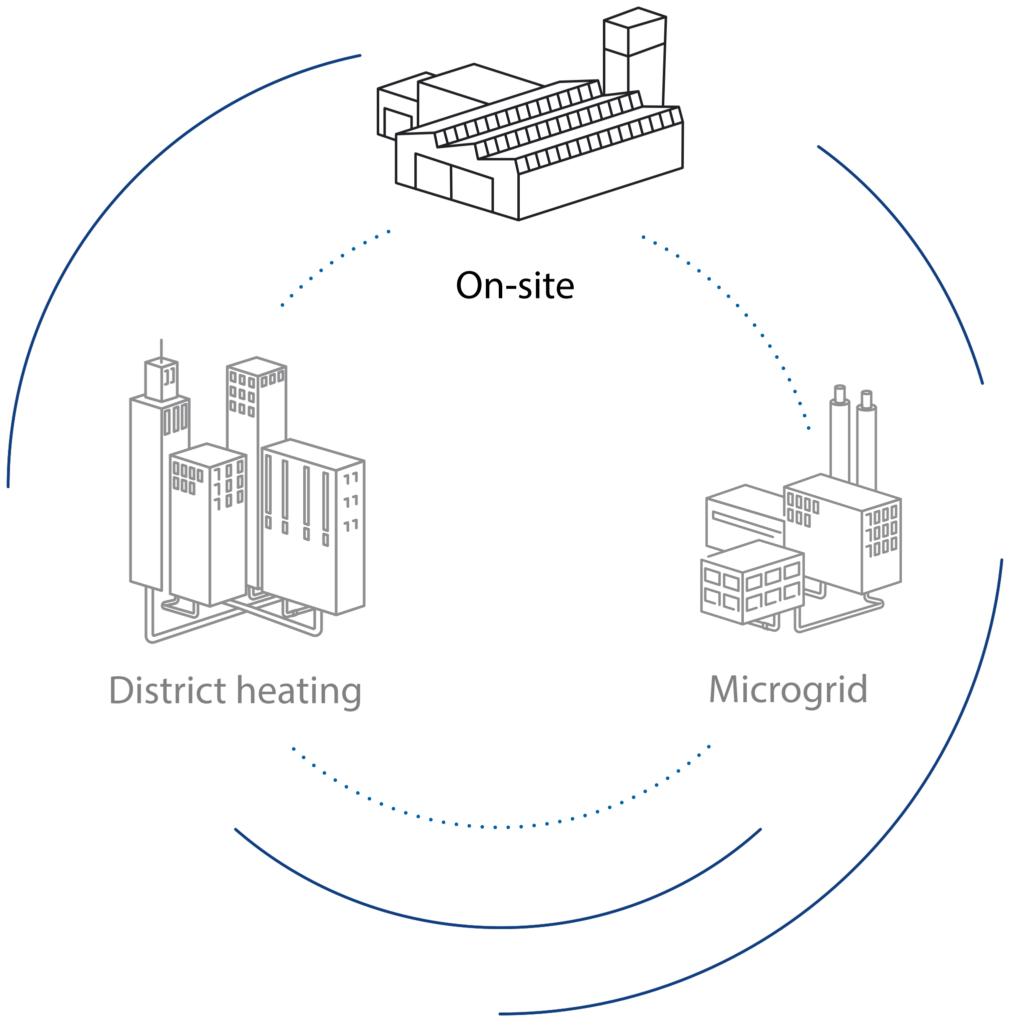
Historically, heating systems were designed independent of cooling systems, generally with separate designers, suppliers, and operators. This originated with the fuel for heating systems coming from burning fossil sources. Now with electric systems for heating, however, integrated climate systems simply move heat from where it's not needed (i.e., cooling) to where it is needed (i.e., heating). This demonstrates the simultaneous efficiency potential of providing both with one electrified system, utilizing the waste heat recovered from cooling processes as a primary heat source. All that is then left is to understand the potential source and demand pathways.

There are three main pathways for the recovery and reuse of waste heat: on-site reuse, microgrid reuse, and district heating integration. Each of these are viable methods but are also often context- and sector-dependent. Chapter 2 explores each of these pathways in detail, describing when and where they are relevant, presenting key benefits and challenges, as well as cases and analyses showcasing their real-world impact and potential.

Chapter 2

Pathways for waste heat reuse

Pathway #1: On-site reuse



The simplest, quickest, and oftentimes *cheapest* pathway for many waste heat producers is on-site reuse. This involves recovering and reusing waste heat directly in the same facilities from which they are emitted as process heat and/or to provide space heating and hot water to the facility.

When is it relevant?

For waste heat to be reused on-site, there must be both supply and demand for heating and/or cooling at that location. Heat pumps are a good alternative to gas boilers and chillers, as they are able to capture heat for reuse, absorbing that heat from processes and/or facility cooling. This is often observed in traditional factory or industrial manufacturing settings where there is a mix of both production and office facilities on-site. This is because there is often a need for both space and water heating as well as supplementary process heating. In particular, heavy industries such as steel, glass, or cement are prime examples of where a great deal of heat is not only produced but also consumed.[20] However, a large portion of the heat produced by these sectors currently ends up as waste. When planned strategically, such resources can be captured and reused on-site to replace or supplement the consumption of fossil fuels.

Main benefits and challenges

On-site reuse provides several unique benefits. First, on-site reuse opportunity is significantly driven by two interrelated factors — efficiency and coincidental operation. Efficiency is based on the ability to recover heat from the highest temperature sources and supply them to the lowest temperature heating demands, maximizing recovery efficiency and minimizing operating cost. Simultaneous operation and on-site reuse is especially tied to industrial processes, where there are coincident cooling and heating loads, recovering the heat from the cooling system to electrify and replace fossil fuel heating through a true symbiosis system, maximizing the efficiency and minimizing the operating cost of both. Moreover, the limited reliance on external stakeholders reduces coordination requirements and implementation complexity compared to offsite heat utilization. Finally, on-site reuse doesn't require access to the expansive district heating networks often found in Europe or major metropolitan areas, meaning its application is more universal and applicable on a global scale.

