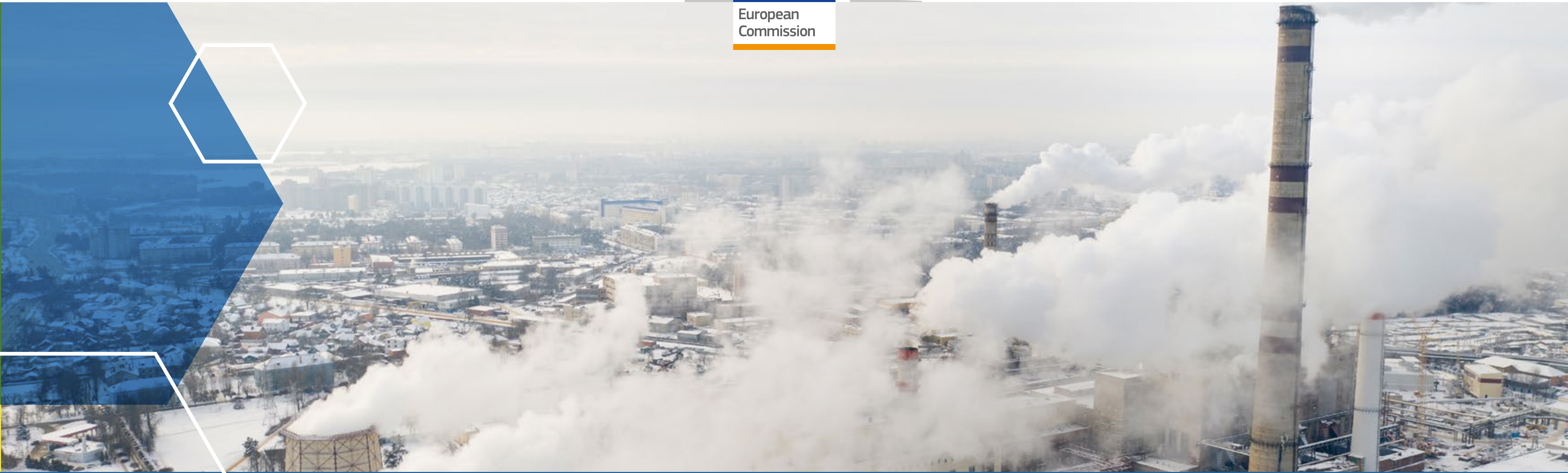

European Commission

Toolkit

District Heating

A technology overview and pathways towards decarbonisation

Energy

SUPPORT MATERIALS

Providing support materials to coal regions in transition

The Initiative for coal regions in transition developed the following support materials to assist practitioners in coal regions (including peat and oil shale regions) across Europe. Click below to download the toolkits.

- **Clean air**
- **Environmental rehabilitation and repurposing**
- **Governance of transitions**
- **Sustainable employment and welfare support**
- **Technology options**
- **Transition financing**
- **Transition strategies**

European Commission

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How to use this toolkit

Slides / Pages 4-20

This section gives an overview about the topic of district heating decarbonisation for EU coal+ regions and covers the main messages & recommendations with regards to the topic.

For each slide, more detailed information can be found in the report section.

In-depth report / Pages 21-78

The more in-depth report follow the same structure as the slides and offer a more detailed look into each section, including a full technology overview with further resources, links, examples, and case studies.

AIMS AND SCOPE

This toolkit overviews the technology options available to support decarbonising DH networks, the roles these networks play in decarbonisation and future heat supply, and showcases possible measures and good practice examples.

WHO IS THIS TOOLKIT FOR?

- Regional and local authorities
- SMEs and Civil Society Organisations
- Relevant stakeholders (e.g., in energy utility management) engaged in district heating decarbonisation at the local and regional level.

WHY DO WE NEED THIS GUIDANCE?

The heating & cooling sector is responsible for a central part of the European Union's energy demand, representing roughly half of final energy consumption.

As the window for action to stay below the 1.5°C goal of the Paris Agreement is rapidly closing, it is now especially crucial that larger energy infrastructure be decarbonised soon.

KEY MESSAGES

- A strategy to transform a coal-based district heating system should **always combine measures to reduce heat demand** and **installing substitutes for supply** (see five steps model, next slide).
- The main pillars for climate-neutral heat generation will be **power-to-heat** – using renewable electricity and ambient heat – **solar thermal heat**, and a proportion of **deep geothermal energy** in suitable areas.
- Public H&C planning is crucial for decarbonising the sector. Main local policy instruments are **H&C strategies**, **zoning**, **energy communities** and **financial support measures**.

APPROACH

A five-step model for district heating decarbonisation

1 Sufficiency

Reduce energy demand (heating reduction in unused rooms)

2 Efficiency

Minimise energy losses (low temperature networks, LowEx concepts, thermal storage, improved building envelope, pipe insulation, Combined Heat and Power (CHP), digitalisation)

3 Local renewable heat sources

Increase its use (solar thermal, geothermal, ambient or unavoidable waste heat)

4 Power-to-heat

Develop and use renewable electricity (heat pumps (base load) and electric/electrode boilers (for times of high RE electricity availability))

5 Alternative energy carriers

Cover residual heat demand by scarce energy resources (biomass, biogas/biomethane, green hydrogen, renewable synthetic gases)

Source: EC 2023, based on IN4climate.nrw 2021

Sufficiency: the long-term goal

- Sufficiency in the context of DH systems should be considered as a **guiding principle that helps to identify ways to increase cost-effectiveness of the system** that goes beyond technological aspects.
- Applying the idea of sufficiency results foremost in thinking about **possibilities to reduce the demand side of H&C**.
- In practice, attaining sufficiency in sustainable heat planning is **a balancing act between covering today's heating needs, while still preparing for tomorrow's needs**.

HOW MUCH HEAT IS TRULY ENOUGH?

Even if we can produce a lot of sustainable energy and use it "well", is it really necessary?

How can we avoid heat energy generation and demand in the first place, before even needing to think about how efficient or clean it is?

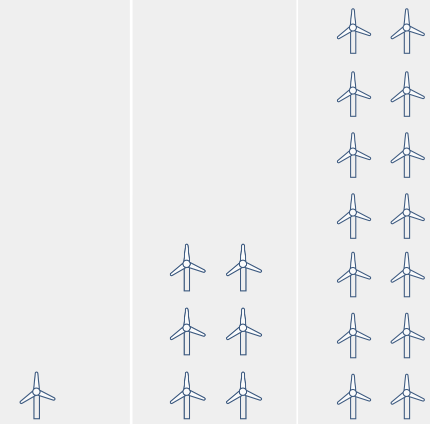
Efficiency: The guiding principle

Key elements

Efficiency of supply: Improving the efficiency of H&C production e.g., with retrofits, heat pumps, excess heat, or sector coupling.

Efficiency of transport and distribution and storage: e.g., with better insulation of pipes, hydraulic optimisation of pumps, closer proximity between end-users and producers, LowEx[1] concepts, thermal storages, interconnection between heating and cooling grids, design optimisation with digital tools.

Efficiency of demand: Improving efficiency of buildings and industrial production (renovations, insulation, process and energy management).



Number of wind turbines (3 MW):	1	6	14
PE (kWh electricity):	400	2,400	5,600
Efficiency (COP):	380%	330%	285%
Useful energy	1,500	8,000	16,000
	Passive house	EnEV 2007	Old building
Spec. useful energy	15kWh/m^2	80kWh/m^2	160kWh/m^2

COMPARISON OF THE ENERGY HEAT DEMAND OF A BUILDING ACCORDING TO ITS INSULATION STANDARD.

Necessary number of wind turbines (3 MW each) to supply 19 000 dwellings with electric heat pumps (in terms of annual balance). Source: Own depiction, based on Greenpeace / WI 2022

1. *LowEx and other concepts are further described in the report section, p. 63. For abbreviations, please see p. 77.*

Energy supply options for decarbonising DHS

Solar thermal

STRENGTHS	WEAKNESSES
• Emission-free, low-wear and noiseless renewable heat source without fuel costs • Ground-mounted: very high land use efficiency compared to other renewable energies • no additional land consumption • Modular, scalable technology • Relatively cheap storage option for heat (compared to electricity)	• Limitations in max. temperature levels • Space availability not always a given • Supply-dependent heat source (seasonal, daily and weather-related fluctuations)
OPPORTUNITIES	**THREATS**
• Very large (theoretical) potential • Ground-mounted collectors can generate very cheap heat even in northern or central regions in Europe (approx. 5 ct/kWhth) • No risk of energy price increases • Potential for hybrid land use (agri-solar thermal) • Good combinability with CHP ("Innovate Cogeneration")	• Ground-mounted: Despite technical maturity, still largely non-established technology in Europe (except in Denmark) • Not as prominent and visible in political and public awareness compared to prominent PV use

EXAMPLE: SOLAR DISTRICT HEATING SYSTEM IN SALAPILS, LATVIA

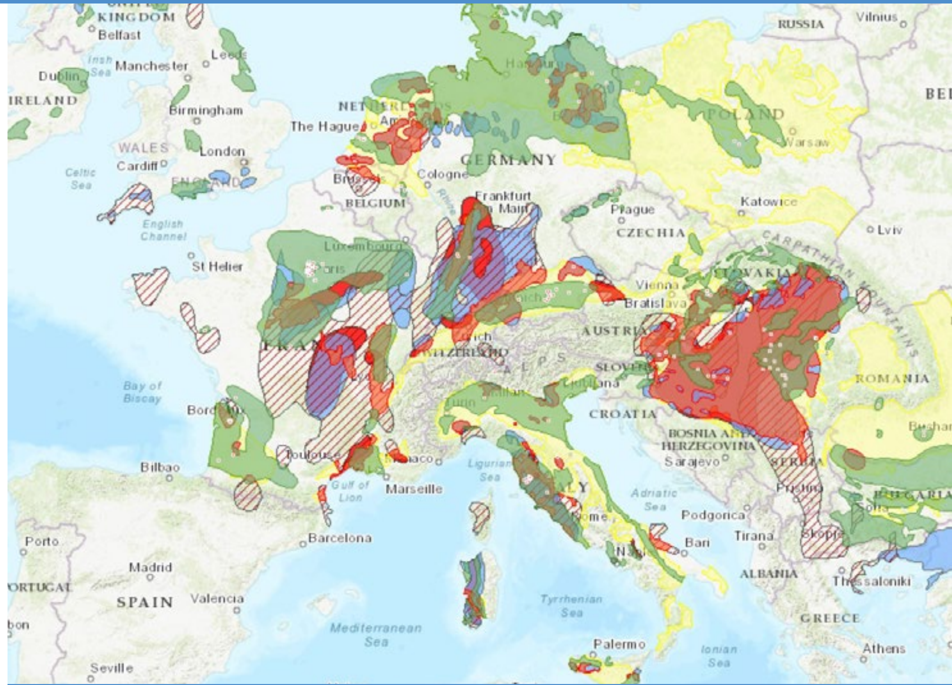
In the town of Salapils, Latvia, a 15 MW solar district heating system is being used to cover 20% of annual heat demand. Combined with a biomass-based boiler, the system will meet 90% of the demand on the local district heating network. The project uses an 8,000 m3 steel tank for heat storage, allowing the use of solar energy even when there is no sunlight for up to five days. The solar power plant was constructed right after the neighbouring cogeneration power plant (old district heating system) was shut down, which primarily relied on fossil fuels. The new system will not only reduce service and operational costs, but will also reduce heat prices for consumers.

Read more

Energy supply options for decarbonising DHS

(Deep) geothermal energy

STRENGTHS	WEAKNESSES
• Geothermal energy is essentially CO_2-free • It is a base-load capable renewable heat source • Low energy costs (pump electricity only) • Very low land-surface footprint • Negligible freshwater needs and • In principle, CHP-capable	• Potential and availability are both highly dependent on location • High investment (drilling, with uncertain potential until first exploratory well) • Sufficiently large heating network may be required for the highest efficiency and cost-effectiveness • Need to monitor (and manage) harmful mineral/gas pollutants
OPPORTUNITIES	**THREATS**
• Combination with other technologies (e.g., heat pumps, solar, biomass, mine water use) to further enhance its efficiency of operations • Generally high public acceptance • Potential for (seasonal) heat and cold storage in aquifers • Theoretical potential for synergetic raw material extraction of lithium	• Generally unknown potentials and exploration risks with regard to temperatures, volume flows and barriers • Geological and regulatory exclusion criteria (e.g. water protection areas) • National/regional legislative and insurance issues • Partial NIMBY problems



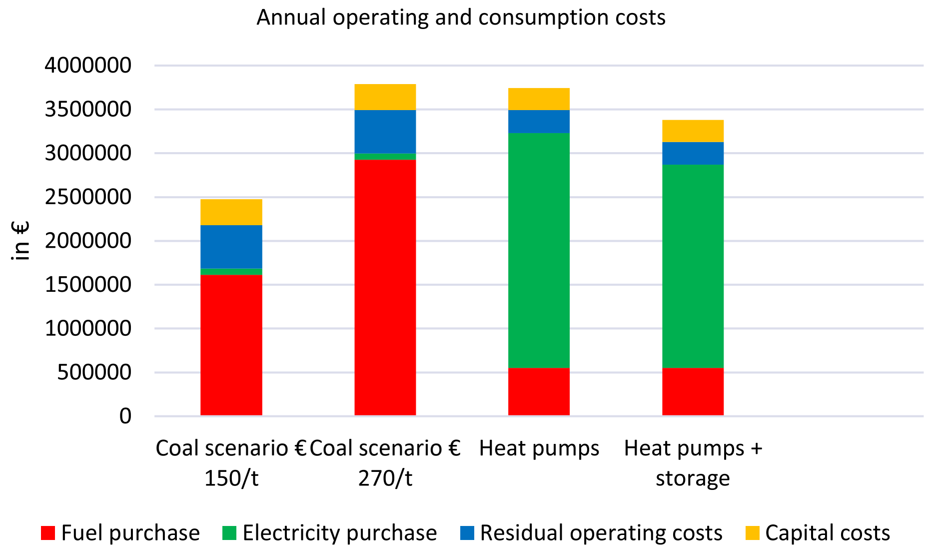
The GeoDH Geographical Information System shows the potential for geothermal heating in 14 EU countries. The colours represent areas which have been identified as favourable geological conditions. The map also shows all cities with district heating systems in place.

➔ Read more

Energy supply options for decarbonising DHS

Power-to-Heat

STRENGTHS	WEAKNESSES
• Proven, low maintenance, locally emission-free and quiet technology • Economies of scale with large HP units • Use of renewable heat (ambient heat, geothermal energy, waste heat, solar heat) • Load shifting instrument • Meets requirements for participation in the balancing power market (only direct electric PtH) • Geothermal probes with potential for energy-efficient and low-cost cooling	• Development of heat sources with sufficient capacity and temperature level is required • Decreasing energy efficiency at higher flow temperatures • Production of large heat pumps not (yet) a mass market • Partly use problematic refrigerants in large-scale HP
OPPORTUNITIES	**THREATS**
• Potential for complete decarbonisation (with 100% RE) • Further cost reductions very likely • Use in cold local heating networks (LowEx) • Integration of heat storage supports utilisation of RE supply peaks and stabilises the electricity grid • Synergies with CHP plants or solar utilisation with heat storage	• Dependence on electricity grid • Degree of decarbonisation and nuclear waste reduction depends on RE expansion (especially wind and PV) • Heat price depends on electricity price and development of surcharges, levies and taxes • Use of HP increases electric load (thermosensitivity).



RENEWABLE POWER-TO-HEAT IN HAJNÓWKA, POLAND

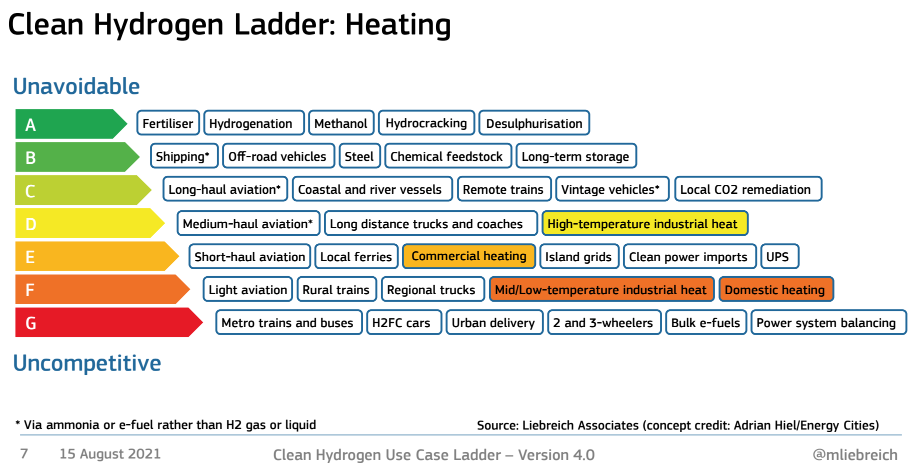
Hajnówka County holds great potential for the use of renewable energies, in particular for wind energy and photovoltaics. As a first step, the Hajnówka county commissioned a feasibility study to explore options for a Power-to-Heat heating system.

The results of the study exemplified that annual operation costs of the network would be lower for the power-to-heat solutions, except prices for coal would be very low, which in the long-run would become more and more unlikely due to the rising CO2 prices.

Energy supply options for decarbonising DHS

Fossil gas and alternatives

STRENGTHS	WEAKNESSES
• Widespread as a technically universal standard • Transport options via pipeline or in pressurised or liquid tanks • Generally efficient and relatively clean combustion properties compared to solid (fossil) fuels	• Climate damage from natural gas • Transport options: • Transport via pipeline need high investment costs • High losses associated with transport and conversion from/to tanks
OPPORTUNITIES	**THREATS**
• Very large theoretical potential for the application of renewable synthetic gases for global production and storage • Potential to use existing infrastructure when switching to more sustainable gases • High potential for efficient and/ or flexible technical applications • Energy carrier remains of central importance for the current supply	• Definite exhaustibility of fossil gases, and subsequent reliance on ever more difficult and expensive sources • Energy security/ geopolitical risks • Volatile prices • Risking a lock-in that prolongs climate change risks from continued reliance on fossil gas as a fallback option in case of renewable gases being not (sufficiently) available or too expensive



THE ROLE OF HYDROGEN FOR HEATING

The so-called Clean Hydrogen Ladder provides a way of visually portraying a supposed merit-order of priority uses of clean hydrogen (in place of grey hydrogen), whereby uncompetitive priorities are placed at lower rungs. Given the H&C orientation of this toolkit, it is worth drawing immediate attention to the fact that the best H&C ranking assigned is a mere “D” for high-temperature industrial heat, followed by the slightly worse “E” for commercial heating, which indicates the risks of “hydrogen-ready” alternatives that are discussed in several countries as a potential heating solution.