Challenges also exist. For example, understanding the supply-demand dynamic of a facility requires specialized knowledge, resulting in the need to contract external experts for guidance. Similarly, how much waste heat can be efficiently recovered depends on the output temperature — the cooler the heat stream, the less of it can be put to work, which is why low-temperature waste heat often needs a heat pump to be 'upgraded' before reuse. A further challenge is related to operational downtime. While this is not necessarily unique to on-site reuse, the installation of new systems almost always results in some period of decreased productivity. Fortunately, smart planning and favorable payback times can help to mitigate these concerns.

Case story

On-site waste heat reuse boosts Hydro's competitive edge

This heavy-industry case focuses on Hydro's aluminum manufacturing facility in Tønder, Denmark, where the company has been working to improve energy efficiency to meet both their commercial and decarbonization needs. Despite already previously electrifying all other operations, the facility's heating process still used gas, contributing to the embodied carbon of their products (e.g., microchannel tubes, electric car cables). As a result of emissions taxes, the high embodied carbon of their products led to higher cost compared to alternative suppliers.

These metal products require a very high induction heating process to heat materials from 20°C to 500°C, demanding significant amounts of electricity. The final formed and cut metal is sent to a cooling tank maintained at an 18°C setpoint, where the waste heat is then rejected through a cooling tower. After heat rejection, the cooled water is then returned to the cooling tank at 16°C.

Additionally, the facility has a high demand for factory floor and office heating, especially during winter seasons. Typically, this heat was supplied through air handlers and office radiators powered by two 550 kW gas boilers supplying 60°C hot water.

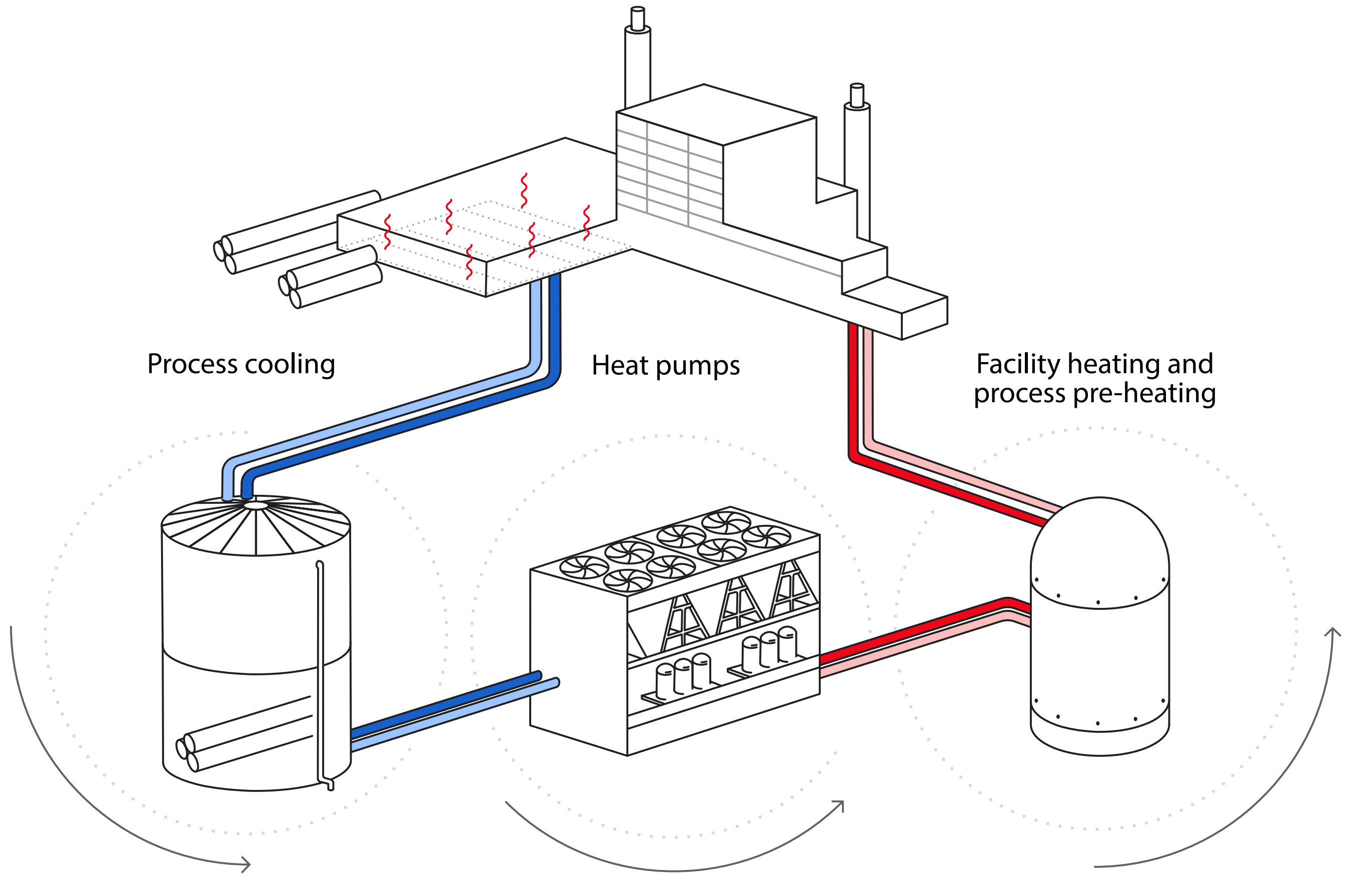
To increase efficiency, Hydro linked these two independent processes — process cooling and facility heating systems — to leverage their synergy. The electrification of heating with a heat pump became significantly more efficient than a boiler because rather than producing new heat, it is simply moving and boosting heat recovered from the point of cooling to the point of heat reuse.