Energy supply options for decarbonising DHS

Biomass

STRENGTHS	WEAKNESSES
• Renewable, storable energy source • Close to CO_2-neutral over entire life cycle with respect to direct emissions • Baseload-capable heat and power generation • Highly efficient cogeneration possible in various CHP technologies • High temperatures achievable (up to approx. 500°C)	• Indirect GHG emissions and local CO_2 and pollutant emissions • Limited potential of waste and sustainable biomass/biogases and high land requirements • Storage space and transport infrastructure required
OPPORTUNITIES	**THREATS**
• Potential for increased flexibility • Technology for covering residual heat and electricity loads • Participation in the balancing energy market possible (biogas CHP) • With CCS, option for negative CO2 emissions (Bioenergy Carbon Capture and Storage, BECCS) • Potential for resource-saving cascade use, material inertisation and methanisation	• There is competition for the use of biomass both with respect to its supply and demand • Price risks for fuels with limited availability • Additional costs and infrastructure risks through CCS technology

BIOMASS CONVERSION IN ZAGORJE OB SAVI, SLOVENIA

Since 2004, the former coal municipality Zagorje ob Savi, Slovenia, has run a district heating system on two wood biomass boilers, each with a capacity of 2.5 MW, and one extra light heating oil (ELHO) boiler with a capacity of 7 MW capacity. It provides heat for around 1,000 end users. Biomass feedstock can be produced locally, yet with conflicting interests of wood use for other purposes, costs might go up significantly in the future. Therefore, the utility is exploring opportunities to install solar thermal plus heat pumps as an addition to the system.

Energy supply options for decarbonising DHS

Waste incineration

STRENGTHS	WEAKNESSES
• Energy recovery via various processes: combustion, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery • Benefits of Waste-to-Energy (WtE) when compared to traditional landfilling	• Similar to biomass, the carbon content in the waste that is burned for energy is emitted as CO_2 • Public financing might be complicated, e.g., ERDF, Cohesion Fund and JTF do not support investments that aim to increase residual waste incineration capacities
OPPORTUNITIES	**THREATS**
• WtE technologies can achieve reductions in GHG emissions when compared to waste landfilling • Future-oriented WtE might be able to recover nutrients and other valuable materials, • Possible application of the integration of carbon capture and storage (CCS), yet with strong limitations	• Improved waste management practices, including waste prevention, reuse and recycling will reduce residual waste in the future • The EU is gradually turning away from WtE, as demonstrated by its targets to halve residual waste by 2030. • New projects could end up as stranded assets.

COPENHILL

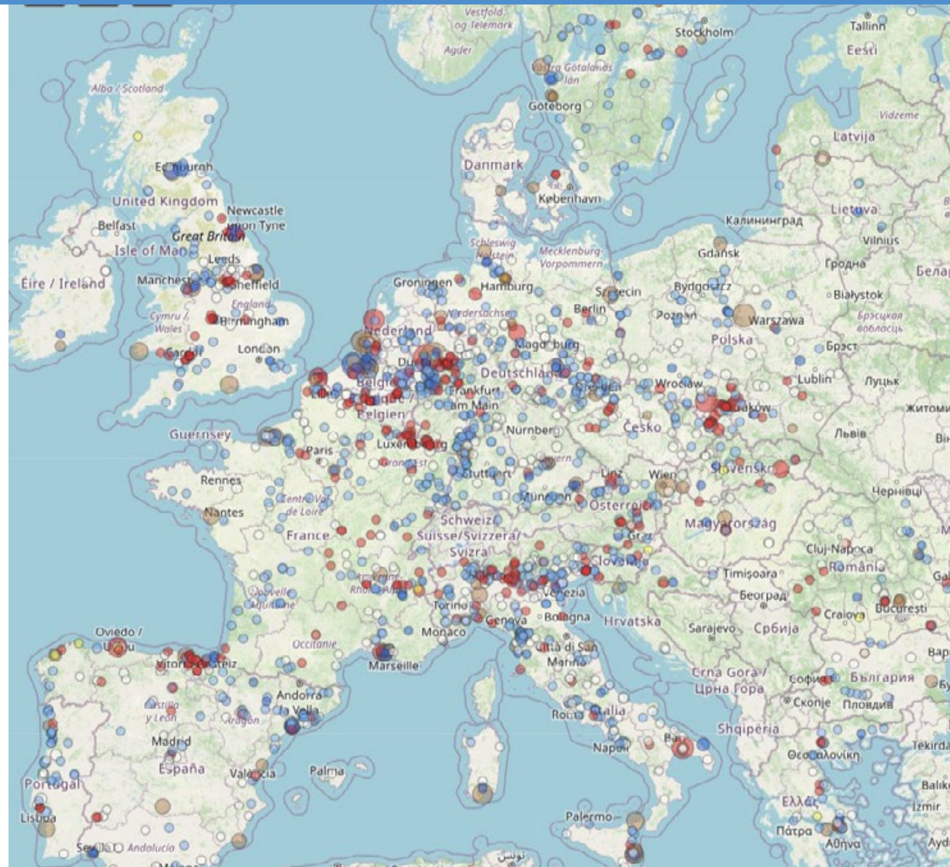
Probably the most famous waste incineration facility, CopenHill in Copenhagen (Denmark) has been showcased as a best practice example for many years. It has been praised for its integration into the urban area and for gaining great social acceptance. However it has also been criticised for being way over-dimensioned and importing waste from overseas, as well as unaddressed environmental concerns.

Energy supply options for decarbonising DHS

Excess heat

STRENGTHS	WEAKNESSES
• (On the balance sheet) CO_2-free and free/low-cost heat source • Very large theoretical potentials from energy production (power plants, electrolyser…) municipal (wastewater, sewage plants…), commercial (data centres…) and industrial (process heat) sources • Only relatively small (additional) area required for heat exchangers, filters, pumps and pipes	• Cost-intensive transport lines may be required • Mismatch of temperatures or load profiles may require investments in heat storage, booster and/or backup systems • Possibly abrasive or corrosive waste heat flows may demand expensive heat exchangers or filters • Radiant heat technically difficult to use

OPPORTUNITIES	THREATS
• Waste heat use can reduce active and cost-intensive cooling and thermal stress on waterbodies • Innovations for the use of radiant heat such as thermo-electric generators (TEG) • Very large low-temperature potentials can be raised with heat pumps • High political and social acceptance	• Detailed potentials on-site are often unknown • Potential risk of default (in terms of quantity, thermal output or temperature) due to loss or relocation of production or change of product or process • Lack of interest on the part of industry to supply waste heat (as long there is no obligation to use waste heat)



The sEEnergies Industrial Excess Heat Potentials Dataset Map shows sites in Europe that are in close proximity to district heating systems, and could therefore be relatively easily exploited.

Read more

Energy supply options for decarbonising DHS

Combined heat and power technologies (CH(C)P)

STRENGTHS	WEAKNESSES
• Efficiency technology (waste heat utilisation) for thermal power plants across a wide range of applications and performance • Technology diversity and possibilities to combine with other heat supply options • Contribution to secure generation capacities • Technical potential for switching from fossil to renewable gases and solid fuels	• Still predominantly dependent on (cheap) fossil fuels • Combustion technologies (especially motor CHP) have disadvantages in terms of noise, vibrations, pollutant emissions, maintenance requirements, service life, and methane slip
OPPORTUNITIES	**THREATS**
• Increasing demand for controllable power plants and flexibility, as well as sector coupling • Remaining heat demand for space and process heat that cannot be covered by alternatives (especially in winter) • Imports of RE gases from countries with lower-cost RE electricity generation potentials • Synergetic use of H2 feedstock pipelines in industry	• No more use of fossil fuels (natural gas, oil, coal) in the long term • Economic viability made more difficult by H2, SNG alternatives • High cost reduction potentials in alternative technologies of renewable electricity and renewable heat • Decreasing refinancing margins on the electricity side • Uncertainty about new gas supply

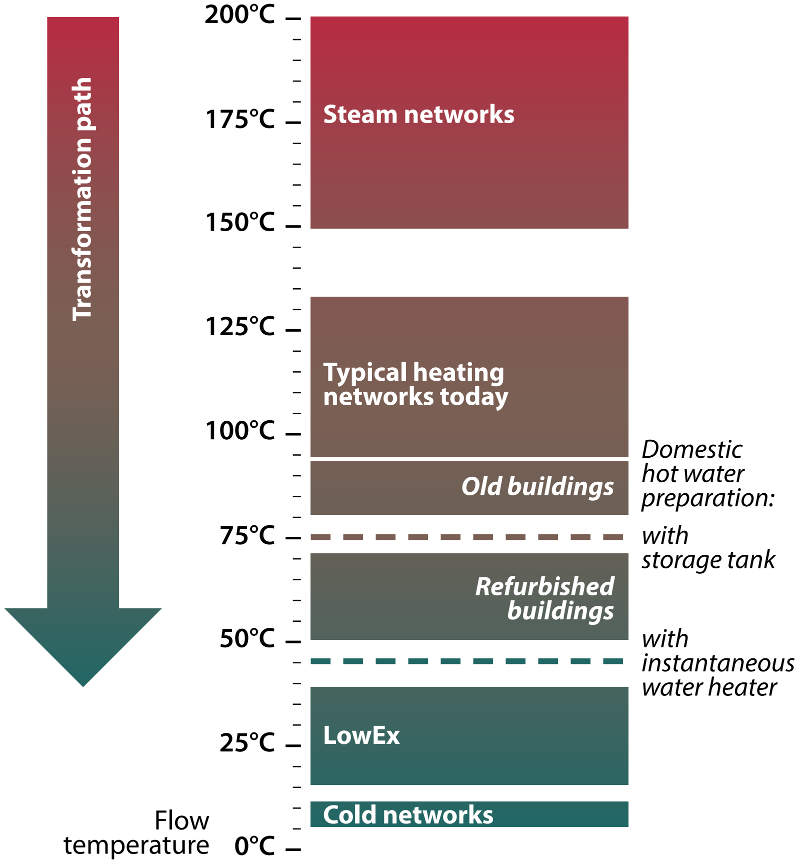
Integrated energy systems

Main levers

For the decarbonisation of district heating systems, the aim should be to create a system that is **very efficient** and can provide **secure H&C supply** at **low cost**.

At best, integrated energy systems can save up to 90% CO2 and 70% resource consumption compared to classic decentralised natural gas boilers.

- **Improving energy efficiency** as guiding principle
- **Lowering temperature levels** up to Cold Heating Networks ("LowEx")
- **Diversification** of supply and integration of excess heat
- **Thermal storages**
- **Flexibility** to use energy at the most efficient time (and to most efficient costs)
- **Decentralisation** of DHS, if more efficient
- **Sector coupling** and integration of cold networks
- **Digitalisation** and interaction between demand and supply



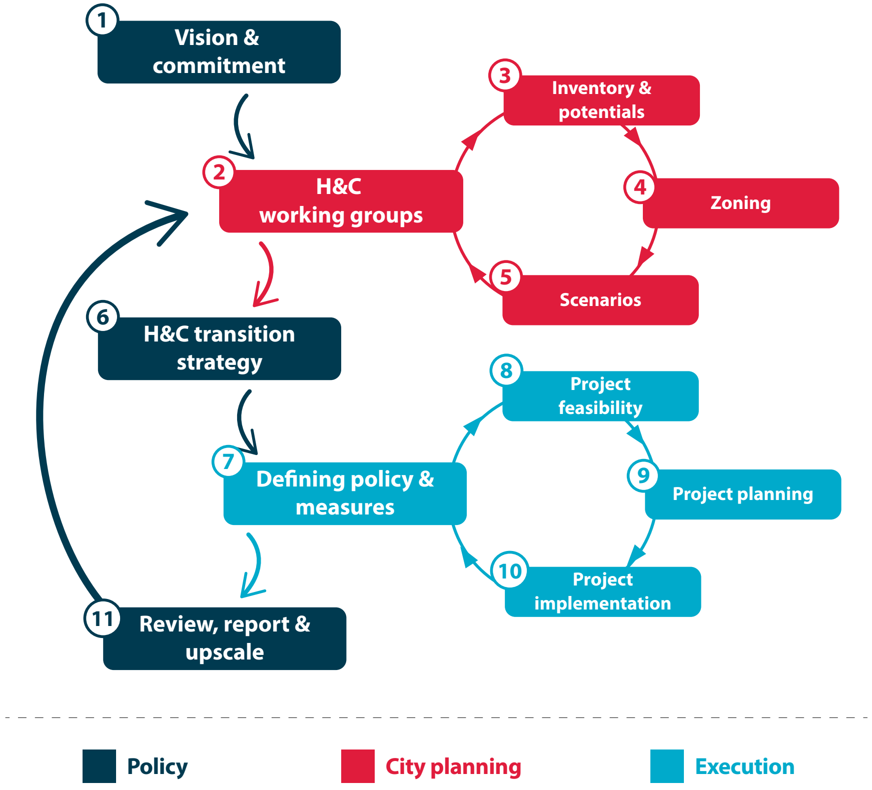
LOWERING TEMPERATURE LEVELS IN DHS IS ONE OF THE KEY ELEMENTS FOR DECARBONISATION.

Source: WI

Strategic H&C planning

Key elements

- **Clear goal-orientation** of local/regional decarbonisation, and with sub-goals and timeframes that are aligned with national and EU goals.
- **Embedding H&C planning** in other local/regional policies.
- **Aiming for efficient governance processes**, and linking strategic and operational levels.
- **Involving stakeholders** in the planning process – a step that is crucial for successful implementation.
- **Formulating a common decarbonisation narrative** to help raise awareness among citizens.
- **Removing unnecessary administrative burdens** and providing certainty and predictability for investors in the H&C sector.



TOOL: Ac!ionHeat WORKFLOW FOR INTEGRATED PLANNING

Strategic H&C planning

EXAMPLE: PROJECTZERO IN SØNDERBORG, DENMARK

AN INTEGRATED APPROACH THAT ACCELERATES CLIMATE ACTION, WHILE CREATING GREEN JOBS

ProjectZero is a public-private partnership established in 2007 in the Danish municipality of Sønderborg. The Sønderborg area is among the world's frontrunners in climate action – through work done as part of ProjectZero, by 2020 CO2 emissions had been reduced by 51% compared to 2007 levels.

THE GOAL

Achieving a carbon-neutral energy system by 2029, which at the same time, creates economic growth and green jobs.

THE APPROACH

- Creation of a Masterplan 2029, which describes how the area will reach its goal
- Energy efficiency and electrification in homes and businesses
- Green transport and conversion to electric cars;
- Creating an integrated energy system via excess heat from industry, biogas, a wind farm, Power-to-X (PtX) and district heating

SCHEMATIC MAP OF THE PROJECTZERO MASTERPLAN IN SØNDERBORG, DENMARK.

Strategic H&C planning

Policy instruments

- **Zoning:** offers opportunities to greatly influence the development of the H&C sector and to proactively create areas for development, while providing the conditions for economic activities.
- **Energy communities:** Cost and supply stability, paired with some degree of local ownership, e.g. through energy communities, can increase public acceptance of H&C solutions.
- **Mandatory H&C planning:** Experiences shows that fostering local planning through national legislation (including necessary planning capacities) can kickstart the development of DHS modernisation and overcome bottlenecks
- **Financial and fiscal incentives:** Crucial in overcoming the barrier of high upfront costs. The most commonly used instruments are financing grants, premium tariffs, low interest loans and tax exemptions.

GUIDANCE ON HOW TO SET UP ENERGY COMMUNITIES

There exist several well-developed guides on how energy communities work and can be deployed at the local level, also for district heating:

- Energy Community Guidebook
- How Cities can back Renewable Energy Communities
- Guidebook for Developing Energy Communities in Rural Areas

In-depth report

Table of contents

Aims and scope

Who is this toolkit for?

The target audience for this toolkit are actors pursuing a bottom-up approach to just transition away from coal, peat, lignite, and oil shale (coal+) in their regions:

- Local governments and regional authorities in coal+ regions in transition – especially those which have a district heating system (DHS) that currently runs on coal/peat, and are looking for guidance on how to decarbonise that system; this toolkit is also for regions that are more broadly looking for support with the decarbonisation of heating and cooling supply and want to expand their knowledge on district heating & cooling (H&C) opportunities.
- Small and medium enterprises (SMEs) and civil society organisations that are part of regional development processes at the regional and local level.
- Stakeholders working in energy utility management and planning processes looking for a broad overview of technologies and real-world examples from a regional systems and policy-complementarity perspective.

Why do we need this guidance?

The heating & cooling sector is responsible for a central part of the European Union's energy demand, representing roughly half of final energy consumption. As such, the decarbonisation of this sector is crucial for a successful transition to a carbon-neutral energy system by 2050. Recently, the EU strengthened their climate law further with the Fit for 55 package, which should enable the EU to reduce their emissions by at least 55% by 2030. As the window for action to stay below the 1.5°C goal of the Paris Agreement is rapidly closing, it is now especially crucial that larger energy infrastructure be decarbonised soon.

District Heating (DH) is infrastructure-heavy and many options to bring down its heat demand (e.g., through energy efficiency and refurbishing buildings) have rather long payback periods. Furthermore, some H&C alternatives are not always scalable for each and every coal+ region (e.g., biomass) or risk long-term lock-in effects on carbon emissions (e.g., natural gas). Targeted knowledge can therefore provide municipalities, regional authorities and district heating system operators with an overview about the options for decarbonisation pathways and governance mechanisms to steer transition in the sector.

Introduction

DH is an important part of H&C decarbonisation for many coal and carbon intensive regions, especially those within northern, central and eastern parts of Europe (see figure 1). The substitution of solid fuel heat supply with low-carbon alternatives calls for regional and local solutions, but also faces many challenges. **This toolkit gives an overview about the technology options available to support decarbonising DH networks, and the roles they play in decarbonisation and future heat supply**. In that way, the following pages can assist stakeholders to assess what might or might not work (e.g., taking into account certain temperature regimes or other prerequisites for a DH system to be successfully switched), as well as if which options complement certain technologies particularly well (where it is possible to distinguish this). Each technology is critically evaluated and presented with an example.

While the technologies are a key piece of the puzzle, it is equally crucial to stress the importance of thinking of district heating as an interconnected, complex heat system, and not only as a power source. Accordingly, this toolkit follows the approach of a five-step model (see figure 2) that builds on up-to-date knowledge about what needs to be done to decarbonise district heating systems.

First and foremost, there is a need to aim for energy sufficiency and increase energy efficiency. This must be done not only on the supply side (e.g., heat production and

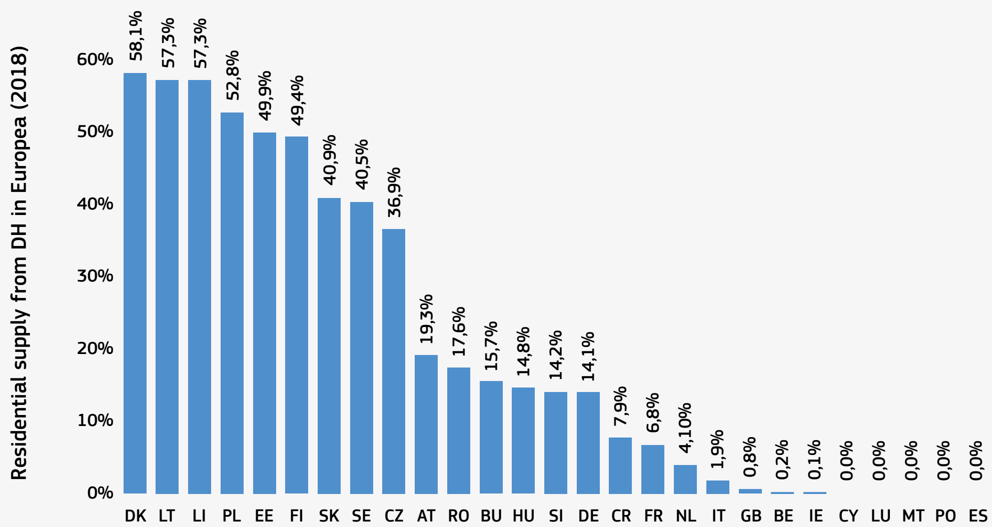


FIGURE 1: SHARE OF RESIDENTIAL HEAT SUPPLY FROM DH IN EU COUNTRIES.