To do this, the heat pump boosts the heat from the return process cooling temperature of 16°C to the 60°C that is needed to provide heat from the facility's radiators and air handlers. This project resulted in an impressive efficiency of 4.9 COP, or five times the efficiency of the boiler providing the same temperature. This resulted in five times less electrical vs. gas input to provide the same heating and significant comfort savings for Hydro.

To further leverage on the opportunity, Hydro developed a concept where a second booster heat pump was added to the system to boost only the portion of the process heat required from the 60°C comfort heating setpoint to the 90°C production pre-heating setpoint. This heat is supplied to a tank where metal production materials are submerged and pre-heated from outdoor or room temperature (~0-20°C) to approximately 90°C. Induction heating then takes over to complete the remaining process heating at 500°C. The booster heat pump provides a COP of 3.8, or roughly four times the efficiency of the induction heating for the portion of process pre-heating it covers.

Regarding the original project goal, which was high embodied carbon in the product, the heating electrification retrofit of Hydro's system is projected to eliminate 205,600 m³ of gas usage per year, resulting in an annual CO_2 emission reduction of 407 tons. Per Hydro's 2024 production, this means a reduction of 0.013 kg of CO_2 emissions per kilogram of processed aluminum. This impressive result indicates less embodied carbon in the final products sold, boosting Hydro's competitive advantage compared to alternative suppliers. The project had a total payback time of only 2.3 years, further underlining the economic attractiveness of waste heat reuse.

Figure 1
Industrial waste heat recovery for on-site reuse at Hydro Tønder.

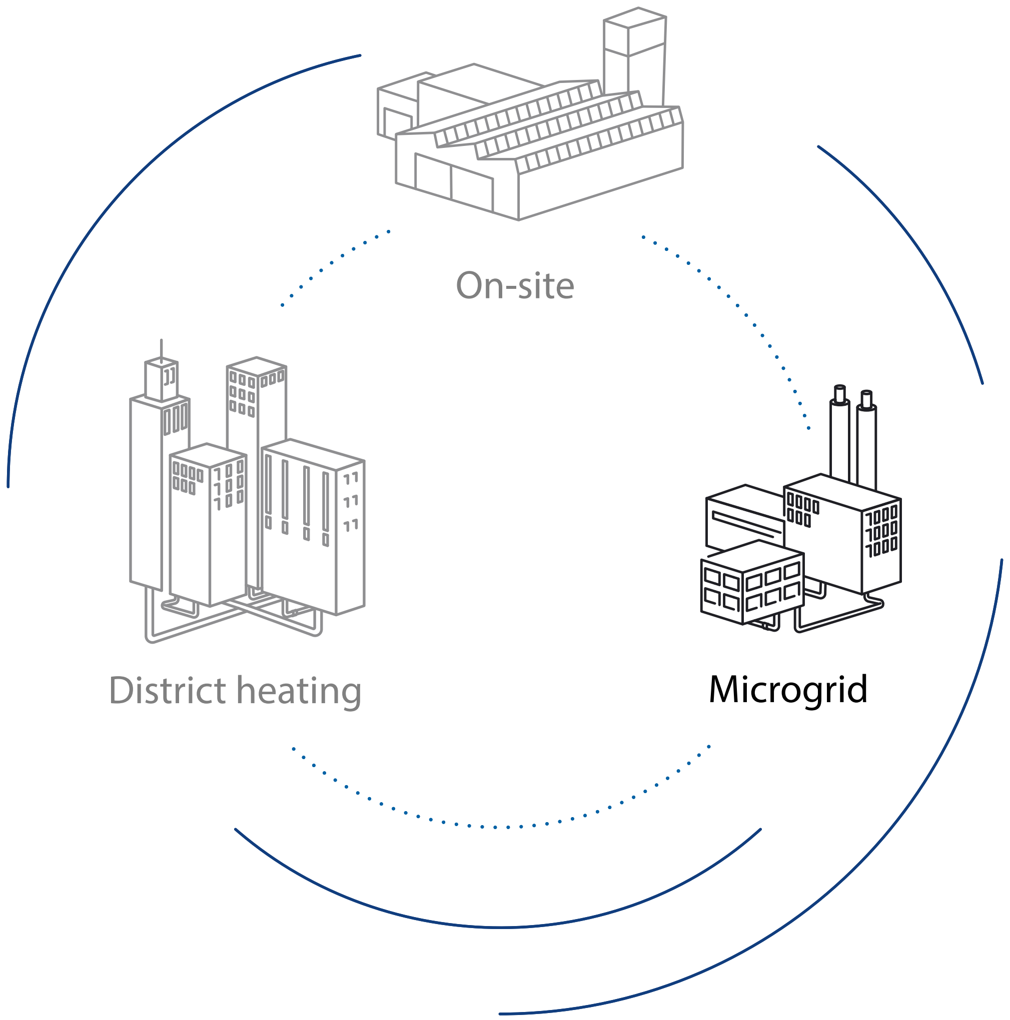


407	205,600	2.3
tons of annual CO_2 emissions reductions	m³ of gas usage eliminated annually	years project payback time

Chapter 2

Pathways for waste heat reuse

Pathway #2: Microgrids and industrial clusters



Microgrids act as localized energy systems that can operate independently from the main utility grid, supplying reliable energy to a specific facility or campus. This approach is particularly effective in cases where waste heat can serve multiple end users, such as when an industrial facility or a data center provides heat to nearby industrial processes or commercial buildings — also known as an industrial cluster. In short, when companies operate in proximity, they can lean on one another as both heavy producers and consumers of waste heat.

When is it relevant?

Both microgrids and district heating systems become relevant when there is no demand on-site, or when supply outpaces on-site demand. In the absence of accessible district heating networks, which are highly efficient but still relatively rare on a global scale, microgrids and industrial clusters are a viable alternative.

One sector with significant waste heat supply and nearly zero on-site demand is data centers. Nearly every unit of energy consumed by a data center is converted into heat, and with global power consumption for data centers set to double to 3% by 2030,[21] the waste heat potential from data centers is significant. In the United States, data center power consumption is expected to quadruple between 2023 and 2030, making it the fastest-growing global market.[22] At this level, data centers could generate enough waste heat to supply 33% of the US combined residential and commercial heating demand.[23] In Europe, data centers are facing mounting pressure to be as energy-efficient and sustainable as possible in line with the EU's transition towards climate neutrality.[24] As data centers run 24/7/365 and are 'critical facilities' with backup power systems to ensure they do not go down, they can provide a stable and resilient source of heat for off-takers, and this heat can be used at different scales. In fact, data centers are not the only form of digital infrastructure capable of providing waste heat to communities. In Denmark, the University of Southern Denmark's advanced AI supercomputer has been designed to provide high-quality waste heat to its local district energy system, proving that the expansion of digital infrastructure can serve as a critical energy asset if planned wisely.[25]

Main benefits and challenges

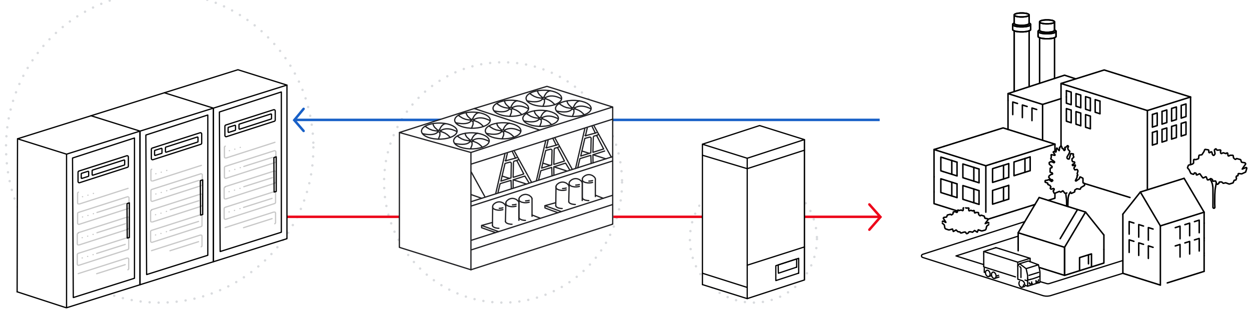
The opportunity to tap into microgrids immediately seems clear, and it can prove to be an important contributor to the energy system. Waste heat producers can earn money on a waste product, and nearby facilities or campuses can tap into this source to phase out fossil fuels from their energy mix. In some regions, the recovered waste heat can even help meet renewable energy targets.[26] Most industrial microgrid projects deliver strong economic performance, with payback periods ranging from 3-7 years (see case on p. 17). Facilities that generate continuous, high-temperature waste heat such as manufacturing plants and data centers, often have the shortest payback periods due to the consistent availability of waste heat.

One of the key challenges is that waste heat from data centers can only be utilized if a suitable off-taker is available. The location of data centers is primarily determined by electricity grid access,[27] whereas other factors, such as access to renewable electricity and to waste heat off-takers, are less determinative. This is not because data center operators are not interested in waste heat reuse, but because doing so involves a complex landscape of stakeholders and legislation. To the contrary, data center operators are in fact interested in repurposing the waste heat as it is a burden for them, expending significant energy and using significant water volumes to reject it. It is in the interest of all stakeholders, including off-takers, to make it easier and more attractive to reuse the waste heat.

Without policies that make electrification more attractive, the economic and decarbonization potential of waste heat will never be fully realized.

Figure 2

Data center waste heat recovery system. [28]



Case story

Waste Heat Reuse at Wuqing Qingshu Science Park, Tianjin, China

Nearly every unit of energy consumed by a data center is turned into heat. With the global power consumption for data centers set to double by 2030,[29] this means there is significant waste heat potential across the sector. However, today, this heat is currently wasted by simply being released into the atmosphere. Tapping into this free source of energy provides a great opportunity for providing affordable, low-emission heating.

From a security perspective, data centers provide a particularly attractive proposition as a heat supplier: because they operate around the clock and are designed to never go down, they provide a steady and predictable source of heat. Furthermore, because the electricity demand for data centers will be concentrated regionally, they provide perfect opportunities for more targeted integration into local energy systems.

One such example can be found in Wuqing, China. The Qing Shu Science & Technology Park is a 103,450 m^2 mixed-use industrial complex located around 400 meters from a cluster of data center facilities. Since 2014, the site has attracted more than 550 companies from Beijing and Hebei. Among the companies that have their company base in Wuqing are two data centers: the Guo Fu Rui Data Center and the China Telecom Data Center. Both centers benefit from heat recovery to heat their offices during winter, and the surplus heat from the data centers will be utilized for hot water all year.