Source: Sayegh et al. 2023

distribution networks), but also on the demand side (e.g., in the industrial sector using process heat, and in individual buildings and districts needing H&C services). This should logically be the first step in any H&C planning, and is thus included as the first chapters in this toolkit, subsequently followed by the technological overview of energy sources and technology options for district heating systems. The fourth chapter will then focus on system integration for DH systems, such as sector coupling (synergies with CHP and electricity production and use), hybridisation and flexibilisation, digitalisation and energy storage.

The fifth chapter introduces strategies for local planning of green DH systems, focusing on lessons learnt, available tools and practices and practical information for local/regional authorities and other key stakeholders.

Since nearly half of the coal heat supply in Europe is burned in household coal stoves, we further briefly introduce the topic of heating individual households. While this toolkit has a distinct primary focus on heating network based solutions, and in many cases connecting individual households to district or local heating network systems proves to be the best option, more sustainable individual heating solutions should not be left completely unaddressed.

Sufficiency: the long-term goal

For coal+ regions in Europe, it's best to ask at the very start, even before contemplating specific energy sources or measures to achieve energy savings:

1. How much heat is truly enough?
2. Even if we can produce a lot of sustainable energy and use it "well", is it really necessary?
3. How can we avoid heat energy generation and demand in the first place, before even needing to think about how efficient or clean it is?

These questions refer to a concept called 'sufficiency'[1]. Sufficiency refers to only producing what is needed, instead of as much as can be produced – which is what the world has been doing for decades, and thereby exceeding planetary boundaries every year. In the context of decarbonising DH systems, applying sufficiency principles result foremost in thinking about possibilities to reduce the demand side of H&C. This means, for example, only switching on the heating when people are actually inside a building, or avoiding larger over-capacities by producing only the amount of H&C that is actually needed. That being said – as there are often misunderstandings of the concept

1 For a better understanding of what "sufficiency" means, especially in understanding its relationship to other similar terms, this "Decoding Sufficiency" glossary may prove useful. For even more about how this concept is becoming seen as more and more crucial to apply to multiple aspects of climate mitigation, and provide a larger context for its importance for DH, please refer to the IPCC's 6th report from 2022.

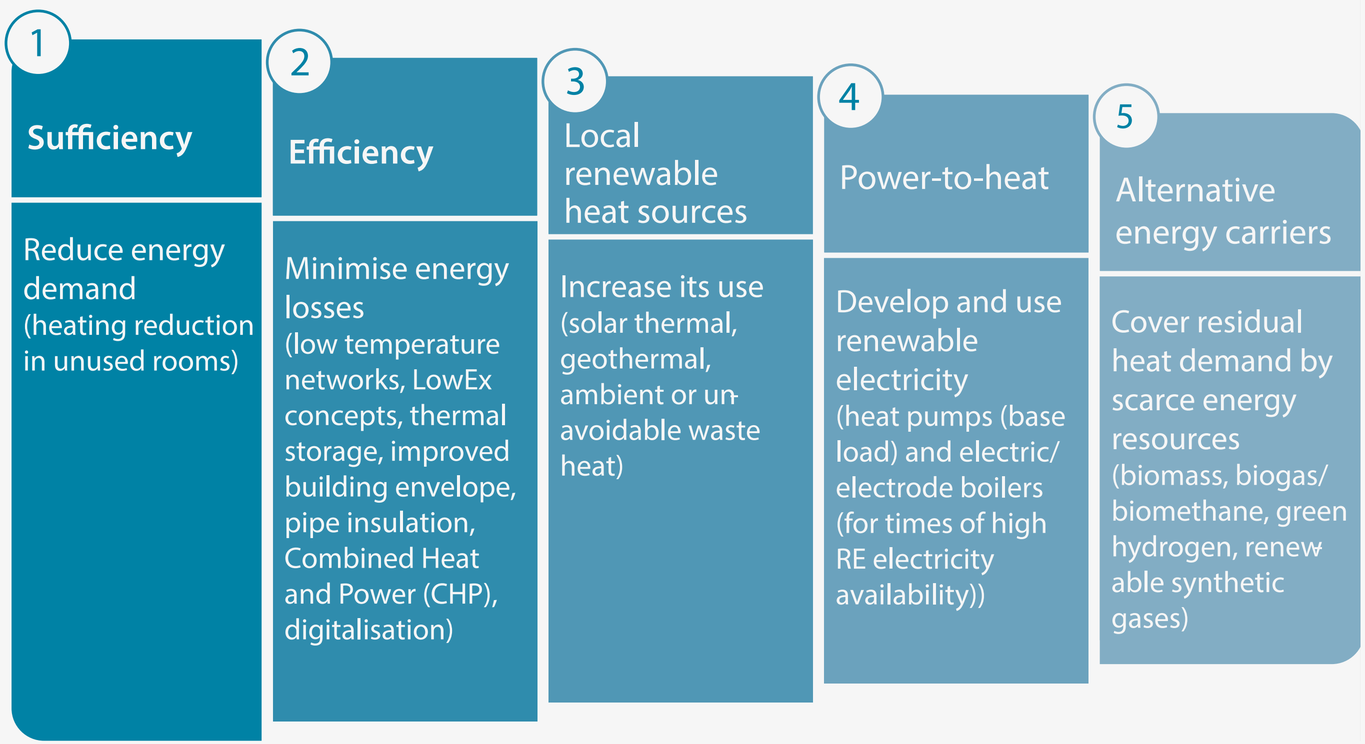


FIGURE 2: A FIVE-STEP MODEL FOR DISTRICT HEATING DECARBONISATION.

Source: EC 2023, based on IN4climate.nrw 2021

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– it is important to mention that sufficiency does not mean sacrificing thermal comfort, renunciation of something that is really needed, nor pushing people into a monastic-like lifestyle. Instead, sufficiency in the context of DH systems should be considered as a guiding principle that helps to identify ways to increase cost-effectiveness of the system that goes beyond technological aspects.

In practice, attaining sufficiency in sustainable heat planning is a balancing act between covering today's heating needs, while still preparing for tomorrow's needs. One must account for current users' heat demand patterns, not to mention overcoming network disruptions, while also anticipating longer-term shifts in both consumption and production.

The marked trend towards renovating existing building stock and constructing new buildings to be more efficient (pushed forward by numerous forward-thinking local to EU policies) may lead to lower heat demands in the future. This could make current DH systems over-dimensioned, with higher capacities and temperatures than needed. On the other hand this could offer the chance to connect more consumers on an existing network or even extend the network without the need to boost the capacity of its heat generators.

At the same time, tendencies in many cities to expand DH networks beyond city centres into older neighbourhoods and brand-new districts could result in system temperatures being too low for higher demand, unless new heating capacities are brought online to compensate.

The concept of sufficiency is not just about the bare minimum of (immediate/future) needs, but also ensuring that operations can be counted on. DH systems require resilience and backups to run reliably and respond to unavoidable network disruptions. This should hardly be news, and is rather a kind of standard practice for DH operations already. Even so, the introduction of renewables into the heat supply often forces a system to account for even more variable production levels, and possibly longer-term shifts in customer usage (e.g., towards reduced heating needs through more efficient buildings and, in some cases, even DH-disconnections in favour of individual heating technologies).

Furthermore, decision-making is not done in a vacuum; just because we may be able to agree that fully decarbonised heating is the ideal, it's not always feasible (at the moment) to quickly integrate sustainable sources. Sufficiency considerations must therefore also take into account socio-economic factors to determine how "clean" heating production should be, at a given moment. It serves almost no one for a DH system to become environmentally sustainable overnight – such a quick change would drastically hit a company's bottom line, and costs would likely get passed on to customers, particularly impacting those already suffering from energy poverty. Instead, the guiding questions should be: how "clean" can we feasibly make heating tomorrow, as well as how and when (*not 'if'!*) do we make it sufficiently "cleaner" after that?

These are not easy questions to address, and there is no one-size-fits-all answer. Nonetheless, the important thing is to earnestly ask yourself such questions from the start, and thereafter find those answers which sufficiently satisfy stakeholders' needs in your region.

Energy efficiency: The guiding principle

Increasing the efficiency of district heating systems is an important building block of district heating decarbonisation and has – broadly speaking – tremendous and often underestimated potential. The updated energy efficiency directive (EED) represents recent efforts at the EU-level to increase energy efficiency and will be transposed by member states by October 2025, indicating that on a country level there will be new legislation affecting district heating as well. Additionally, various EU-countries have introduced policies to increase energy efficiency in the H&C sector.

In this toolkit, we put the primary focus on the major technological shifts that will be necessary to decarbonise the district heating system as a whole, switching from fossil fuels to renewable heat source alternatives. These big technological changes will make a huge difference, but are very much place-based and need to be planned thoroughly to not only change the source of H&C, but also to change the whole system to a more efficient one. While aiming for *sufficiency* is the long-term goal for H&C supply, rebuilding the system with the aim to reach very high *efficiency* can be considered as the guiding principle for all systematic approaches to decarbonise district heating systems.

This is also reflected in the ways district heating systems have evolved over the last century: district heating systems have improved a lot in terms of energy efficiency over time (see figure 3). There are two major indicators that are characteristic of this development:

1. The **temperature level** of the flow temperature fell from far over 100°C in a system using hot steam pipes to 50-70°C in the latest generation system. At the same time the return temperature is lowered.
2. The **system integration** of the heating grid increased, with stronger interconnectivity between consumers and supply, new forms of energy generation, storage, sector coupling and connection to cooling grids.

Both temperature level and system integration are strongly correlated with the overall efficiency of the system. It is therefore imperative to increase efficiency by using both these levers.

The questions then emerge: how can the temperature of the system be lowered, while still providing all consumers with their needed/requested level of heat? And what is the most efficient combination and grid setup for an efficient interconnected system?

Generally, all modern district heating systems are demand driven, meaning that the heat producer reacts to the demand from the consumers, and ensures that there is sufficient temperature and water pressure. It is therefore on the heat supplier (and/or owner of the grid, as these are sometimes not the same) to find ways to optimise the system. Meanwhile, the actual biggest potential for overall system optimisation lies on the demand side via **energetic renovation of buildings** (see box). For regions and municipalities with a district heating system, it will therefore be absolutely crucial to simultaneously invest

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in the decarbonisation and optimisation of the district heating system itself, while also encouraging and incentivising energetic modernisations to significantly lower the heat demand of buildings.

Supply and demand measures should be developed in tandem, as there is a risk that higher efficiency in H&C supply (and accordingly, lower prices in the long-term) will result in fewer incentives for building owners for energetic modernisations. An example of how an energy policy design based on an energy-efficiency-first principle can look like has been developed in a recent paper by [Yu, Mandel and Thomas (2022)](). Further guidance on regulation can be found in the "strategic H&C planning" chapter.

In short, the following elements will be most important for increasing the efficiency of district heating systems:

- **Efficiency of supply:** Improving the efficiency of H&C production e.g., with retrofits, using more efficient technologies such as heat pumps (HP), using industrial, municipal or commercial excess heat, application of sector coupling such as combined heat and power (CHP), Power-to-Heat (PtH) or Power-to-Gas (PtG)
- **Efficiency of transport and distribution and storage**: Improving the distribution of the H&C grid e.g., with better insulation of pipes, hydraulic optimisation and retrofit with high-efficiency pumps, closer proximity between end-users and producers, integration of sub networks with lower temperature level (LowEx concepts), integration of (seasonal) thermal storages, interconnection between heating and cooling grids, design optimisation with digital tools like smart (non-)linear programming of district heating systems and improved pressure difference control)
- **Efficiency of demand**: Improving efficiency of buildings and industrial production (renovations, insulation, process and energy management) to lower the energy and capacity demand as well as the necessary temperature level.

In the following sections of this toolkit, we provide further insights into several of the aforementioned aspects in more detail. For example, system integration has its own chapter, including further explanations about the latest (and most efficient) generation of district heating systems shown in figure 3. All relevant energy sources & technologies have their own sub-chapters, including details regarding their technical and economic efficiency, benefits and challenges.

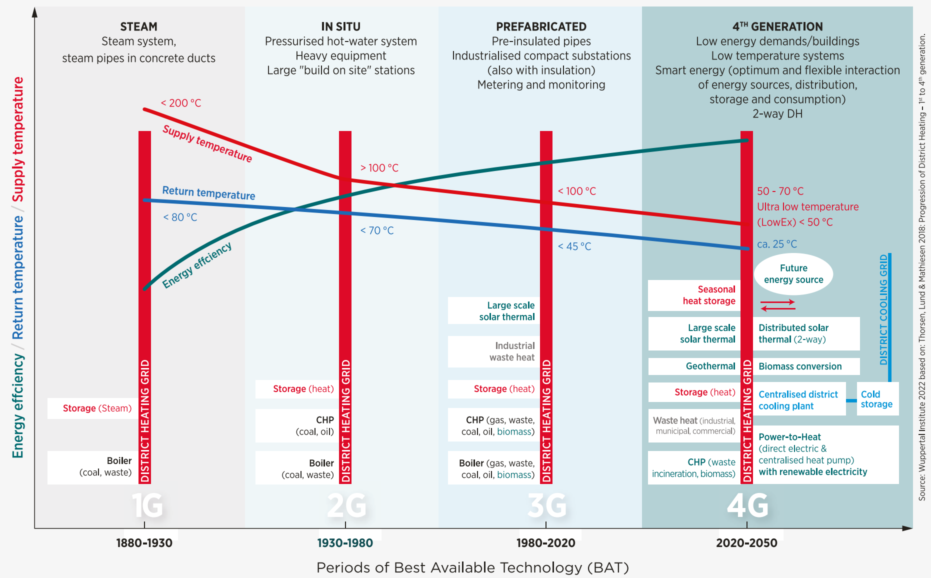

FIGURE 3: GENERATIONS OF DISTRICT HEATING SYSTEMS.

Generally speaking, there are four (some sources also speak of five) generations of district heating systems, each with its own characteristics. The first generation, which was developed in the 19th century, used steam as the heat carrier. The second generation, which emerged in the 20th century, used hot water as the heat carrier. The third generation, which is currently the most common type, uses prefabricated components and is more efficient than previous generations. The fourth generation of district heating systems is characterised by the use of low-temperature heat (below 70°C), closer integration of consumers, and the use of various renewable energy and waste heat sources. The usage of even lower temperatures (near ambient ground temperatures) and a combined cooling network is sometimes referred to as the 5th generation, yet the differences when compared to the 4th generation are rather marginal, which is why it is often left out.

Source: Wuppertal Institute based on Henrik Lund et al. 2014

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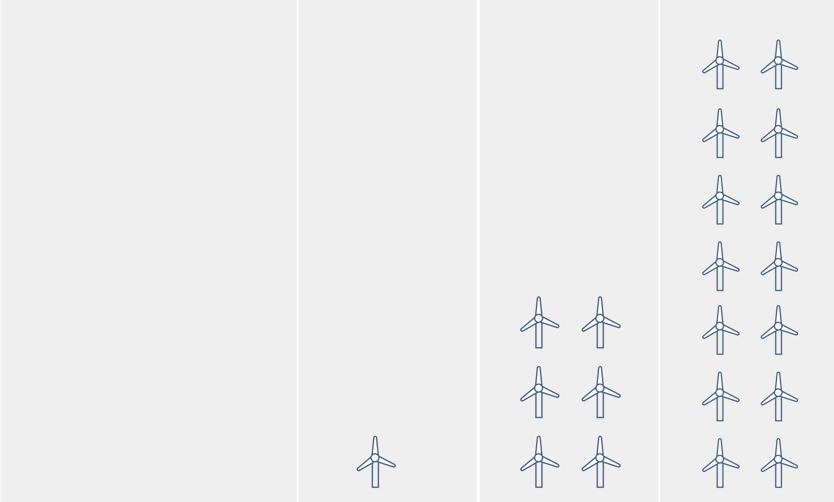
ENERGETIC MODERNISATION OF BUILDINGS IS A MAIN LEVER TO INCREASE ENERGY EFFICIENCY AND LOWER GHG (GREENHOUSE GAS) EMISSIONS

Most activities today focus on the renovation of buildings – and for good reason. Today, roughly 75% of the EU building stock is energy inefficient, resulting in a huge portion of produced energy being wasted. The European Commission (EC) expects that renovating existing buildings could reduce the EU's total energy consumption by 5-6%, and lower carbon dioxide emissions by about 5% – this represents more carbon dioxide that is currently emitted by the whole aviation sector (3.8%) in the EU, and this is even based on rather conservative assumptions (generally, buildings can often save 30-50% of GHG emissions after energetic modernisations). Figure 4 illustrates the staggering difference between the energy that is needed to electrically heat energy efficient buildings (PH, passive house standard), compared to inefficient unrenovated buildings. The figure is to be read from bottom to top and from left to right: As an example, 19,000 residential units (100 m^2 each) of the most efficient building standard require 7.6 million kWh of renewable electricity, which (purely in terms of the balance sheet) is about the annual production of a single 3 MWel wind turbine[2]. To supply the same number of units in a renovated, but less-efficient (German) EnEV 2007 standard building requires six times as many wind turbines, while an unrenovated or only partly renovated old building (also with a heat pump) requires 14 times as many. To heat old buildings with heat pumps, you would therefore need 14 times more wind turbines compared to the supply of buildings with the most efficient standard. Even though this is a comparison between the extremes (and should not be mistaken as a recommendation that all buildings could or should be modernised to a passive house standard), this exemplifies the huge impact energy efficiency measures on the demand side will have on the overall H&C supply, and how much easier it will be to implement a technology shift to renewables if, at the same time, efficiency measures are taken seriously.



Number of wind turbines (3 MW):	1	6	14
PE (kWh electricity):	400	2,400	5,600
Efficiency (COP):	380%	330%	285%
Useful energy	1,500	8,000	16,000
	Passive house	EnEV 2007	Old building
Spec. useful energy	15kWh/m^2	80kWh/m^2	160kWh/m^2

FIGURE 4: COMPARISON OF THE ENERGY HEAT DEMAND OF A BUILDING ACCORDING TO ITS INSULATION STANDARD.

One wind turbine (3 MW each) can supply around 19 000 dwellings with electric heat pumps in terms of annual balance. Source: Own depiction, based on Greenpeace / WI 2022

2 Assumed here is a modern wind turbine at a good location with 2,500 full utilisation hours and thus an annual yield of 7.5 million kWh

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Energy supply options for decarbonising district heating systems

Scenarios that are congruent with Europe's 2050 carbon neutral target, which also implement the ideas of energy efficiency and limited use of scarce resources such as biomass and hydrogen, show what the European energy mix for DH could look like. Figure 5 illustrates the **reduction of energy demand** due to energy efficiency measures and the **phase out of coal, fossil gas and oil**.

Following this approach, the main pillars for heat generation will be **power-to-heat** – using renewable electricity and ambient heat – **solar thermal heat**, and a proportion of **deep geothermal energy** in suitable areas. The use of **biomass** and **waste** will be more or less stable until 2035, but then will decline, as significant shares of these energy carriers will have to be redirected to industry for high-temperature applications, and be used as raw materials or chemical feedstock. **Hydrogen** (ca. 60 TWh in 2050) will only replace a small part of fossil gas (ca. 275 TWh in 2018).

This scenario exemplifies the pathway that district heating will most likely need to take to ensure that Europe is fit for a climate neutral future. In the pages that follow, we explain the role various technologies and energy sources will play in this transition. For each option, we provide a SWOT analysis overview (Strengths, Weaknesses, Opportunities and Threats), showcasing the most important aspects of each technology. More technical aspects are overviewed in a detailed table in the annex on page 78.

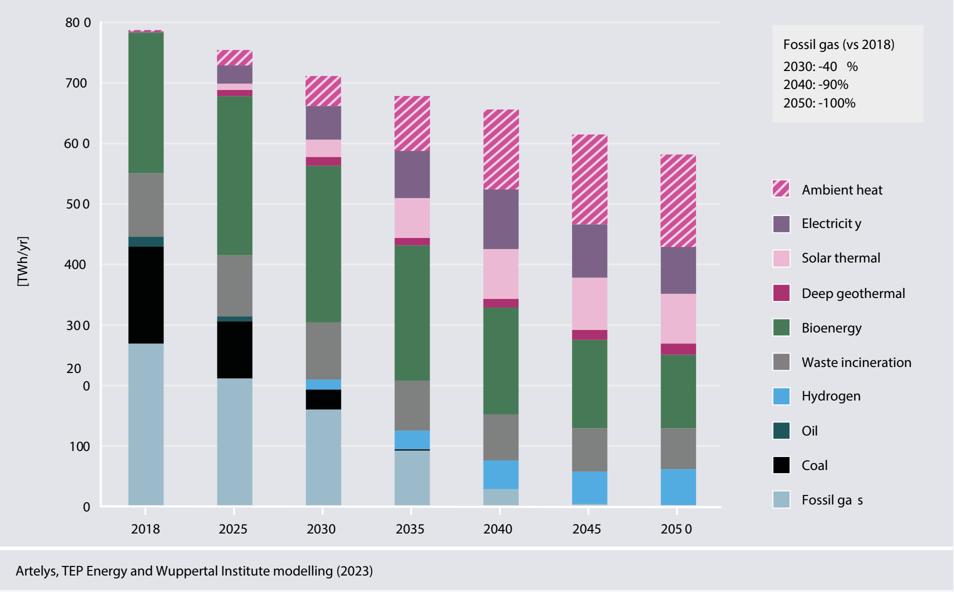

FIGURE 5: ENERGY MIX AND ENERGY DEMAND FOR DISTRICT HEAT GENERATION IN A CLIMATE NEUTRAL SCENARIO (EU-27)

Source: Agora, WI et al 2023: Breaking free from fossil gas - A new path to a climate-neutral Europe

1. Solar energy

In many places around the world the infinite source of solar energy will be a major component of decarbonised heating systems. In fact, solar collectors function well even with the medium levels of solar irradiance found in most parts of Europe. Solar energy technologies are scalable from decentralised micro solutions to large scale plants in the megawatt range.

Unlike photovoltaic technology, solar thermal technology converts sunlight into heat instead of electricity. The main component of this technology is the collector that absorbs thermal energy from the sun. This energy is then used to heat a carrier fluid through a pipe system. The thermal energy of the heated agent is transported via a heat exchanger to a storage tank, where it can be used to generate heat for buildings (space heating and/or domestic hot water generation) or district heating systems, depending on the system design (see figure 6). Both fuel-based and electricity-based heating systems can be combined with solar thermal technology since it is very flexible, scalable, and adaptable.

Various technologies, such as solar thermal (flat plate or vacuum) collectors, concentrated thermal collectors (CST), and hybrid photovoltaic thermal collectors (PVT), can be utilised to integrate solar energy into the district heating system. While all three technologies can help promote sustainable energy, lower greenhouse gas emissions and reduce dependence on fossil fuels, their achievable temperatures, efficiencies (in terms of specific solar yield per square meter and year), and costs can vary (see figure 6). Concentrated thermal collectors - also known as a parabolic trough collectors - are more effective and the only one that reach higher temperature level, so that there are even suitable to deliver industrial process heat/steam up to 300°C. However, they are currently also more expensive than non-concentrating solar thermal collectors, which have made great progress in efficiency and costs, and now are the most established and cost-effective option, especially for larger ground-mounted systems up to 80

STRENGTHS	WEAKNESSES
• Emission-free, low-wear and noiseless renewable heat source without fuel costs • Ground-mounted: very high land use efficiency compared to other renewable energies (PV, but especially bioenergy) • Building-integrated: no additional land consumption • Modular, scalable technology • Relatively cheap storage option for heat (compared to electricity)	• Limitations in max. temperature level: - flat plate: ≈ 80°C - vacuum collector: ≈ 120°C - concentrating collector: ≈ 300°C • Sufficient space availability not always a given, especially in densely populated areas • Supply-dependent heat source (seasonal, daily and weather-related fluctuations) → investment in heat storage, booster and/or backup systems required
OPPORTUNITIES	**THREATS**
• Very large (theoretical) potential • Ground-mounted collectors with potential for very cheap heat generation even in northern or central regions in Europe (approx. 5 ct/kWh_{th}) • No risk of energy price increases • Potential for hybrid land use (agri-solar thermal) • Good combinability with CHP (“Innovate Cogeneration”), as CHP electricity generation tends to be unprofitable in summer due to high PV electricity feed-in and lower electricity and heat loads • As a fuel saver, good combinability with biomass/biogas or hydrogen	• Ground-mounted: Despite technical maturity, still largely non-established technology in Europe (except in Denmark) • Not as prominent and visible in political and public awareness compared to prominent PV use

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to 100°C. Solar PVT or photovoltaic collectors are a more recent hybrid technology that combines thermal energy collections with solar electricity generation, resulting in higher combined thermal and electrical efficiencies. By this combination they achieve a very high area efficiency. This can be particularly advantageous when space is limited. However, this also makes them more expensive than conventional solar thermal collectors. Despite common public perception to the contrary, most places in Europe are suitable for use of thermal solar systems as a source of renewable energy to supply local heating networks. These solar systems can also be connected to a heat network and used in combination e.g. with a peak load boiler, biomass cogeneration plant, or a heat pump. SDH with lower solar shares (up to 15%) only need a smaller, temporal storage tank. For higher solar shares (up to 50% and more) seasonal heat storage is indispensable. To store solar heat seasonally, well-insulated big water tanks, underground pits (such as ex-coal mines), geothermal boreholes, or aquifer storage fields are used (read more in the chapter System Integration).

Solar District Heating (SDH) is a type of district heating system (partly or dominantly) based on solar thermal technology; SDH plants are a large-scale application of conventional solar thermal technology. These technologies can be integrated into local district heating networks for both residential and industrial use, reducing dependence on fossil fuels. Additional seasonal storage allows the system to meet a share of heating demand during the winter months, even with little to no sunlight. District heating systems based on solar energy could achieve temperatures of 80°C to up to 300°C.

Advanced controls and metering are crucial for effective operation and maintenance of the SDH systems. SDH systems usually consist of solar thermal plants made up of hundreds of solar thermal collectors and several thousand square metres of solar collector area in total. More than hundred realised SDH plants make Denmark to European's front runner in SDH technology. The greatest plant Silkeborg Forsyning has already been established in 2016 and has a capacity of 156 700 square meter and 110 MWth.

Larger collectors with bigger loads are required for such large scale installations. For smaller systems, such as block heating, normal solar thermal collectors, either flat plate, evacuated tube, or even concentrating, can be used. The network can consist of a centralised supply, where a very large collector field delivers heat to a main centre. It can also provide a large seasonal heat storage that will increase the input of the solar thermal plant to the whole system.

Another possible configuration of SDH systems is decentralised supply or distributed solar district heating. In this case, solar collectors are placed at suitable locations such as buildings, small fields, and connected directly to the district heating primary circuit on-site. This solution can also be interesting for small district heating networks or block heating networks. This is demonstrated in Spain, where solar collectors are being installed as building-integrated solutions in a building complex owned by the Basque Government. The solar collectors will deliver energy for heating and domestic hot water preparation for the building itself, while simultaneously providing excess heat to a low-temperature district heating network. The entire heating district network was originally designed for an operational temperature of 80 degrees, but part of the network has now been transformed into an ultra-low temperature network. The lower temperature will ease the integration of low-energy heat sources such as solar heating systems into the network.

The success of SDH projects depends on factors such as the availability of renewable resources (in the sense of available open spaces), the cost of and space for storage, and the readiness of the district heat network to integrate heat from solar thermal collectors. The initial cost of the system, the system's lifetime, and performance are the main parameters that affect the cost of energy produced by the system. When thinking about solar thermal systems, it is crucial to keep these things in mind, especially because prices might change greatly between systems and between nations.

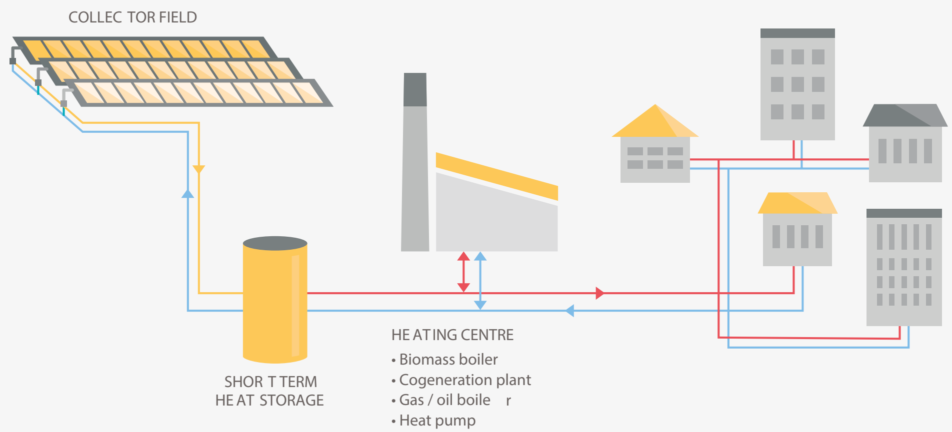

FIGURE 6: SCHEMATIC SET-UP OF SOLAR THERMAL COLLECTOR FIELD COMBINED WITH DISTRICT HEATING.

Source: IEA SHC TASK 55

According to the International Energy Agency (IEA), the average investment costs for large solar thermal systems in Europe can range from 530–1800 USD/kWth (approximately 500–1685 EUR/kWth). Upfront costs, especially when investing in thermal storage, are a usual challenge. However, running costs are comparatively low, with systems that run on lower temperatures (≤ 100°C) in particular seen as quite robust and efficient DH.

Overall, solar district heating systems are a promising solution for providing large quantities of hot water for space heating and domestic hot water. They are efficient, marketable, economic, and environmentally friendly, making them a sustainable alternative to decentralised fossil fuel-based boilers.

EXAMPLES FOR SOLAR DISTRICT HEATING

In the town of Salapils, Latvia, a 15 MW solar district heating system is being used to cover 20% of annual heat demand. The solar district heating in Salaspils, combined with a biomass-based boiler, will meet 90% of the demand on the local district heating network. The project uses an 8,000 m^3 steel tank for heat storage, allowing the use of solar energy even when there is no sunlight for up to five days. The solar power plant was constructed right after the neighbouring cogeneration power plant (old district heating system) was shut down, which primarily relied on fossil fuels. The new system will not only reduce service and operational costs, but will also reduce heat prices for consumers. The EU's Cohesion Fund contributed 2.73 million EUR toward the overall project investment costs of 7.08 million EUR.

THE SOLAR COLLECTOR FIELD FOR THE DISTRICT HEATING SYSTEM IN SALAPILS, LATVIA

Source: Salaspis Siltums

Another example of solar district heating is the project being developed at the Municipality of Obiliq near Pristina, Kosovo[3], by Pristina's municipal district heating firm Termokos. The project is funded by grants provided by the EU and the German development bank KfW, as well as a loan from the European Bank for Reconstruction and Development (EBRD). To date, a majority of the energy consumption in Kosovo comes from the burning of coal, affecting air pollution. The integration of solar power in this district heating project will reduce the burning of coal and wood for heating by households, which in turn will increase air quality and reduce carbon emissions by up to 47,000 tons per year.

The new solar project includes a solar thermal system with 40.6 MW solar collectors fields and a seasonal storage of 408,000 m3 with absorption heat pumps. The heat pumps play an essential role in solar power district heating solutions, as it can heat up water from the seasonal storage tank when demand of the supply line for the heating network is not met. The heat pump can also extract additional energy from the return flow of the heating network before it enters the storage tank again. As a result, the lower layers of the storage tank remain relatively cool so that the operating hours and thus the yield of the solar field increase. Overall, this allows high solar shares in district heating grids even with higher temperatures.

More examples and resources can be found at the website of the International Energy Agency (IEA) 's Solar Heating and Cooling Programme.

3 This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ opinion on the Kosovo declaration of independence.

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2. (Deep) Geothermal energy

Generally, one can differentiate between "near-surface/shallow geothermal" (<400 m depth as a rule) and "deep geothermal" (>400 m) As near-surface geothermal is mostly a source for heat pumps, it is discussed mainly in the chapter "Power-to-Heat".

Deep Geothermal energy takes advantage of naturally-stored underground heat, whether from deep underground magma chambers, or particular geomorphologies (e.g., Europe's Pannonian Basin). Geologists have demonstrated that temperatures increase an average of around 30°C/km of depth into the rock below, though locations with the right conditions can have even higher geothermal gradients.

Though exploited even in ancient times, geothermal technologies have continued to develop via two main methods, which have (literally) gained steam through to the present day: "flashed steam" or using "binary" plants. The former uses very hot water from underground, generating steam by artificially reducing its pressure, while the latter entails hot water being pumped above-ground to pass through a heat exchanger, before a closed loop transfers steam to a turbine. Both approaches can allow for much) higher production capacities, and the utilisation of lower temperatures, than was possible through the earlier "dry steam" approach (e.g., power production in Alaska with geothermal fluid at just 57°C). These kinds of technological advancements have resulted in even wider exploitation of geothermal potentials in all parts of the world, especially in tectonic plate boundaries (e.g., Indonesia or El Salvador), on/near mid-ocean ridges (e.g., Iceland or the Azores), and along continental rift zones (e.g., Kenya or Turkey), or volcanic hotspots (e.g. the Canary Islands or Hawaii).

Europe accounts for nearly half the total installed geothermal heating capacity (~28 GW_{th}) worldwide.

STRENGTHS	WEAKNESSES
• Geothermal energy is essentially CO_2-free, though geothermal production (especially for power/CHP) may need to manage small/medium CO_2 discharges, and leakage of (trace) methane • It is a base-load capable renewable heat source • Low energy costs (pump electricity only) • Very low land-surface footprint • Negligible freshwater needs and pollutants into the atmosphere due to direct-use DH plants recirculating geothermal fluid • In principle, CHP-capable (electricity and heat generation)	• Potential and availability are both highly dependent on location • High investment (drilling, with uncertain potential until first exploratory well) • Sufficiently large heating network may be required for the highest efficiency and cost-effectiveness • Need to monitor (and manage) harmful mineral/gas pollutants (e.g. B, As, Hg, NH3, H_2S, SO_2, and NO_x), though this is generally more relevant to power/CHP geothermal and less of an issue for closed-loop DH plants
OPPORTUNITIES	**THREATS**
• Combination with other technologies (e.g., heat pumps, solar, biomass, mine water use) to further enhance its efficiency of operations, degree of total decarbonisation and wider uptake • Generally high public acceptance due to low emissions and visual perception (largely underground system) • Increasing interest in the technology from public utilities, industry (e.g. paper industry), as well as politics and science (e.g. Interreg project DGE-Rollout) • Potential for (seasonal) heat and cold storage in aquifers • Theoretical potential for synergetic raw material extraction of lithium	• At specific sites, generally unknown potentials and exploration risks with regard to temperatures, volume flows and barriers • Geological and regulatory exclusion criteria (e.g. water protection areas) • National/regional legislative and insurance issues (mix between mining and water laws) • Partial NIMBY problems due to micro-earthquakes and land subsidence (though this is more of a concern for certain geothermal power plants than most DH ones, and can anyway actually be largely mitigated through water re-injection)

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There are around 350 geothermal DH networks in place around Europe (~70% within the EU), with the GeoDH map (figure 8) indicating particularly strong usage across Hungary and within/near both Paris and Munich.[4] In many cases (at least in Europe), geothermal plants are designed from the start to function as CHP plants that cover local heat demand, as well as serving their primary purpose of generating electricity – this can even be done retroactively, as in the case of a Romanian coal-based CHP system decarbonising its DH via geothermal sources, while in other (modern) cases energy for heating purposes is the primary purpose.

Regardless of the type, geothermal plants are becoming more and more favoured by energy planners worldwide, because they require little energy inputs (primarily electricity to operate the pumps extracting the geothermal fluid), and can reliably cover even base loads of electricity, heating, and cooling; although geothermal-based district cooling systems are relatively rarer. Geothermal cooling remains quite poorly developed around Europe (with just ~30 MW_{th} total installed capacities), demanding additional research into its potential to cover substantial summertime cooling demands, which are being exacerbated by climate change.

Geothermal facilities tend to be installed at locations that benefit from (much) higher

4 The GeoDH map may be a useful tool - please note its layers at its top right - to identify nearby geothermal DH projects, as well as a few favourable geological characteristics (e.g., heatflow density >90 mW/m², or a temperature distribution at depth: >50°C at 1 km or >90°C at 2 km) deemed to be beneficial to any initial geothermal DH planning. Unfortunately some of its data is limited to 14 EU countries (for the most part), but it is also possibly data relatively easy to gain, especially for coal+ regions with their long history of exploiting geological data and expertise.