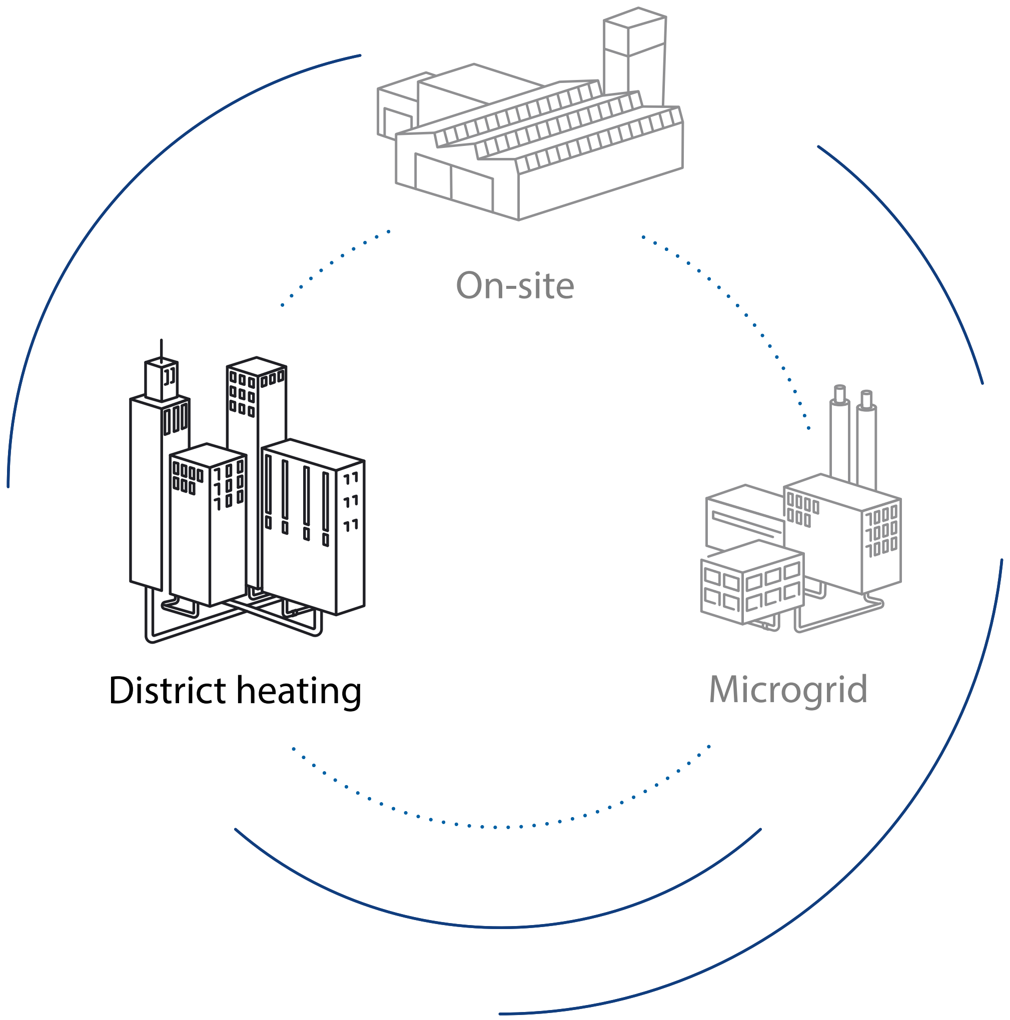
The complex recovers heat from the data centers' cooling loops and uses it locally across the industrial park. In winter, the recovered heat supplies space heating and domestic hot water. In summer, the system switches mode and provides cooling for the park using rooftop cooling towers. Even during its first winter of operation, when the complex occupancy was below its full capacity, the average heat cost fell by about 60% compared with local commercial district-heating rates.

At the complex's target occupancy level, the project is expected to reduce annual energy use by 1.1 million kWh for the adjacent data centers, while cutting emissions by an estimated 1,659 tons of CO_2 per year. The overall payback time is less than 3 years for additional initial investment.

Chapter 2

Pathways for waste heat reuse

Pathway #3: District heating integration



District heating offers a large-scale solution for utilizing waste heat, especially in densely populated cities. District heating uses a network of interconnected pipes to supply heat via water to buildings across a neighborhood or city. Most often, these networks are served by centralized heat production units, such as combined heat and power plants, but they are also capable of including smaller, more decentralized heat sources. Producers of waste heat can thus play a key role in providing low-emissions heat to local district energy systems.

When is it relevant?

Despite the increased global use of district heating systems by 32% from 2010 to 2021,[30] 90% of district heat is still produced with fossil fuels today, leaving an untapped potential to decarbonize heating on a large scale.[31] Waste heat can play a major role in achieving this by replacing fossil fuels in commercial and residential heating. For example, the IEA estimates that recovered heat from data centers could cover up to 10% of Europe's space-heating demand by 2030 — and at a much more attractive price than natural gas.[32]

Cities are the global centers of economy and culture where more than half of the world's population resides and are only predicted to increase in size and density. One consequence of this population density is high energy consumption. Presently, cities account for 75% of global energy consumption and 70% of global greenhouse gas emissions,[33] and we know that energy supply must evolve to meet growing demand. What is driving this urban energy demand? Other than everyday consumption in homes, several sectors represent an outsized demand. For example, wastewater treatment plants use an estimated 1.8-5.4% of total global electricity consumption.[34] Similarly, in some countries, supermarkets consume approximately 3% of electricity production.[35] Other high-demand sources include facilities such as hospitals and public transportation systems. These urban-based sectors therefore present strong opportunities for waste heat reuse, as their essential services require continuous operation.