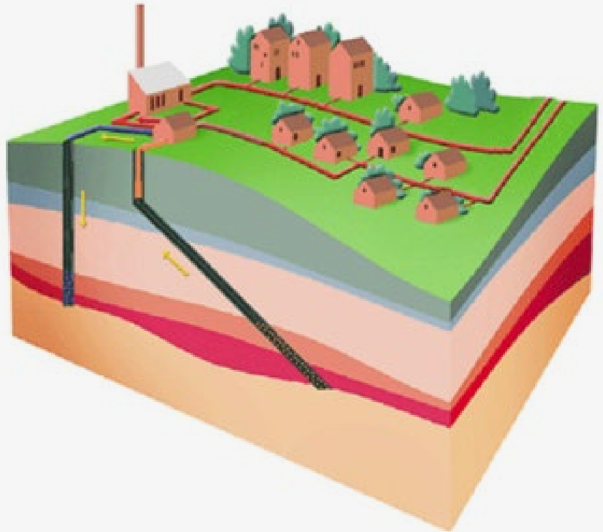

FIGURE 7: DISTRICT HEATING BASED ON GEOTHERMAL

Source: JRC 2012

GEOTHERMAL DH-RETROFIT IN SZEGED, HUNGARY

Although Szeged is not a coal region, it nonetheless demonstrates the feasibility of retrofitting a fossil gas-based DH system such that it can use geothermal sources instead.

The Szeged DH system consists of nine geothermal units in total, each with one well for extracting energy, which is run in a closed loop through heat exchangers at local DH plants, and two re-injection wells per site. All boreholes are each 1.7–2 km deep, and yield on average 90°C water at a rate of ~70–80 m³/hr.

The Szetáv DH company is completely owned by the municipality and serves nearly 28,000 homes and public facilities in the area, delivering 135 GWh_{th} in total, with over one third of this coming from geothermal sources. The estimated reduction of greenhouse gas emissions thanks to geothermal is around 25,000–35,000 tons of CO_2/yr (~65-68%). The whole project cost about 63 million EUR, financed 60% by private investment (of the drilling/operator company), and the rest via European funding schemes (e.g. European Regional Development Fund). Operators express that it is worth the high upfront cost to save long-term operation costs, not to mention reduced CO_2 emissions and air pollution. The chosen approach was for a geothermal specialist company to operate production, and then sell it to the city's DH company.

A key lesson learnt was the benefits of strong cooperation with both the municipality, and with the wider community, with robust engagement ensuring public acceptance.

Useful sources: Innogeo article, CrowdThermal project case study, Szetáv DH slides and a Bankwatch video

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temperature gradients than the 30°C/km average, largely to minimise expensive drilling. Sites that register more than ~150°C at economically-feasible depths are usually prioritised for generating electricity, while locations with low to intermediate temperatures (~30-150°C) are rather utilised for H&C purposes, including agriculture, aquaculture and industrial applications. The GeoDH project indicates that locations with a medium enthalpy more than 60°C at less than 3 km deep, especially those in urban areas, should be top priorities for geothermal DH. This could indicate that ~25% of the EU's population lives in areas very favourable to geothermal DH exploitation.

The great advantage of aiming to develop geothermal in locations with low-to-intermediate temperatures is, of course, that they are more plentiful worldwide. Such geothermal sites can also exploit the heat rather directly, meaning that they can avoid many losses experienced by geothermal power plants, and can be relatively easily scaled up or down due to simpler drilling and H&C equipment needs. Geothermal is generally considered to be most suitable for modern or low-temperature DH systems (i.e. 3rd or 4th generation DH), and plants might have capacities with the range of 0.5–50 MW_{th}. The startup of a geothermal DH plant is generally quicker (and likely less expensive) than one for power production, and most become operational within a year.

Unfortunately, geothermal energy still has rather specific (and immovable) resource requirements. Though powerful and relatively environmentally-friendly to exploit, such prerequisites can constrain where this resource could actually be used economically, whether for electricity or heating.

While geothermal is rather low in climate emissions (and in some cases can even be considered emission-free, see box), it can potentially pose other environmental concerns. Fortunately, many of these are primarily issues only for certain (older) types of geothermal power production, and already have well-established solutions which have become rather standardised to make them non-issues anymore. For example, CO_2 discharge can largely be extracted and repurposed, (e.g., for carbonated beverages or used in greenhouses), methane (almost always in rather miniscule amounts) is typically burned on-site to warm up water further, and H_2S can undergo on-site treatment through any number of well-established processes upstream or downstream from the turbine. Other pollutants (e.g., B, As, Hg, NH3, SO_2, and NO_x) can be by-products of geothermal energy, though usually only in trace amounts and with rather reliable abatement methods already being standard practice.

In any case, environmental considerations from geothermal energy still remain generally more favourable compared to traditional electricity generation, and in most cases hardly an issue at all for direct-use plants used for H&C purposes. For example, geothermal power production requires much less freshwater (e.g., ~69 times lower than coal-burning plants per MWh, and ~85 times lower than nuclear plants), and a smaller land-use footprint (e.g., ~9 times less per MWh than a coal-burning facility). There may remain concerns about induced seismicity and land subsidence (though this is markedly less of a concern for DH plants due to being closed loops), both of these can be mitigated by ensuring that any geothermal fluid extracted is replaced, either from re-injecting the water used, or topping it off with fresh imports. There remains a need to account for negative impacts on ecosystems and natural/cultural features, but most such problems can be avoided via properly-designed facilities compliant with robust regulations (e.g., water protection zones).

A relatively major obstacle for many geothermal installations is their high investment costs. As mentioned, ground source heat pumps are becoming more and more affordable to install, but for many they still remain difficult to afford. Unfortunately, the upfront costs of conventional geothermal DH facilities are even more expensive (depending on local factors, ~1-1.5 million EUR/MW_{th} installed capacity). Unlike fossil fuel-burning plants, the majority of the cost of geothermal DH plants lies not in the above-ground infrastructure itself, but rather

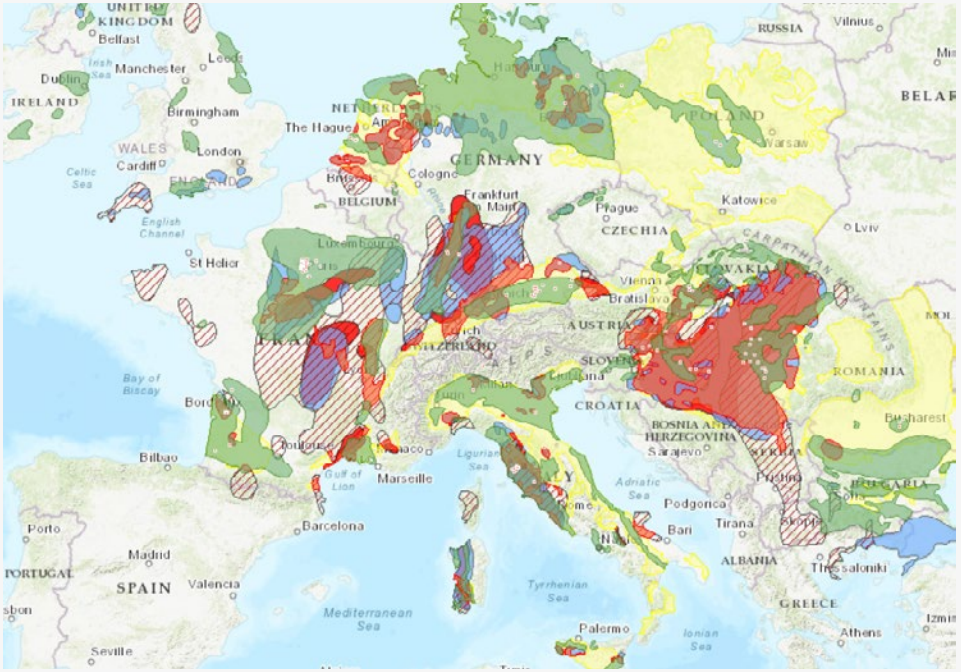

FIGURE 8: THE GEODH GEOGRAPHICAL INFORMATION SYSTEM SHOWS THE POTENTIAL FOR GEOTHERMAL HEATING IN 14 EU COUNTRIES

Source: GeoDH

SOURCES OF GHG EMISSIONS RELATED TO GEOTHERMAL ENERGY

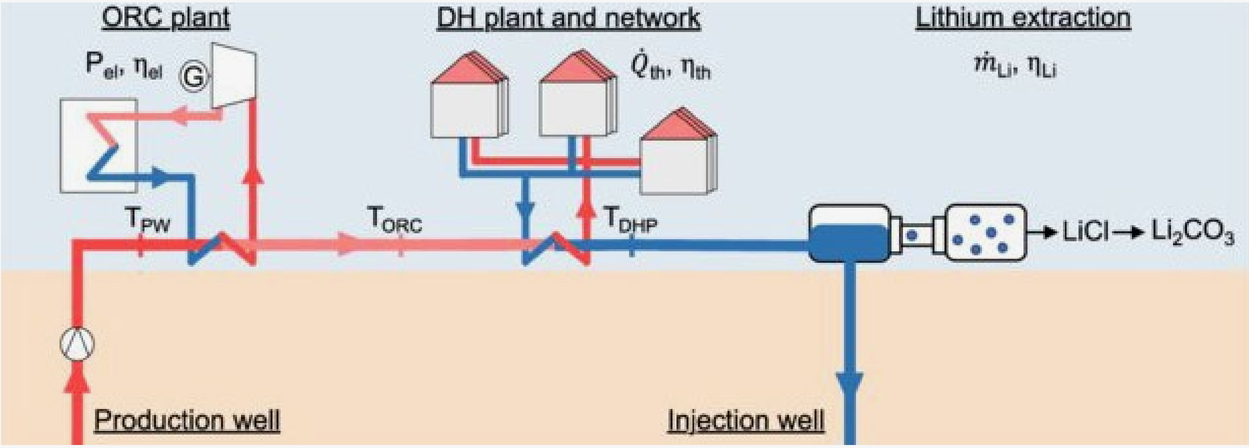

FIGURE 9: PRINCIPLE DIAGRAM OF THE SYNERGETIC USE OF ORC (ELECTRICITY FROM GEOTHERMAL ENERGY), DH (HEAT FROM GEOTHERMAL ENERGY) AND LITHIUM EXTRACTION.

Source: Weinand et al.

Regardless of the technology used, geothermal climate emissions are, without a doubt, much lower (or even negligible) compared to any type of fossil fuel, and are therefore aligned with EU and national climate policies. When considering full life-cycle analysis, emissions are still lower than fossil fuel plants, with most emissions resulting from discharges found naturally within geothermal fluid, which might be released through exploitation. In practice, even these can often be avoided through proper treatment, re-injection, or active collection.

There is a definite chance of greenhouse gases being naturally embedded within underground rock layers (e.g. CO_2 and/or methane), with quantities varying by location. Within Europe, regions with hydrocarbon-prone sedimentary basins and the highest heat flow (i.e. Greece, Iceland, Italy and Turkey) may have the highest methane concentrations from geothermal exploitation, which is particularly critical to avoid due to its substantial global warming potential. Although bringing geothermal fluids up to the surface runs a risk of leakage of these gases, many modern facilities operate with closed loops and robustly-cased boreholes, and/or treatment processes that minimise discharges. Certain plants even actively (re-)inject (additional) CO_2 down the borehole, which in theory enhances energy recovery, while storing CO_2 underground (Carbon Capture and Storage, CCS).

Apart from the CO_2 storage option, newest research suggests the synergetic extraction of Lithium. Studies show relevant potentials that could alleviate Europe's dependence on this critical resource that is essential for many technologies (e.g. batteries, wind turbines…) in the context of energy transition.

In all cases, thorough feasibility studies should be done to evaluate gas-content, any potential storage capacity for CO_2, and any effects of either CO_2-injection or methane-collection onto geothermal production levels. Proper monitoring and measures, such as effective reinjection practices, should always be implemented, even for decommissioned geothermal plants, to avoid long-term leakage or sudden discharges of these gases.

The World Bank and others commonly cite ~128 g CO_2/kWh as a global average emission factor for geothermal power production (though there can be large variations between locations, geomorphology and plant types). Trace amounts of methane are found in certain locations as well. Geothermal DH and heat pumps can be climate-friendlier than geothermal power production, with an EC-funded study finding emissions range from 14-202 g CO_2/kWh_{th}.

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the drilling needed to reach economically-viable depths; drilling wells accounting for ~28-64% of total costs. In particular, the first exploratory well is crucial to establishing the technical (and therefore economic) viability of a particular site. It is worth conducting a robust series of preliminary technical studies (e.g., geomorphology, geophysics and hydrology) to determine key underground characteristics of a potential site well before a first exploratory well is started, since this results in higher success rates for economic viability than comparable drilling for fossil fuels.[5]

What makes geothermal energy-competitive with, and in many cases more economically attractive than, fossil fuels are: its complete freedom from fuel needs and their related price fluctuations, as well as supply risks if imported, much lower operating costs that amount to little more than maintenance and electricity for pumps and control equipment; and the avoidance of having to pay carbon taxes (e.g, in the EU-Emission Trading System (ETS)). Meanwhile, the levelised costs of geothermal DH continue trending downwards from an average ~0.06 EUR/kWh$_{th}$ in 2014, to the current forecast of ~0.04 €/kWh$_{th}$ by 2030, while selling costs are quite attractive (~60 EUR/MWhth).

Deep Geothermal energy has real potential to be an excellent way to decarbonise existing DH systems, or to start new ones. For example, Agora Energiewende's "Breaking free from fossil gas" names it (and large-scale heat pumps) as the key technologies to displace fossil gas from DH systems, calling for deep geothermal to cover 10% of DH demand by 2050. Geothermal largely lacks GHG emissions, has a rather low/mitigatable environmental footprint, can provide reliable and scalable base-loads of clean heat through mature technology, and can viably synergise with other types of renewable energy production and storage.

Its main drawback, other than high investment costs, remains its relative dependence on certain locations. Fortunately, the GeoDH map indicates that within/near most EU coal+ regions, there may be decent-to-strong geothermal potential. And, with recent improvements in heat pump technology and affordability, even regions with lower potential for conventional geothermal technology may still tap into this underground resource to decarbonise their DH, as can be found in the very next chapter.

Coal+ regions should take advantage of the intimate geological knowledge and experts already typically at their fingertips from years' of mining experience. Whether harnessing geothermal potential through conventional plants, synergising it with other available renewables and storage in an integrated system, or even exploring the innovative repurposing of flooded mines, the time is ripe for coal+ regional stakeholders to switch towards more sustainable ways of extracting energy from underground.

5 Within the geothermal field, there tends to be a very high success rate (~80-90%) in known/developed areas (albeit in previously unexplored areas somewhat lower success rates ~20-60%). However, these values ought to be compared to oil/gas exploration, where 20% is already considered to be a quite good success rate.

EXAMPLE: USING UNDERGROUND MINE WATER FOR DISTRICT HEATING

Using mine water for DH is a relatively new H&C approach that harnesses geothermal energy, and which is specific to regions with underground mining. There have been several recent examples of former coal mines being retrofitted with heat pumps and/or heat exchangers (either as open or closed loop systems). This concept largely avoids the need to drill major boreholes by repurposing the flooded underground shafts and tunnels to function as a hybrid hydro and ground-based heat source (~11-46°C, depending on shaft depths).

This is a promising concept that is gaining ground, particularly in North America and Europe. Mine water systems have been launched, or soon will be, in many former mining regions in all corners of Europe including France, Germany, the Netherlands, Poland, Spain and the UK. In the integrated energy systems chapter, we further describe the Dutch pilot mine water DH installation in the town of Heerlen, launched in 2008.

Regions with underground mining are especially encouraged to investigate this approach, but also there are even more recent explorations for adapting open-pit lignite mines to a similar purpose.

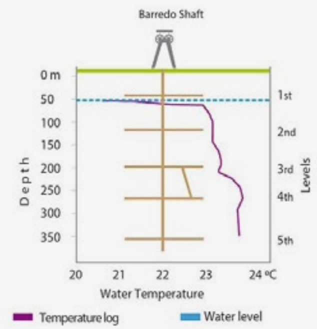

FIGURE 10: THE BARREDO-SANTA BÁRBARA COAL MINE WATER SYSTEM IN ASTURIAS, SPAIN, PROVIDES H&C TO A NEARBY HOSPITAL AND A FEW UNIVERSITY BUILDINGS.

Source: Lara et al.

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3. Power-to-Heat (Renewable electricity)

The share of renewable electricity in many European countries has grown substantially in recent decades. Technology development, stable investment conditions (supported by regulation like the German feed-in-tariff, established in 1990), and mass production thanks to market roll-out have led to high learning curves especially for wind and solar power. Low and ever-decreasing costs, in combination with huge potentials, help explain why energy scenarios assign a key role to renewable power generation not only for the energy sector, but also in the industrial, building and transport sectors. Thus, power-to-heat (PtH) is a crucial technology for the decarbonisation of the heating sector, which makes use of this incredible rise in renewable power generation.

The decarbonisation potential of PtH is large both in terms of breadth (possible applications) and depth (100% decarbonisation potential with use of 100% renewable electricity generation). The technology can be used both for small units in individual supply, and for medium or large units in municipal or industrial district heating networks. PtH can be divided into **direct electric use** (electric boilers or heating rods, electrode boilers) and **applications by means of electric heat pumps** (see Figure 11).

Electric boilers, also called electric instantaneous water heaters, offer the possibility of heating water without an additional water circuit. They consist of one or more heating elements that are immersed in the flow of the district heating. As soon as current flows to the heating element, it heats up thanks to its electrical resistance, and transfers the heating

STRENGTHS	WEAKNESSES
• Proven, locally emission-free and quiet technology • Low maintenance • Economies of scale with large heat pump (HP) units • Use of renewable heat (ambient heat, geothermal energy, waste heat, solar heat) • Load shifting instrument • Meets requirements for participation in the balancing power market (only direct electric PtH) • Geothermal probes with potential for energy-efficient and low-cost summer cooling	• Development of heat sources with sufficient capacity and temperature level is required (for heat pumps), leading to space requirements and costs • Decreasing energy efficiency at higher flow temperatures (for heat pumps) • Production of large heat pumps not (yet) a mass market • Partly use problematic refrigerants in large-scale HP: global warming potential (GWP), ozone-depleting potential (ODP), flammable (butane, propane), or toxic (e.g. ammonia)
OPPORTUNITIES	**THREATS**
• Potential for: – complete decarbonisation (with 100% RE) – cost reduction and efficiency increase for HP – use in cold local heating networks (LowEx) • Integration of heat storage supports utilisation of RE supply peaks and stabilises the electricity grid • Synergies with CHP plants (“innovative CHP”): high degree of freedom for grid-serving and/or cost-optimised flexible operation • Synergies with solar utilisation with heat storage: increase in storage capacity and solar yield	• Dependence on electricity grid (expansion) • Degree of decarbonisation and nuclear waste reduction depends on RE expansion (especially wind and PV) • Heat price depends on electricity price and development of surcharges, levies and taxes • Use of HP increases electric load (thermosensitivity), which is especially challenging in winter and during periods with little sunshine or wind

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energy to the flowing water (see figure 12). Electric resistance boilers are usually operated in the power range of 50 kW to 15 MW, and are connected to the power grid at a low-voltage level of 690 V or lower.

Electrode boilers represent another kind of resistance heating. These directly heat electrically conductive water that is in contact with two current-carrying electrodes. The water circuit of the boiler must be electrically isolated from the district heating water circuit, since the district heating water is deionized and thus not electrically conductive. The heat generated by the boiler is transferred to the district heating water circuit via a heat exchanger (see figure 13). The heat output of the boiler can be continuously controlled by the water level in the boiler and the resulting immersion depth of the electrodes. Electrode boilers are usually used above an output of 10 MW. Unlike electric boilers, they are connected at a medium voltage level of 6 to 24 kV.

Large scale heat pumps raise low-temperature heat (e.g., ambient, geothermal or waste heat) to a usable temperature level in a thermodynamic cycle using electrical energy. Figure 14 shows the four main components of such a heat pump: 1) evaporator (evaporates the liquid refrigerant, which absorbs heat from low-temperature heat source), 2) compressor (compresses the gaseous refrigerant and thus raises its temperature), 3) condenser (liquefies the gaseous refrigerant and delivers useful energy at the higher temperature level), and 4) throttle valve (expands the liquid refrigerant and thereby cools it down). Depending on the available heat sources, heat pumps can be used at several voltage levels, ranging from approximately one kW to several tens of MW. Suitable low-temperature heat sources are ambient air, (near surface) geothermal heat, river water or waste heat (e.g. from municipal waste-water, sewage treatment plants), as well as commercial (e.g. supermarket refrigerators) or industrial (e.g. exhaust gases, cooling towers) heat sources (see chapter 6 on Waste Heat).

Direct electric applications (DE), like direct electric heaters, cover a temperature range up to about 95°C with simple heating rods, and can go up to 240°C using an electric or electrode boiler, or even to 500°C with an additional electric steam superheater.

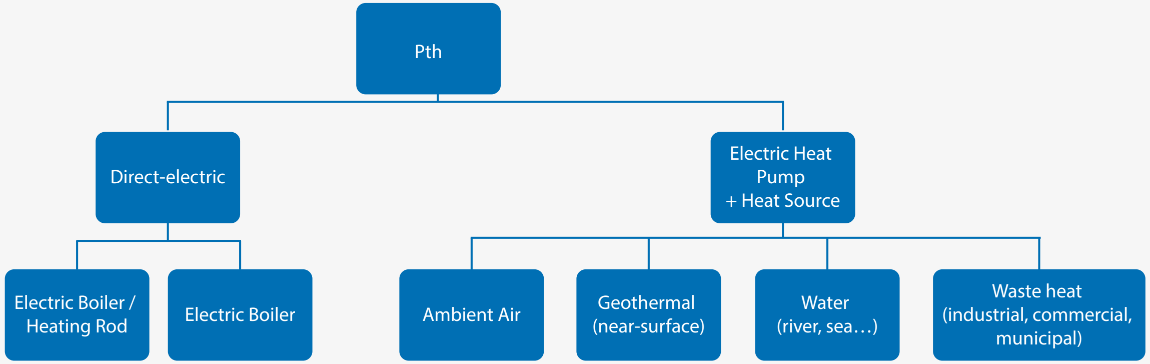

FIGURE 11: DIFFERENTIATION OF POWER-TO-HEAT TECHNOLOGIES AND HEAT SOURCES.

Source: Wuppertal Institute

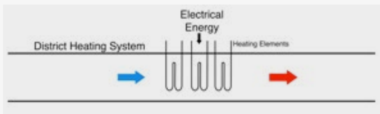

FIGURE 12: SCHEMATIC DIAGRAM OF AN ELECTRIC BOILER

Source: AGFW e.V.

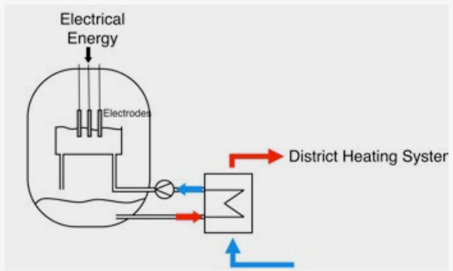

FIGURE 13: SCHEMATIC DIAGRAM OF AN ELECTRODE BOILER

Source: AGFW e.V.

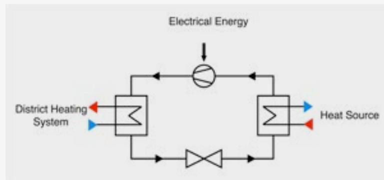

FIGURE 14: SCHEMATIC DIAGRAM OF AN ELECTRIC HEAT PUMP

Source: AGFW e.V.

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The greatest **strengths** of DE applications are their low investment costs (compared to heat pumps), their good and fast controllability, and their flexibility potential. Thanks to steep power gradients, DE also meet requirements for participation in the balancing power market[6]. When they make exclusive or predominant use of surplus electricity – which is facilitated in many countries, as they otherwise have to be regulated as part of a feed-in management regulation – there is no (or only low) additional requirement for the extension of electricity generation plants. However, they are limited in terms of operating times[7], and thus DE presupposes hybrid operation, so that heat provision is also guaranteed when there is not sufficient renewable electricity.

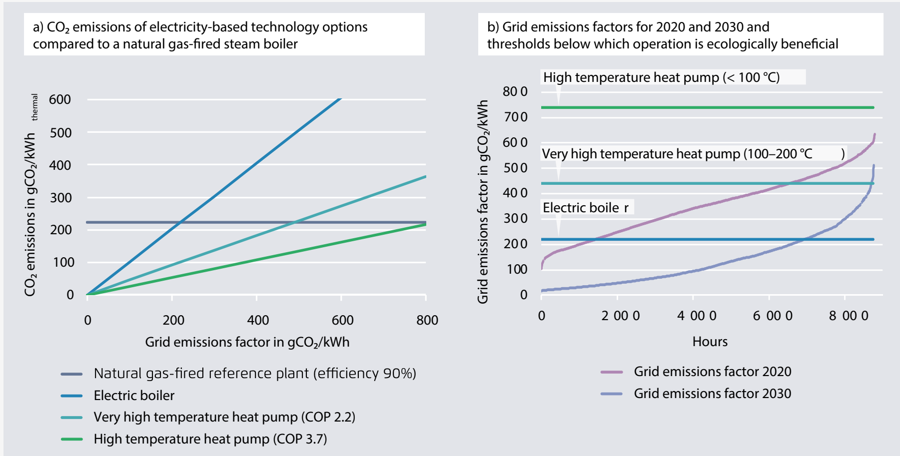
This limitation is also one of the **weaknesses** of DE. In cases where electricity generation capacities would have to be expanded, this would result in high space demand (for additional wind and PV installations) in the upstream chain.

Furthermore, depending on the temperature level of the application, the energy efficiency (Coefficient of Performance COP ≈ 200-500%) of a heat pump can be higher than that of a DE application (≈ 99%) by a factor of two to five. Therefore, high-temperature applications well above 150°C (e.g., for process heat) are more suitable for an “exergy[8]-efficient” use of DE, where the efficiency advantage of the heat pump decreases due to falling COPs. In monovalent operations – i.e. cases where a heat pump provides all heat without being complemented by any other heat source – DE enters into a certain path dependency, as it exposes itself to the risk of insufficient renewable electricity.

Figure 15 (left side) shows the relative carbon footprints of direct electrification and of heat pumps for different electric grid emission factors, in comparison to a natural gas-fired boiler. Figure 15 (right side) shows how long different operations can run (running times) and continue to be ecologically advantageous in the scenario years of 2020 and 2030. This diagram indicates that direct electrification is beneficial for approximately 1700 hours in 2020, and this value increases to 7000 hours in 2030. Heat pumps become more advantageous from 6500 hours (2020), and over 8000 hours (2030).

Heat pump applications (HP), or electric heat pumps, cover temperatures up to approx. 60°C (standard HP), 90°C (large HP), or 150°C (high-temperature HP), and can deliver base load capacity. While individual heat pumps are usually operated monovalently, large heat pumps in future central heating networks will be supported by additional low-carbon heat sources like waste heat or solar heat. Boilers or CHP plants fuelled by biomass, biogas or green hydrogen can cover residual heat in times of scarce renewable electricity, such as during periods with little sunshine or wind. HPs in combination with CHP offer a high degree of freedom for grid-serving and/or cost-optimised flexible operation. In addition, hybrid use with central solar thermal energy and heat storage results in synergies, as HPs can increase both storage capacity and output of the solar field.

The **strengths** of HP lie, in particular, in their very high decarbonisation potential. In addition – as explained above — they present high energy and exergy efficiency, especially in low-temperature applications. HPs only need one unit of electricity to generate two to five units of heat. The residual one to four units are covered by renewable heat sources or by waste heat see chapter on Waste Heat. This high energy efficiency leads to low operational costs, and minimal space requirement for the provision of renewable electricity. Due to the thermal inertia of buildings and heat grids, heat pumps are, in principle, also flexible, although less so than the very flexible direct electric applications. Running times, flexibility and system costs can be further enhanced by the use of big heat storage tanks. If near-surface geothermal heat is used, geothermal probes additionally allow renewable and energy efficient cooling during summer. HP can also efficiently be used in *cold local heating networks* (so-called LowEx concepts, see infobox in chapter on Energy efficiency: The guiding principle).



The grid emissions factors for 2020 are historical values taken from the Agorameter (Agora Energiewende 2022a); the grid emissions factors for 2030 correspond to an electricity system that is 80 percent based on renewable energy (Agora Energiewende, Prognos, Consentec 2022).

Agora Industry (2022)

FIGURE 15: CARBON FOOTPRINT OF PTH AS FUNCTION OF GRID EMISSIONS FACTOR (LEFT) AND THRESHOLDS FOR ECOLOGICALLY OPERATION OF PTH (RIGHT)

Source: Agora 2022

6 E.g. for grid-serving operation by the provision of positive or negative balancing energy.

7 Use of DE only makes sense from an ecological perspective in times when the carbon footprint of the electricity mix is lower than that of a fossil based heat generation (e.g. by a natural gas boiler) and from an economic perspective in times when the price of electricity is lower than that of a fossil fuels.

8 See also chapter on Integrated energy systems.

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Among their **weaknesses** is a certain expenditure for infrastructure, both because it may be necessary to reinforce electricity transmission capacities, and for the development of waste heat (pipelines and heat exchanger) or environmental heat (ventilators for ambient air, geothermal probes, heat exchanger for river water) sources with sufficient capacity. The risk of too little renewable electricity should be countered by a simultaneous rapid expansion of renewable electricity. When selecting the refrigerant for a HP, care should be taken to ensure low global warming potential (GWP) and ozone-depleting potential (ODP).

Market acceptance – at least for large heat pumps – is still in need of development. So far, market introduction in DH networks is only well advanced in the Scandinavian countries. This development was favoured in particular by the early introduction of CO_2 prices (since the 1980's), by favourable electricity prices in relation to the price of gas and by a stable and strong political commitment for the introduction of climate friendly technologies. Here, too, Denmark is considered a best-practice example for successful heat planning and heat transition. But even in countries where the share of heat pumps is still low, there are signs of a market rollout. For example, there are at least 30 large-scale heat pumps with a total of approx. 60 MW heating capacity in operation in Germany and 30 further projects for heating grids and industry with at least 600 MW currently under construction or in planning (as of May 2023).

However, good practice experiences from other countries, especially in Scandinavia and various green district heating scenarios, e.g.,in Germany, show that in the future large HPs may fill a substantial portion of the heating market.

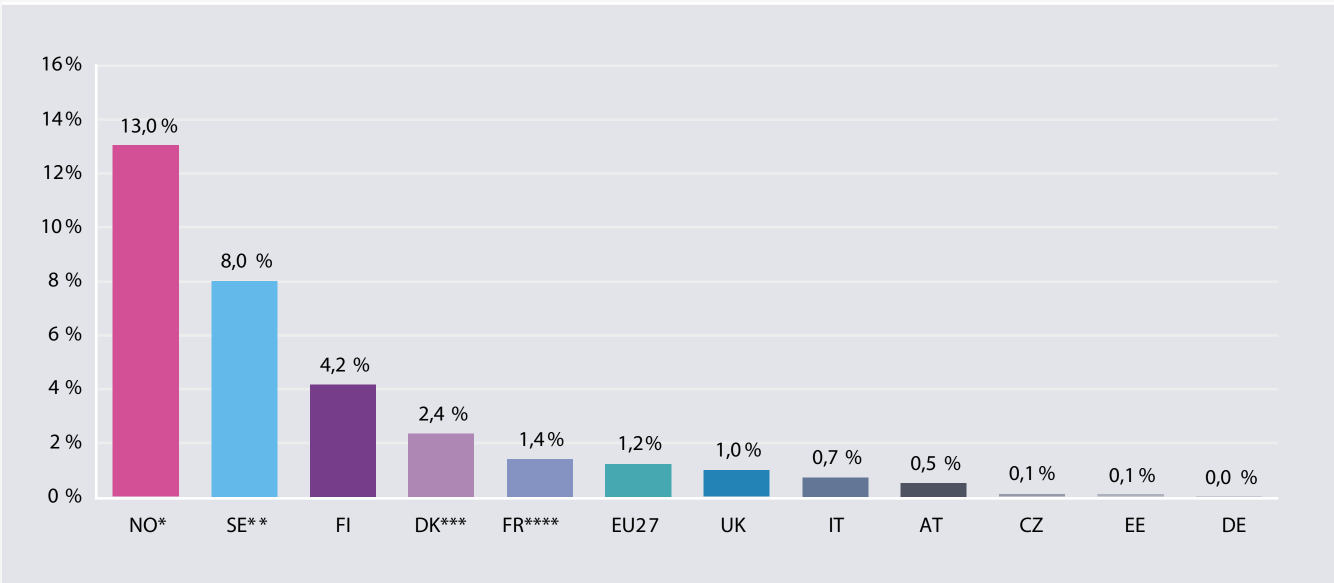

FIGURE 16: COUNTRIES IN EUROPE WITH THE LARGEST SHARES OF LARGE HEAT PUMPS IN HEAT GENERATION IN THE DISTRICT HEATING SECTOR (DATA STATUS: 2020/2021).

Source: Agora Energiewende 2023

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4. Fossil gas and alternatives

In recent years, the use of natural gas has been heavily promoted among coal+ regions as an interim solution to phase out coal, including for DH. The idea is to utilise gas as a so-called “bridge” before eventually switching entirely over to RES solutions. This has been largely driven by concerns about climate change (since burning gas produces ~40-45% less CO_2 than burning coal), and an economic standpoint, since the technical conversion from coal-based technologies to those that use gas requires relatively low capital investments, and converting an existing coal boiler costs just 15-30% of the expense of installing a new gas boiler.

Such a technological conversion is, of course, not a simple procedure of merely substituting a coal chute for a gas pipe, and therefore requires checking on several engineering considerations. Nonetheless, it certainly remains feasible and is by now a rather standard option available to operators. However, this chapter will move beyond just technical feasibility to explore the question of “why” in order to see whether or not gas serves as a truly viable solution for DH in coal+ regions, or risks becoming a bridge to nowhere.

Before diving into this topic in earnest, it may be important to clarify first what is meant by “gas” in the context of energy, especially for DH purposes. The catch-all term “gas” most often is used to refer to “natural gas”, which is composed primarily of methane (CH_4) and other hydrocarbons, though often also with other (trace) gases, including problematic ones (e.g., CO_2, CO or H_2S). Within

STRENGTHS	WEAKNESSES
• Widespread as a technically universal standard (boilers, turbines, engines, fuel cells) and can be used in many sectors (heat/cold/power generation, CHP, reducing agent, raw material) • Transport options: - Pipeline: simple, energy-efficient, cheap (OPEX), and high-capacity transport - Non-pipeline-bound in pressurised tanks or liquid tanks (deep-frozen): globally flexible and tradeable • Can be stored well and in large quantities (tanks, cavern storage) • Generally efficient and relatively clean combustion properties compared to solid (fossil) fuels	• Climate damage from natural gas (CO_2 emissions from combustion and methane leakage from pre-combustion stages) • Transport options: - Pipeline: low flexibility (spatially and in terms of capacity) and high investment costs - Non-pipeline-bound: high losses associated with transport and conversion or conditioning (e.g. liquefaction through cooling or compression, regasification). • In the case of a gas switch, there may be technical restrictions with respect to transport infrastructure (e.g. hydrogen diffusion in natural gas pipelines), compression and/or application (e.g. change of combustion properties in burners or turbines).
OPPORTUNITIES	**THREATS**
• Very large theoretical potential for the application of renewable synthetic gases (power-to-gas, though not really biogas) for global production (especially in sun- and wind-rich regions) and storage • Potential to use existing infrastructure (grids, storage, applications) when switching from fossil gas to more sustainable gases (with some definite limitations) • High potential for efficient and/or flexible technical applications (e.g. gas turbines, combined cycle power plants, CHP engines, fuel cells) • Energy carrier remains of central importance for the current supply of independently-provided residual electricity and heat loads	• Definite exhaustibility of fossil gases, and subsequent reliance on ever more difficult and expensive sources • Danger of explosion • Piped gas supply: - Risk of long times for planning and approval processes, and therefore of stranded investment - Political and economic dependence on individual suppliers with large reserves (e.g., Russia) - Risks posed by critical infrastructure (e.g. dubious explosion of the NordStream pipeline) • High risk of lack of availability and high prices for renewable gases • Risking a lock-in that prolongs climate change risks from continued reliance on fossil gas as a fallback option in case of renewable gases being not (sufficiently) available or too expensive

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the context of this toolkit we will refer to it as "**fossil gas**" in order to make clear its primary origins as a fossil fuel extracted from underground.[9] Such a distinct term is also useful to differentiate fossil gas from other processed forms of natural gas (e.g., propane) not generally used for DH (though certainly used for individual H&C purposes), as well as to distinguish it from other forms of gas dominated by methane - e.g., biogas, landfill gas, synthetic natural gas (SNG), renewable natural gas (RNG) or similar - or even hydrogen, which is increasingly discussed in multiple sectors, including for DH.

Fossil gas has gained its current foothold and strong market share because it, admittedly, benefits from a number of strengths. First and foremost is its versatility, as it can be used to produce electricity, heat and/or cold (including as CHP). It has even been promoted as an alternative fuel for transport, and is a key ingredient in a number of industries (e.g., in fertilisers, glass, steel, plastics, etc.). As energy, the majority of fossil gas is burned in power plants, supplying ~23% of global electricity, and ~20% in the EU. In Europe, a lower share of fossil gas power production is largely due to its often high prices, causing operators to reserve its use for peak times only.

Beyond electricity, its versatility is one of the main reasons for the modern importance of fossil gas. Fossil gas can be piped directly into individual buildings for direct use (e.g., cooking or industrial processes), and for direct heating via water heaters, boilers and furnaces. Such individual uses, along with more centralised DH, means that fossil gas still plays a major role in the heating sector for a number of countries (e.g., 73% of heating in the USA, 55% in Japan or 45% in Germany), and with a ~43% share overall worldwide.

In practice, simple fossil gas-fuelled boilers in DHSs are not greatly different from those found in individual buildings, but are simply at a larger scale compared to units used for an individual building or a single home. Typical fossil gas-DH boiler stations can be installed with capacities around 0.5-20 MW_{th} (with an investment cost ~€100 000/MW) and can potentially supply a rather wide range of service temperatures (~80-140°C) over an operational lifetime of 30-40 years. Nonetheless, such thermal-only boilers are generally being phased out, except to cover peaks or for smaller DH networks. Instead, energy efficient CHP-ready units are often seen as more favourable in terms of heat generation costs and carbon footprint (see chapter on Combined heat (cooling) and power technologies (CH(C)P)).