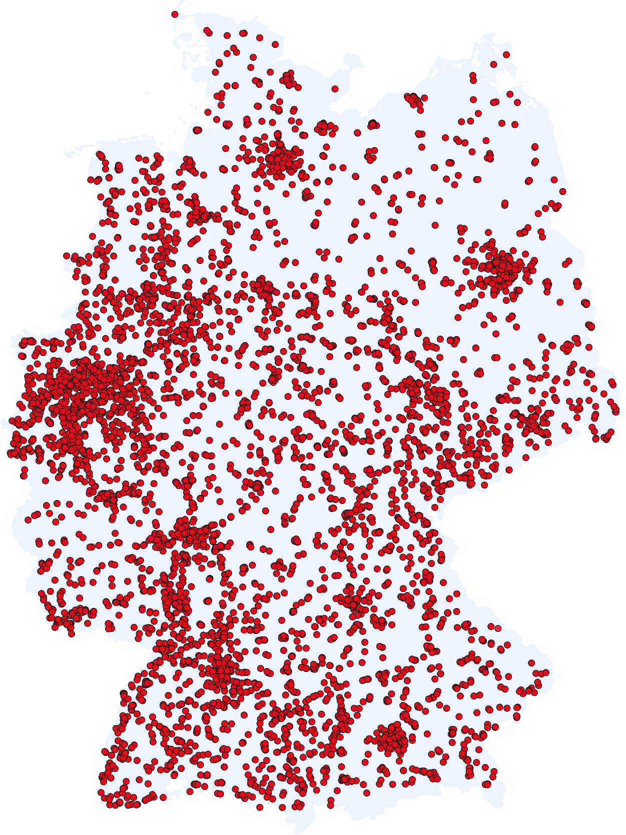
Main benefits and challenges

One of the main strengths of district energy systems is their capacity to integrate different heat sources that can push fossil fuels out of the heating and cooling mix. This can serve as an environmental and economic benefit both to industrial producers of heat and to consumers who get their heat via district heating networks. Compared to individual heat pumps in specific areas in a city, district heating is a more cost-effective option by sharing infrastructure and reducing equipment duplication.

Integrating waste heat into district heating systems faces several challenges. Temperature mismatch is common, as waste heat is often available at relatively low temperatures (30–60 °C), while district heating networks typically operate at 70–100 °C. Rather than burning fossil fuels to boost heat to suitable temperatures, heat pumps can serve the same purpose, thereby electrifying urban heating while also integrating waste heat. Contrasting two markets on this aspect, Denmark has transitioned its district energy networks over the last thirty years from ~100°C third-generation networks to ~70°C fourth-generation networks, enabling efficient heat recovery from sources such as data centers and heat pumps. Germany, on the other hand, has established the requirements to recover heat from data centers, but their district energy networks have only just begun to transition to lower temperature operation, with most still operating near 100°C. This difference drives a corresponding economic return difference, based on heat pump efficiency, of five years or less in Denmark versus ten-plus years in Germany. Lowering operating temperatures is a critical systemic challenge to overcome.

On top of temperature mismatches, there can also be seasonal mismatches, with high heating demand in winter and much lower demand in summer. Finally, district heating projects often require high upfront investment and have long payback periods, which can make them less attractive than conventional heating particularly when electricity prices are high, as heat pumps depend on electricity.[36] As such, these projects often require government support and long-term vision to implement.

Figure 3: Supply
Registered industrial waste heat emitters
Industrial and commercial waste heat emitters registered under Germany's EnEfG with an average temperature of 500 C or below, the technically recoverable range for district heating.



Analysis

Waste heat can feasibly cover over 30% of German district heating demand

Germany sits at the center of Europe's industrial waste heat story, accounting for more than 20% of the EU's total industrial waste heat recovery potential.[37] Italy, France, and the UK each contribute roughly 10%, placing Germany in a category of its own.[38] What Germany does with its waste heat matters more for the global heating transition than what any other European country does, and right now, almost all of it is being wasted.[39]

To understand how much of this potential could be realistically captured, Danfoss conducted an analysis of Germany's industrial waste heat emitters and district heating networks (see Appendix 1 for analysis details). Using Germany's national waste heat register, created under the Energy Efficiency Act, and a national map of district heating networks from RWTH Aachen University, 178 of the largest networks in the country were identified.[40] These networks are defined as those serving more than 5,000 households. Qualifying emitters of waste heat were then identified, classified as those with average waste heat temperatures at or below 500°C, which is the practical threshold for district heating integration.[41]

Around each network, a one kilometer catchment zone was drawn, representing the distance within which a pipeline connection to a nearby emitter is economically plausible.[42]

The analysis found that across Germany, the waste heat currently produced at industrial sites within one kilometer of those 178 networks is enough to cover approximately 30.4% of annual German district heating demand.[43] This

Figure 4: Demand
A map of the German district heating network system
This dataset was used to identify the 178 German district heating networks that met Danfoss' waste heat integration standards (see Appendix).

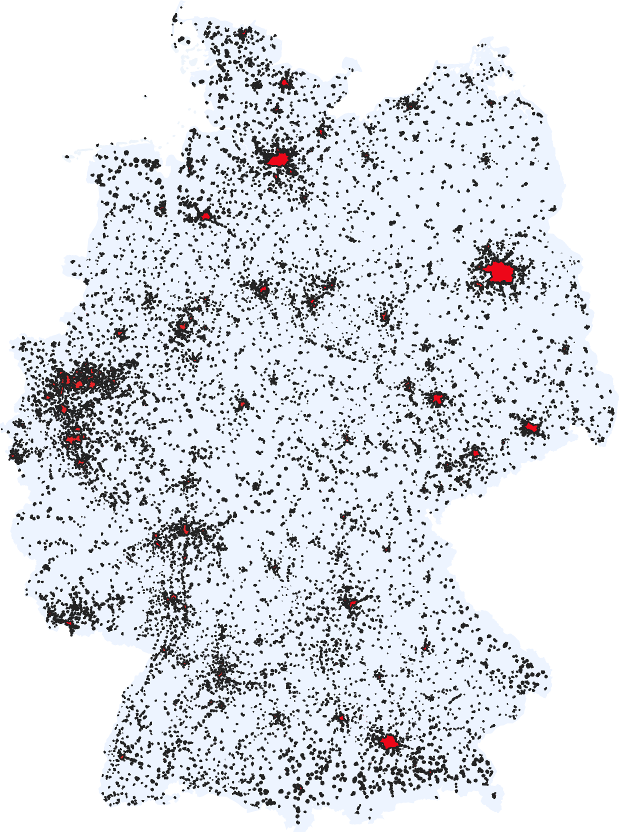


figure goes beyond Germany's own 2030 legal threshold, which requires district heating networks to source 30% of their heat from renewable sources or waste heat by that date.[44] In other words, the industrial waste heat alone, without accounting for other renewable sources, is sufficient to meet near-term national targets.