Thermal-only and CHP plants for DH tend to be more energetically efficient, especially if providing district cooling services in addition, than many larger power-only or power-dominated CHP plants, because the

9 Fossil gas can be found in conventional reservoirs (often associated with oil or coal deposits), which lend themselves to rather straightforward drilling due to amenable geology underground. Fossil gas can even be a (relatively minor) by-product of drilling for geothermal energy in certain locations with naturally-high methane concentrations (e.g. near volcanic areas). However, as gas reserves are running out while prices are increasing, gas exploration companies have found it economically attractive to tap into unconventional gas pockets (e.g. shale gas or "tight gas"), with the USA leading the way worldwide in commercial production. It's estimated that China has nearly twice the reserves as the USA, while Russia may have the most fossil gas in Europe, followed by Poland, Ukraine and France. Geology is less favourable for conventional drilling to extract fossil gas in these locations, and it thus requires complex approaches (e.g. hydraulic fracturing, also known as "fracking"), which result in their own set of proven environmental and public health problems.

THE ROLE OF GAS TURBINES FOR DHS (DISTRICT HEATING SYSTEMS) AND ASSOCIATED RISKS

Though this document is focused on DH, it is also worth being aware of fossil gas-fired power plant options, especially since they represent a mature technology, and can be CHP-ready to feed into a DHS. Simple open-cycle gas-turbines (OCGT) are less efficient (though if used in a CHP configuration, the overall efficiency improves). While capital expenditures for GT are very low, operational costs are comparatively high, even more than coal-fired power plants – with an anticipated levelised cost of energy (LCOE) in 2040 of ~€0.15-0.29/kWh_{el}. Nonetheless, they still are typically used to provide peak power for a few hundred or thousand hours a year, as they can be switched on or off rather quickly as immediate demand requires.

On the other hand, combined cycle gas-turbines (CCGTs), with capacities 50-1300 MW, are more efficient than OCGTs. This is thanks to their very nature – CCGTs recover excess heat from a gas turbine for a secondary steam turbine. In terms of operational costs they are also more affordable than simpler gas turbines with an even lower LCOE. Both types of gas turbines can be operated in a cogeneration mode to supply a DHS, and the industry claims that these plants could be modified to instead burn hydrogen, or as an interim solution blended mixes thereof.

However, even if such systems become more efficient overall through cogenerating heat and power, the economics of gas turbines are still becoming riskier and riskier as stranded investments – this was true even before Russia's invasion of Ukraine made fossil gas even more politically unattractive in Europe. A "tipping point" was already visible in 2019, at which point building a new CCGT was more expensive than investing in clean energy instead; at the time, it was anticipated that even continuing to operate existing CCGTs would cost more than renewables by 2035. With falling demand (at least partially a response to Russia's war in Ukraine), fossil gas prices might eventually plateau or decrease such that a temporary economic lifeline is extended to fossil gas power plants. But, it is also likely that the political and energy security costs will remain too high for this to materialise, especially given that carbon prices are finally becoming embedded and rising ever higher in Europe.

former types tend to waste much of the heat naturally produced by combusting fossil gas. Even though centralised DH systems have distinct advantages over decentralised individual boilers (e.g., higher efficiency, more effective reduction of pollutants, and better ability to combine/synergise heat sources), it should be noted that they still need to contend with higher temperature levels and larger heat losses, which can be largely avoided within individual buildings operating their own systems internally.

Greenhouse gas emissions can produce lock-ins and result in expensive heating prices

The gravest issue, of course, to be addressed for fossil gas – regardless of whether used for heating, cooling and/or electricity – is its greenhouse gas emissions. Combustion in a fossil gas-fuelled power plant is ~297 g CO_2/kWh_{el} while the emission factor for a DH plant is ~176 g CO_2/kWh_{th} (as opposed to ~224 g CO_2/kWh_{th} for a simple gas boiler). Total emissions from fossil gas in the EU were nearly 784 million tons of CO_2 in 2021 (roughly a tenth of global fossil gas emissions), which was about 12% higher than that same year's EU emissions from coal.

Furthermore, these numbers do not even consider the oft forgotten climate risks posed by methane leakage during the transport of fossil gas, which may **altogether outweigh any emission reductions from burning fossil gas instead of coal**. Lifetime assessment analyses for fossil gas have found that total emissions from all stages of the production and distribution supply chain (e.g., extraction, processing, transport) actually contribute an extra ~50% indirect emissions in addition to the emissions from the direct combustion of fossil gas itself. This is in line with legitimate concerns raised about European pipelines, such as the European Investment Bank (EIB) and EBRD-financed Southern Gas Corridor[10], which may exceed over 3% leakage. This is an important threshold defined by the International Energy Agency, as they have determined that any pipelines leaking more than 3% of the methane actually would not bring any net climate benefit at all for burning fossil gas rather than coal.

Unfortunately, with the prevalence of numerous large pipelines and terminals already operating, as well as all those still being planned and constructed, there is a distinct risk of economic lock-in with stranded assets in Europe and worldwide. This risk is, of course, exacerbated by geopolitical concerns (e.g., Russia's war in Ukraine accelerating a shift away from (Russian) gas, or the still-undetermined underwater explosions halting throughflow in three out of four Nord Stream pipelines in 2022), as well as by the threat of natural disasters which may prevent reliable fossil gas imports (e.g., much of the Southern Gas Corridor pipeline travels across earthquake-prone regions).

Even without such concerns about methane leakage or pipelines being cut off, Europe has seen a general decrease in demand for fossil gas for energy since 2010. By 2021, overall demand seemed to have returned to 2010 levels, but the subsequent invasion of Ukraine certainly triggered a strong political push across the EU to diversify away from fossil gas. One of the EC's most prominent flagship initiatives, REPowerEU, already achieved 19% fossil gas reductions EU-wide by late 2022. Related EU directives (e.g., EPBD, RED and EED)[11] have all been recently revised in order to consciously accelerate sustainable energy in response to the energy crisis, including a rather strong emphasis on decarbonising Europe's DH systems. The goal is not only to make them coal-free, but also to gain freedom from reliance on fossil gas.

10 The Southern Gas Corridor has three main sections, starting off the Azerbaijani Caspian Sea coast and later crossing Georgia (via the South Caucasus Expansion Pipeline, and then all the way across Turkey (the Trans Anatolian Natural gas Pipeline), before finally entering Europe via northern Greece, Albania, across the Atlantic and into southern Italy (Trans Adriatic Pipeline).

11 Energy Performance of Buildings Directive 2010/31/EC (EPBD), Renewable Energy Directive 2018/2001 (RED), Energy Efficiency Directive (EED).

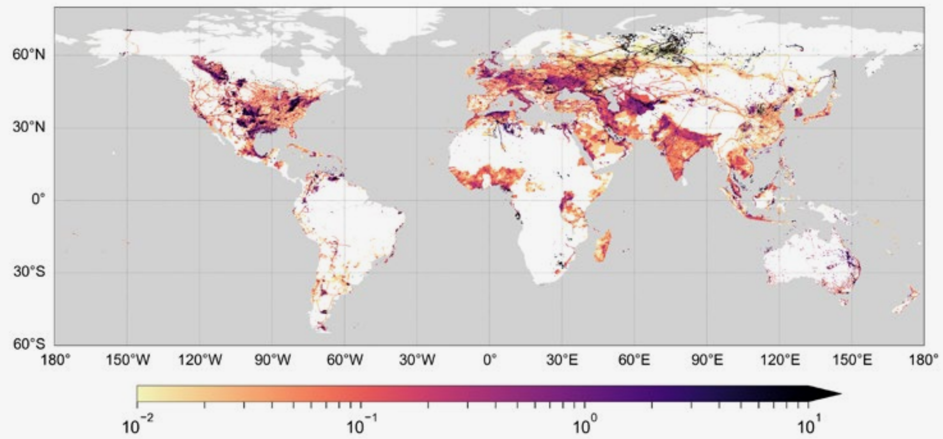

FIGURE 17: THE MAP SHOWS THE LEVEL OF METHANE LEAKAGE FROM ENERGY-ORIENTED INFRASTRUCTURE/SYSTEMS.

Source: NASA

Synthetic natural gas (SNG), biogas and biomethane

One of the main pathways away from fossil gas being considered by many is a switch in the type of gas used in the system. The core idea is to exploit existing fossil gas technologies and pipelines with alternative gas sources (e.g. biogas, landfill gas, sewage gas, biomethane, SNG, RNG or even hydrogen). In some cases, these alternative gases could be burned as a (nearly) one-to-one replacement, but in others (e.g. hydrogen) they would be blended (up to 20% without major replacement of boilers, which would

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then only minimally reduce CO_2 emissions compared to fossil gas). The EU sometimes refers to all these as "low-carbon gases" (e.g. within its larger decarbonisation strategy, "Fit for 55"), and aims to shift from relying ~95% on fossil gas today, to using at least 66% low-carbon gases by 2050 (yet climate advocates criticise that a 66% share of renewable gases will not be enough to reach the EU climate targets).

Perhaps the most mature "low-carbon gas" technologies exist for **biogas**, which can itself be used as something of a catch-all term for methane-dominant gases generated primarily by anaerobic microorganisms (though other options exist, such as thermal gasification). Raw biogas can have varying compositions depending on source material, but primarily includes methane (e.g. ~55% methane from agricultural sources, or ~65% from food waste), with most of the remainder being CO_2. Water vapour and problematic contaminants are also commonly found within raw biogas, particularly corrosive H_2S. Biogas can occur naturally, such as in marshes, though this is not typically exploited for energy purposes. Raw biogas has been proven to be commercially viable when collected via special facilities that take advantage of agricultural waste, sewage/wastewater, landfills, or certain commercial activities (e.g. breweries). A variety of business cases are by now already rather well-established in support of this process, assuming that market demand enables these processes to become more affordable.

Once raw biogas has been processed to remove impurities, this upgraded product is often called **biomethane** and usually has a methane (CH_4) content of more than 90%.[12] As it is more or less chemically similar to natural gas, it can be transported and distributed via the same infrastructure (e.g. existing pipelines or compression units) and used in the same combustion technologies typically used for burning fossil gas, including CHP. For example, CHP engines installed onsite where biogas is produced and/or processed can provide 70/90°C flow/return low grade heat (often used to help keep nearby digester tanks optimally warm), as well as ~450°C high grade exhaust heat that is usable directly in a boiler or to create hot water for heating. Ultimately, this means that, at least technically speaking, in any situation where fossil gas could be used for DH purposes, biomethane from (upgraded) biogas could more or less replace it.

Due to its organic origins, biogas is generally considered to be a renewable source – in fact, since the CO_2 released from burning biogas is derived from plants that had previously sequestered that carbon from the atmosphere, it is even considered 'carbon neutral' by some. Even so, it remains essentially equivalent to fossil gas in terms of its weaknesses. Like with fossil gas, there is still a danger of stranded assets for biogas, not to mention that current high prices for biogas tend to delay its wider uptake, meaning that fossil gas infrastructure is often kept online just for the not-yet-proven potential future use of biogas (once it becomes more affordable). Perhaps more importantly, being so-called carbon-neutral does not mean that biogas is not problematic for climate change. Its combustion still certainly re-releases its embedded greenhouse gas emissions directly, and methane leakage during its production-to-distribution stages remains a threat, just as it is for fossil gas. Therefore, anyone planning a switch to biogas DH would do well to see if better options exist instead. For more details about biogas, please refer to the chapter on Biomass.

12 Sometimes other names, including "synthetic methane", "SNG" (for "substitute natural gas" or "sustainable natural gas") or "RNG" (renewable natural gas) are used. In this Toolkit we use "biomethane" for upgraded "biogas" and "SNG" as abbreviation for "synthetic natural gas" as a power-to-gas product out of water electrolysis with renewable power.

Hydrogen

One other alternative gas that has become rather hyped in recent years, including/especially for coal+ regions, is hydrogen. Its combustion (at least in theory) can generate ~3-3.54 kWh/Nm³ of heat energy, though this is actually only about a third of the heating value from the same volume of fossil gas. Unfortunately, the majority of hydrogen produced today is sourced from fossil fuels, including conversion from fossil gas. There are growing calls for more sustainably-sourced hydrogen, including to make use of this hydrogen for DH (see box).

Unsurprisingly, green hydrogen is (deservedly) getting most of the attention these days. The EU's hydrogen strategy from 2020 (tied to its Green New Deal) aims to produce 10 million tonnes of renewable hydrogen by 2030. Even though it clearly prioritises green hydrogen, it also does not necessarily exclude other types, most notably including pink[13] and blue hydrogen.

The main problem faced by green hydrogen is that it still costs much more to produce the hydrogen than the energy combusting it would generate, and also more expensive than other alternative (sustainable) sources. For example, when thinking about hydrogen for use in the heating sector, even when it is produced from sustainable sources, it has been estimated to be ~500-600% more energy intensive than obtaining equivalent thermal energy from heat pumps instead, meaning that the cost of green hydrogen likely still remains prohibitively high for DH.

An analysis of theoretical hydrogen production for Bulgarian coal power plants finds that, due to electrolyser efficiencies maxing out at 80%, the process requires at least 49 kWh_{el}/kg of hydrogen, which, once combusted, may only generate 11 kWh of useful energy. This study further estimates that about a million tonnes of hydrogen would be needed to replace the coal used in those Bulgarian power plants to maintain production at full capacity, which would in turn necessitate about 43 GW_{peak} of photovoltaics. This would itself require at least 1000 km² of land for PVs (in addition to land for associated roads, substations and other infrastructure), and poses additional life cycle assessment issues (e.g. water consumption and liquefaction/storage needs). Assuming that most of that author's calculations are correct and reasonable, it may seem that **hydrogen has serious concerns for real implementation in DHSs on the ground**.

13 In the EU, pink hydrogen is included under "electricity-based hydrogen", differentiated from both green hydrogen and those based on fossil fuels. There was a controversial attempt to include pink hydrogen under the green label in the REDIII legislation. Although it failed, a "pink hydrogen loophole" was inserted that introduces special rebates for pink hydrogen to count (partially) towards green energy goals in nuclear-reliant countries (e.g. in France or Sweden).

THE 'COLOURS' OF HYDROGEN

Over the past years, different hydrogen production methods have been classified using a rainbow of labels used to identify differently-sourced hydrogen:

- **Black or brown hydrogen**: uses bituminous or lignite coal, respectively, in a gasification process; it releases the most greenhouse gas emissions of any type of hydrogen production
- **Grey hydrogen:** currently the most common and least expensive type; uses "steam reforming" of fossil gas (or much less commonly, biogas) instead of coal, resulting in slightly lower emissions than black/brown hydrogen (~9.3 kg CO_2/kg grey hydrogen, or ~0.28 kg CO_2/kWh of grey hydrogen production)
- **Blue hydrogen**: essentially the same as grey hydrogen, but using CCS[14] in the production process to reduce CO_2 emissions. Though some define it as carbon-neutral, ~10-20% of blue hydrogen's CO_2 still evades capture. A life-cycle assessment of blue hydrogen demonstrates that its greenhouse footprint may actually be >20% higher than just burning coal or fossil gas for heat – as such, many claim that blue hydrogen is little more than an operational lifeline for fossil gas industries. However, some industrial processes (e.g. in the steel industry) might have to rely on blue hydrogen as a "bridge technology" to establish new hydrogen-based plants until enough green hydrogen becomes available.
- **Turquoise hydrogen**: a rather new approach that uses methane pyrolysis to produce hydrogen and solid carbon (instead of gaseous CO_2); theoretically promising for its carbon sequestration, but has not yet proven to be scalable or even commercially viable
- **Pink (sometimes also red or purple) hydrogen**: uses nuclear power to produce hydrogen through the electrolysis of water
- **Green hydrogen**: uses renewable energy sources (primarily solar and wind) for the electrolysis of water to produce clean hydrogen

It should also be noted that this list is not exhaustive, since there are additional colour designations which are (less frequently) in use for less common sources of hydrogen as well.

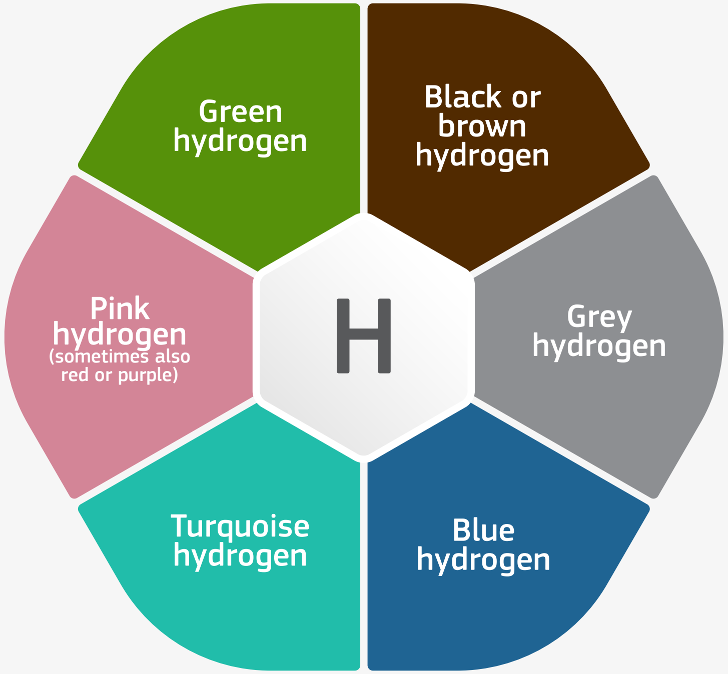

FIGURE 18: THE COLOURS OF HYDROGEN

Source: Own depiction, based on SpectraMHI

14 CCS (Carbon Capture and Storage)

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To some degree, this is all a matter of economies of scale, because current capacities need to drastically increase to produce green hydrogen in foreseen quantities. However, there remain real questions regarding whether the EU's goal to supply 10 million tonnes of green hydrogen is even feasible for Europe.

As a further example from a study about potential hydrogen heating for Germany, if just half of the heating demand currently covered by fossil gas were replaced with hydrogen instead, this would result in a greater need for an additional 25-40% more hydrogen than already foreseen for other sectors. Therein lies a problem with security of supply and how to source it, not only in terms of being green, but also available capacities to produce it sustainably. In practice, the majority of this hydrogen would have to be imported from beyond Germany (which could only supply a maximum of 20-60% of its own green hydrogen needs in such a scenario) and other parts of Europe. Considering a technical preference for pipeline-based transport, the main supplier for Europe could be North Africa, but even those countries would only be able to provide a portion of Europe's overall green hydrogen needs – and that is without taking into account their own needs for domestic hydrogen use. Importing from other potential green hydrogen suppliers (e.g., from South America or South Africa) is likely to be even more expensive, and such long-distance transport may not be safely, economically, or physically possible.

Even assuming that hydrogen can somehow be efficiently produced in usable quantities for DH from reliably secure sources, there still remains a question of whether this is the most appropriate use of hydrogen. One prominent voice in this debate from BloombergNEF has been rather critical of the hydrogen hype, likening hydrogen to an (economic) bubble in danger of bursting, and to a Swiss Army Knife in that it is framed as able to solve everything, when in fact trying to do it all simultaneously is both impossible and counterproductive.