Critically, the waste heat register used in this analysis excludes combined heat and power plants and does not yet include data centers. Germany has more than 3,000 data centers, around 1,000 of which fall within the reporting scope of the Energy Efficiency Act.[45] Their inclusion would push the coverage figure considerably higher and will be essential as Germany works toward the Heat Planning Act's longer-term target of 80% renewables or waste heat supply.[46]

At the individual network level, most sites had more waste heat nearby than their demand requires, pointing to specific locations across Germany where the investment case for connection infrastructure is already strong. These are the natural starting points for accelerating integration.

The broader lesson extends well beyond Germany. Heating accounts for nearly half of global energy consumption, and the vast majority of it still comes from fossil fuels.[47] Industrial waste heat is a largely invisible resource sitting alongside that demand in virtually every highly industrialized economy. This analysis of the German potential of waste heat demonstrates that with the right data, spatial tools, and policy frameworks, the gap between wasted heat and unmet demand can be quantified, mapped, and closed. That is a model other countries can follow.

Chapter 3

Leveraging waste heat requires action

Waste heat is an incredibly powerful means to provide a competitive advantage for energy resilience, industrial growth, and decarbonization across sectors and geographies. Progressing on waste heat proliferation requires several key actors to take action — namely industry, energy system operators, and governments. In this section, we have outlined key actions for each of these groups to take.

What can industry do about it?

Industrial actors are at the heart of waste heat production and include a broad range of sectors such as data centers, manufacturing, food and beverage, steel mills, and cement factories, which despite being central to our economies, are energy-intensive functions. Recovery and reuse of this waste heat requires that industrial actors:

1. **Evaluate the most suitable pathway(s) for recovery and reuse** based on on-site supply and demand, operating load profiles, temperatures, interconnection potential, potential nearby industrial off-takers, and local energy system context.
2. **Engage in cross-sector waste heat exchanges.** Industrial actors should proactively seek partnerships with neighboring facilities, even across different sectors, to identify complementary supply and demand profiles.
3. **Integrate waste heat planning into capital investment cycles.** When upgrading or building new facilities, industry should treat heat recovery infrastructure and integrated system potential as a standard design requirement and lock in efficiency gains for asset lifetimes.
4. **Monitor and report waste heat continuously.** Real-time metering of waste heat output allows industrial actors to better understand their own supply patterns and demonstrate reliability and recovery potential to themselves and potential off-takers.
5. **Advocate for favorable regulatory conditions.** Industry associations and individual companies should actively engage with policymakers to shape waste heat legislation, grid access rules, energy cost legislation, and incentive schemes.

What can energy system operators do about it?

Energy systems provide the connection of production to demand. These actors include grid and transmission system operators, district heating network operators, and utility and energy companies. It is critical that these actors:

1. **Lower district energy operating temperatures** to enable efficient and economically attractive recovery of waste heat.
2. **Map and publish waste heat potential data.** Energy system operators are uniquely positioned to overlay heat demand data with industrial waste heat sources, identifying where supply and demand align geographically. Public availability accelerates investment decisions and reduces planning uncertainty for all stakeholders.
3. **Push for flexible grid tariffs that reward waste heat integration.** Pricing structures that incentivize industrial actors to feed waste heat into district networks make the economics more attractive for both producers and off-takers.
4. **Establish long-term heat purchase agreements with waste heat producers.** Predictable, contractual off-take agreements reduce revenue uncertainty for industrial suppliers, making it easier to justify upfront investment in recovery infrastructure.
5. **Push to integrate waste heat recovery into grid and district heating infrastructure strategies.** When possible, coordinate with spatial planners to protect heat corridors and reserve underground routing options for future heat pipelines during urban development to prevent costly retrofits.

What can governments do about it?

Unlocking waste heat requires matching industrial supply with demand in the energy system. Governmental actors at national, regional, and municipal levels can enable this connection by creating regulatory and financial conditions that make cooperation and investment possible. To do so, they should:

1. **Address the electricity-to-gas price ratio** to create a more attractive environment for investments in heating electrification. Subsidies on gas and taxes on electricity are the primary factors currently limiting the potential of heat recovery, heating electrification, and the corresponding decarbonization.
2. **Develop and implement heating and cooling strategies that recognize waste heat as a strategic resource.** Waste heat should be seen as contributing to decarbonization and energy independence while also easing constraints on energy systems.
3. **Set dedicated waste heat recovery targets**, or at the very least indicators, at national level. This should include requirements for and monitoring of waste heat recovery in specific sectors where the potential is particularly high, such as industrial sites, supermarkets, and data centers.
4. **Support the development of local heating and cooling plans and ensure opportunities are effectively leveraged.** To do so, provide financial and technical support to municipalities, particularly smaller ones, to enable the development of such plans.
5. **Reward heat recovery projects in industry.** The use of waste heat should be incentivized through targeted financial support schemes.
6. **Improve data availability and transparency on waste heat sources**, as shown in Germany, where waste heat reporting mandates have provided high-quality public data on waste heat availability and characteristics.

Appendix

German district heating analysis

Analysis Target

The question this analysis set out to answer was a practical one: how much waste heat exists in close enough proximity to Germany's district heating networks to be realistically usable? And does the potential, on paper, come anywhere close to meeting the legally-binding targets the country has set for itself?

What data we used

Two datasets formed the basis of the analysis. The first was a spatial dataset of Germany's district heating networks produced by RWTH Aachen University, showing the geographic footprint of networks across the country along with data on the number of households each one serves. We applied a threshold of 5,000 or more households, focusing the analysis on larger, more significant networks where demand is highest and the economics of connecting new heat sources are most likely to be viable. After applying that filter, 178 qualifying networks remained.

The second dataset was Germany's national waste heat register; the reporting database created under the Energy Efficiency Act. This requires that industrial and commercial operators above a certain size register the waste heat they generate. There was a variety of significant industries and sectors in the dataset with the largest contributors to overall waste heat being utilities, chemicals and refining, steel and metals, paper and pulp, food and beverage, and waste and water treatment. The utilities category is dominated by large power stations, principally lignite and gas-fired plants. These stations discharge heat via cooling towers and flue stacks where the heat goes unused. The utility category does not include waste heat from combined heat and power plants already supplying district heating networks, which would not represent new available supply. Each operator had to report on where their site is located, how much heat they produce annually, and at what temperature. That temperature figure matters because district heating systems can only accept heat below certain thresholds, and at the same time are only economically or environmentally viable above certain temperatures, as temperature boosting can be required to match demand temperature. It is also important to note that at the time this data set was published, it did not include data centers. This is significant as Germany has the highest number of data centers in Europe (more than 3,000), 90 of which have a capacity of more than 50 MW. Around 1,000 data centers are covered by the EnEfG reporting scope.

With the register, we filtered to include only emitters with an average waste heat temperature of 500°C or below, broadly reflecting the range that is technically recoverable and usable for district heating purposes. Very high-temperature industrial processes, such as certain steel or glass production stages, were excluded on the grounds that the heat is not practically transferable to a residential or commercial heating system.

What we did with the data

Both datasets were loaded into QGIS, a geographic information system used for spatial analysis. The coordinate reference system of the datasets was standardized so that distance measurements would be accurate across the whole of Germany, which requires using a projected coordinate system rather than standard latitude and longitude.

Around each of the 178 qualifying district heating networks, we drew a one-kilometer buffer zone. This represents the catchment area within which a waste heat emitter could plausibly be connected to that network, on the assumption that pipeline distances beyond one kilometer start to become economically difficult to justify without very large heat volumes. We then identified every waste heat emitter from the filtered register that fell inside any of those buffer zones.

For each individual network, we summed the total annual waste heat output of the emitters within its one-kilometer zone and compared that to the network's own annual heat demand. This produced a supply-to-demand ratio for each network. A ratio above 1.0 means that the waste heat available nearby theoretically exceeds what the network needs. A ratio below 1.0 means the nearby supply falls short.

For the national-level figure, we merged the overlapping buffer zones together before summing supply, so that a single emitter sitting between two networks was not counted twice in the aggregate total. This produced a more conservative and more honest headline figure for Germany as a whole.

All technical assumptions are provided by Danfoss' Sector Coupling team, who specializes in waste heat recovery and reuse.

What the results showed

At the national level, the total waste heat available from qualifying emitters within one kilometer of qualifying district heating networks covers approximately 30.4% of the combined annual heat demand of those 178 networks. That figure exceeds Germany's 2030 Heat Planning Act legal threshold that 30% of heat supply must come from renewable energy or waste heat. It suggests that at an aggregate level, the potential exists in principle to meet the near-term target from proximate industrial waste heat sources alone, without factoring in renewables or other heat sources such as data centers, which will bring much higher waste heat values. For future planning, the Heat Planning Act mandates 80% of heat supply comes from renewables or waste heat, making eventual data center integration critical.

The picture is more varied when you look at individual networks. The majority had a supply ratio below 1.0, meaning that for most networks, the waste heat available within one kilometer is not sufficient on its own to meet demand. Many fell well below that threshold, with ratios close to zero, often because they are in areas with little heavy industry nearby.

A smaller but significant group of networks had ratios above 1.0. These are the most interesting findings from a practical standpoint. They represent specific places in Germany where industrial waste heat is concentrated near district heating infrastructure, thus the geographical case for integration is strong and investment in connection infrastructure would have the clearest potential return. Identifying and prioritizing these locations is one of the most actionable outputs the analysis produces.

Where the analysis has limitations

There are important limitations that should be kept in mind when interpreting these results. The one-kilometer buffer is a practical simplification, not a hard engineering rule. Whether a given emitter can realistically supply a given network depends on factors the spatial analysis cannot capture: the existing pipe network layout, the specific routing a connection would need to take, local planning constraints, and whether the temperature of the waste heat is compatible with the network's operating requirements. A site 800 meters away on the wrong side of a motorway or industrial zone might be harder and more expensive to connect than one 1.4km away with a clear routing option.

The waste heat register reflects what companies have declared, not what has been independently verified or assessed as technically recoverable. Some entries may describe heat that is difficult to capture in practice, or heat that a company has already taken steps to reduce. The register is also relatively new, and coverage of some sectors, including data centers, may not yet be complete. This means the analysis likely understates the true potential in some areas, because not all relevant emitters will yet be in the dataset.

A small number of entries in the register, identified through a review of company notes, describe waste heat that is already contractually committed to supply a district heating network. These entries represent a very minor share of the total supply share (less than 1%) and do not affect the 30.4% headline result. They are, however, a reminder that the register captures declared potential rather than heat that is in all cases freely available.

The analysis is also a static snapshot. It does not account for seasonal variation in waste heat availability, the reliability of supply, or whether the heat is available at the times of year and times of day when demand is highest.

Why the analysis is still useful

Despite limitations, the analysis provides a defensible, evidence-based starting point for understanding Germany's waste heat opportunity. Germany currently uses only a small fraction of its industrial waste heat in district heating, estimated at roughly 7 to 8 TWh per year from non-CHP sources against a total district heating supply of around 140 TWh nationally. The gap between that baseline and the 2030 target is substantial, and there is strategic uncertainty about its closure.

This analysis helps to provide certainty. It demonstrates that the raw geographic potential exists at scale, that the 30.4% coverage figure is achievable in aggregate, and that there are specific networks across the country that are particularly well-placed to act. For planners, policymakers, investors, and network operators trying to decide where to focus heat planning efforts, the information has real practical value.

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