The so-called Clean Hydrogen Ladder (figure 19) provides a way of visually portraying a supposed merit-order of priority uses of clean hydrogen (in place of grey hydrogen), whereby uncompetitive priorities are placed at lower rungs. Given the H&C orientation of this toolkit, it is worth drawing immediate attention to the fact that the best H&C ranking assigned is a mere "D" for high-temperature industrial heat, followed by the slightly worse "E" for commercial heating (which also includes tertiary sector DH demand). Meanwhile, both mid/low-temperature industrial heat and domestic heating (which would include the majority of DH demand) were assigned only an "F", indicating that they are unsuitable priorities for green hydrogen.

While this is, of course, just one voice within the wider hydrogen debate – and these views certainly have their own detractors, including those in various heavy industries who even call into question their credibility – there are also many other experts coming to similar conclusions[15].

Finding alternatives to (all) gases

Summing up, there remain serious concerns associated with pursuing fossil gas, or even hydrogen (and possibly also biogas, SNG, RNG, etc.), as a future-oriented pathway, whether for DH or other purposes. EU-level decision-makers have definitely decided that fossil gas should be on its way out, even while many of them actively promote the future of biogas and hydrogen as key alternatives. Given the evidence, it should be clear that fossil gas is not a bridge to anywhere Europe should want to go. At the same time, though hydrogen may be beneficial for certain uses, it remains problematic if designated as too crucial for too many uses, it is not ideal for DH and unchecked reliance on hydrogen is liable to leave us all stranded. Basing DH on fossil gas or hydrogen (as well as many varieties of SNG) might be more accurately equated to a harmful hoax or hopeful hype, rather than helpful for heating homes.

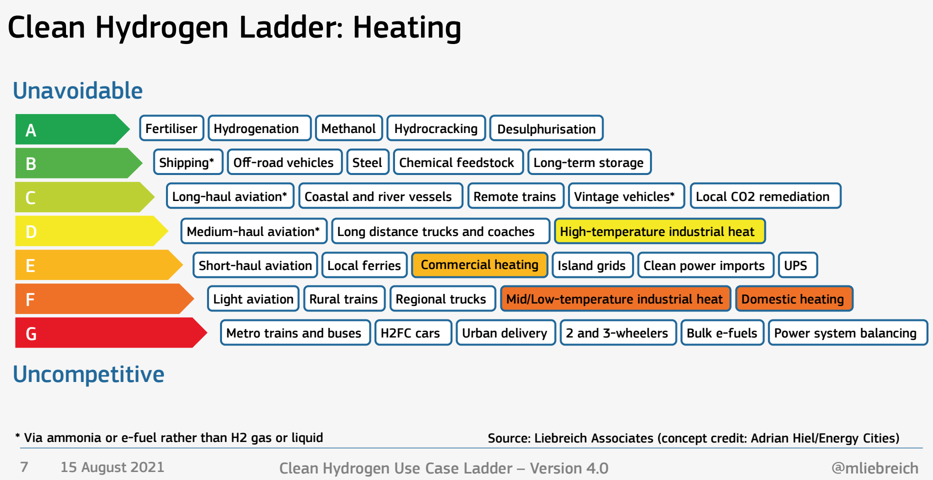

FIGURE 19: THE USAGE OF HYDROGEN FOR DIFFERENT PURPOSES RANKED FROM UNAVOIDABLE (AND THEREFORE PREFERRED USE) TO UNCOMPETITIVE, WHICH MAKES ITS USE MORE UNLIKELY.

Source: own depiction, based on M. Liebreich

15 For example, a 2022 review of independent scientific papers (i.e. those not funded by any fossil fuel industries) points out that, despite some legitimate priorities to use green hydrogen (e.g. for fertiliser production), using hydrogen for H&C purposes (as a replacement for fossil gas) is not generally supported by the science. Rather, it has higher costs (for both systems and consumers) and environmental impacts. Likewise, Agora Energiewende's recent 2023 report "Breaking free from fossil gas" calls for a kind of sufficiency thinking when it comes to hydrogen (reminiscent of this toolkit's own first chapter "Sufficiency: the long-term goal") and suggests that (RE) electrification may be a better option to cover 80% of REPowerEU's hydrogen targets, including for DH. All this tracks also with the positions of other prominent voices e.g., Friends of the Earth, WWF, Greenpeace and Ember/Europe Beyond Coal.

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5. Biomass

Bioenergy continues to be the main source of renewable energy in the EU, occupying almost 60% of all renewable energy. The heating and cooling sector is the largest end-user, using about 75% of all bioenergy. In the context of DH, biomass utilisation remains one of the most versatile renewable energy options available, usable directly in boilers and/or in CHP plants.

Bioenergy is produced from a wide range of feedstocks that can be divided in four main categories: energy crops, agricultural residues, forest feedstock, and other types of organic waste. The most widely used form of biomass for heat generation is wood, for example in the form of firewood, wood chips and pellets.

Forestry accounts for more than 60% of all EU domestic biomass supplied for energy purposes. In 2016, EU biomass came 32.5% from direct supply of woody biomass from forests and other wooded land; 28.2% from indirect supply of wood; almost 27% from agricultural biomass (split equally between agricultural crops and agricultural by-products); and the remaining 12.4% from waste (municipal, industrial, etc.). A Joint Research Centre (JRC) report shows that about 50% of wood used for bioenergy in the EU is derived from secondary products, such as forest-based industry by-products and recovered post-consumer wood, 17% from treetops, branches and other residues, and 20% from stemwood – which is mostly coppice wood, small stem thinning wood and harvested stems of poor quality that cannot be used in sawmills or pulp and paper production.

The technical potential[16] for bioenergy in the EU coal regions is estimated at 18-44 GW of

STRENGTHS	WEAKNESSES
• Renewable, storable energy source • Close to CO_2-neutral over entire life cycle with respect to direct emissions • Baseload-capable heat and power generation • Highly efficient cogeneration possible in various CHP technologies (biomass: steam turbine, ORC / biogas: gas turbine, ICE-CHP, fuel cell) and wide power range (approx. 50 kW_{th} CHP to 500 MW_{th} heating power plant) • High temperatures achievable (up to approx. 500°C)	• Indirect GHG emissions (e.g. through fertiliser in the case of cultivation of renewable raw materials) and local CO_2 and pollutant emissions • Limited scalability and high land requirements (cultivated biomass) • Storage space (biomass) and transport infrastructure (biomass/waste: truck, biogas: pipeline) required • For biogas use, requirement that heat consumers are in spatial proximity • For waste incineration, low efficiencies and high purification effort needed for waste gases
OPPORTUNITIES	**THREATS**
• Potential for increased flexibility (in combination with material or thermal storage or solar thermal energy) • Technology for covering residual heat and electricity loads • Participation in the balancing energy market possible (biogas CHP) • With CCS, option for negative CO_2 emissions (Bioenergy Carbon Capture and Storage, BECCS) • Potential for resource-saving cascade use (combustion of residues and gasification of liquid manure, etc.) • Synergy of material inertisation and thermal utilisation (for waste and manure) • Potential for methanisation (biomethane feed into natural gas grid)	• There is competition for the use of biomass both with respect to its: - production (supply) – biomass can be cultivated for energy, food production, etc.; and - use (demand) – biomass can also be a building material, chemical base material, etc. • Price risks for fuels with limited availability - Additional costs and infrastructure risks (required connection to CO_2 pipeline) through CCS technology

16 Technical potential describes the physical potential minus the constraints caused by topography, land and system framework conditions.

thermal capacity for forest biomass, 16 GW for crop residues and 3 GW for livestock biogas. However, realising bioenergy potentials is a major challenge as bioenergy involves a wide range of stakeholders and has many potential environmental and social impacts.

Bioenergy is intertwined with many sectors, such as agriculture, forestry, environmental protection, and waste management. Bioenergy has both positive and negative environmental and socio-economic impacts, depending on the feedstock used and management practices implemented (see Is bioenergy truly sustainable?). The potential sustainability risks of the bioenergy supply chain and its deployment are linked to land use, carbon stocks, water and soil quality, biodiversity, competition with food supply, etc. Moreover, increasing emphasis on bio-based economy in the EU has led some to argue that feedstock should be used for different, higher value applications than energy production. Thus, cascading use is recommended, where available feedstock is used and recycled for as long as possible and is allocated to the most valuable purposes possible at each stage, postponing its use for energy. However, translating this principle into policy and practice has proven difficult. In the EU, the discussion has mainly focused on woody biomass and is closely connected with ongoing debates over the role of wood-based bioenergy in future EU energy policy.

The production of heat from biomass combustion is a mature technology and is widely used across Europe in DH networks. Biomass is usually combusted in boilers with a capacity of 1-15 MW (for one boiler) with an average thermal efficiency of 85%. This technology allows the use of different types of feedstock, and a boiler can be fuelled with a mix of fuels. However, most systems use only one fuel due to logistical constraints or local contexts (e.g. proximity to a sawmill). Biomass, unlike other renewable sources, enables production at high temperature heat, and is thus compatible with any types of DHS; however, it is most suitable for modern (prefabricated) or low-temperature DHS. Biomass boilers are most efficient when operated continuously, and the minimum acceptable load factor (proportion of energy produced with respect to the maximum possible) is usually set at around 25%. The total installed costs of biomass DH in the EU vary significantly, ranging between €0.3-0.7 million per MW. The fixed operation and maintenance costs of a bioenergy DHS typically vary from 1.8-3% of the investment.

There is a long history of using biomass as a co-firing fuel in coal plants in relatively low shares (around 10 to 20% of the fuel input). Biomass repowering seems like the next step towards the use of high shares of biomass in the fuel mixture (often up to 100%). This offers several advantages: i) it is a mature technical solution to produce base load; ii) it provides an option for utilities to continue using their assets and retain jobs; and iii) conversion requires significantly less investment compared to building a new biomass power plant, while also reducing implementation time. A biomass repowered plant may also pioneer delivering negative emissions through the applications of **Bioenergy Carbon Capture and Storage** (BECCS) technologies, whereby BECCS is the process of capturing and permanently storing CO_2 from biomass energy generation.

On the other hand, such large biomass power plants – which require sourcing of biomass over long distances – seem to be counter to the local character of biomass-to-energy value

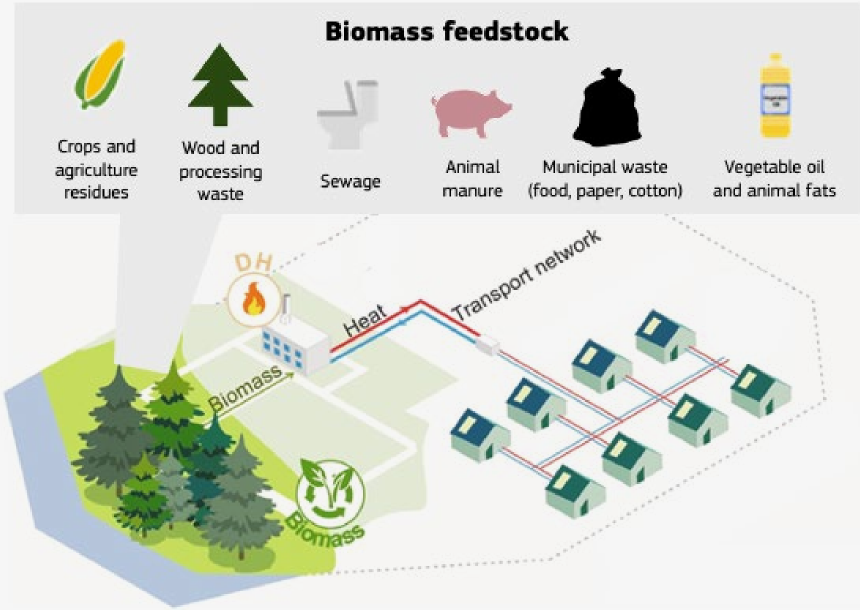

FIGURE 20: DIFFERENT TYPES OF BIOMASS FEEDSTOCK FOR DH SYSTEMS.

Source: Own depiction

chains and pose a sustainability risk. Moreover, it is unlikely that bioenergy will comprise a significant portion of the energy mix in the future. The rising demand for biomass energy is probably mostly transient, and its share in the energy mix should decline after about 2050. This is expected due to various drivers, including the availability and cost of alternative technologies, and competition for land and feedstock. In addition, many studies dispute the assumptions that there is scope for large-scale deployment of BECCS.

For DH systems that transition away from fossil fuels, especially coal, the path of least resistance points toward burning wood biomass. Wood pellets are already being used to prolong the life of coal-fired energy systems in the EU through co-firing, or a complete switch to biomass fuel. These baseload power plants, once built, might slow a transition to energy systems that are more efficient in terms of cost or land-use intensity. Sustainable biomass is a scarce resource, whose use should be optimised at local, regional, and national levels, and should primarily be used in sectors that are difficult to decarbonise, such as agriculture, steel, cement, chemistry, and aviation. Current units and investments will contribute to a lock-in effect where other potential uses are prevented due to lack of feedstock availability. In addition, bioenergy can be scaled-up only with the utilisation of vast amounts of land, a resource that is also limited in supply. Therefore, policies related to biomass energy development should aim to avoid lock-in, and to open doors for the technologies that can replace bioenergy in the future. One of these climate friendly technologies can be large solar thermal fields (see chapter Solar energy), in combination with (seasonal) storage, that can usefully complement an existing biomass based DHS (see chapter Integrated energy systems).

IS BIOENERGY TRULY SUSTAINABLE?

Bioenergy is often characterised as being "carbon neutral" based on the observation that the biogenic carbon released when biomass is combusted was previously sequestered by that biomass as the plants grew, and will be sequestered again during regrowth. This is valid in the case of annual crops or short rotation energy crops (in the absence of emissions related to direct and indirect land use changes (LUC)), as the biogenic CO_2 emitted by combustion is quickly reabsorbed or, in the case of residues and waste, has a fast decomposition rate. However, in the case of stemwood from dedicated harvest for bioenergy, a JRC report indicates that this actually results in an increase in greenhouse gas (GHG) emissions compared to those resulting from fossil fuels in the short- and medium-term (decades), and this process may only start to generate GHG savings in the long-term (several decades to centuries). In the case of feedstock, such as harvesting residues, thinnings or salvage loggings (if not used for other purposes), GHG savings are achievable in the short-term. This payback time is of great importance in order to limit temperature increase to 1.5°C above pre-industrial levels by the end of the century, which requires GHG to peak in the near term.

This knowledge is slowly being reflected in new policies on EU and national levels that aim to ensure that biomass is only used in a sustainable way. Projects that use biomass feedstock (which is not truly sustainable – despite current policies not reflecting that) will face problems when legislation is sharpened towards environmental goals.

Signs that policy is moving in this direction can be observed already today. So far, the recast Renewable Energy Directive 2018/2001 (RED) extended sustainability criteria to cover large-scale biomass for heat and power. In 2021, the Commission proposed a revision of the RED which includes a further strengthening of the biomass sustainability criteria. The proposal extends the scope of sustainability and GHG criteria to installations with a capacity equal or above 5 MW. According to the proposal, no support shall be granted to the production of energy from saw logs, veneer logs, stumps and roots. In addition, the proposal reinforces the implementation of the cascading principle as a main driver for changes in bioenergy policies.

The EU's Biodiversity Strategy for 2030 and the New EU Forest Strategy for 2030 promote the use of waste and residues for energy production, while the use of whole trees, food, and feed crops for energy production – whether produced in the EU or imported – should be minimised. These strategies aim to protect, restore, and enlarge the EU's forests to combat climate change, reverse biodiversity loss and ensure resilient and multifunctional forest ecosystems. As highlighted in the EU Bioeconomy Strategy, holistic management, which considers multiple forest services, is needed to move towards sustainable wood use. Any additional demand for wood for bioenergy will simply add to the overall demand for wood for other uses, meaning that even if wood for energy is subject to strict sustainability criteria, wood for other uses may be produced through harmful practices and pathways. It is therefore necessary to extend the requirements of sustainable forest management to all forest products consumed in Europe, regardless of end use and geographical origin, in order to ensure a sustainable forestry sector as a whole.

All these developments show that using biomass for district heating must ensure that truly sustainable feedstock is used, and that projects are planned in a way that they consider likely policy developments and current knowledge on GHG emissions. If this is ignored, projects can end up as stranded assets that will be a liability for their owners and the public.

Read more about the use of biomass for energy production in the technology options toolkit.

BIOMASS CONVERSION IN ZAGORJE OB SAVI, SLOVENIA

Zagorje ob Savi is a municipality with around 16,000 inhabitants, located in the Zasavje region in central Slovenia, which is the most industrialised region in Slovenia. The region stopped coal mining activities in 2013, closed a thermal power plant in 2014, and is currently seeking to develop new sectors to support the restructuring of its economy. The municipality has a long tradition of using woody biomass in district heating.

The district heating system and production capacities are owned by the municipality, and are managed by the utility company Komunala Zagorje. The heating plant has three hot water boilers: two wood biomass boilers, each with a capacity of 2.5 MW, and one extra light heating oil (ELHO) boiler with a capacity of 7 MW capacity. Biomass boilers are used independently, or in parallel depending on heating needs. The temperature of the heating water in the network is regulated according to the outside temperature, with a maximum of 120°C. The ELHO boiler serves as a back-up, and since 2004, when the two biomass boilers were installed, there was practically no need for a backup source. The length of the district heating system is approximately 1.2 km supplying almost 1,000 apartments and 95 businesses. Biomass feedstock can be produced locally, yet with conflicting interests of wood use for other purposes, costs might go up significantly in the future.

The city is currently exploring opportunities into solar thermal plus heat pumps as an addition to increase the overall efficiency of the system.

Source: Komunala Zagorje

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6. Waste incineration

Waste-to-energy (WtE) is a process whereby energy is generated using waste as a fuel source. This is often done through direct combustion using waste incinerators, or via the production of a combustible gaseous fuel such as methane. The most common application is in the processing of municipal solid waste (MSW). However, WtE technologies can be applied to other types of waste, including semi-solid (e.g. sludge from effluent treatment plants), liquid (e.g. domestic sewage) and gaseous (e.g. refinery gases) waste.

In the EU, overall energy production from all waste (industrial waste, renewable and non-renewable MSW) amounts to about 2.4% of the total energy supply. However, around 10% of the energy provided to European DH networks comes from WtE plants. Technical potential for production of energy from MSW in the EU coal regions is estimated at 5 GW.

Compared to traditional waste management methods, such as landfilling, WtE technologies (waste incineration or utilisation of landfill gas) certainly have some benefits, including utilisation of an otherwise wasted resource, reduction in landfilling and methane emissions from landfills, and providing the opportunity for resource recovery.

However, there remain many disadvantages of WtE, which have become more apparent in recent years. These include high CO_2 emissions, air pollution, destruction of useful materials, and the potential to disincentive more sustainable waste management solutions and renewable energy sources. WtE furthermore depends on society's increasingly wasteful consumption, which will amplify upstream environmental impacts.

STRENGTHS	WEAKNESSES
• Energy recovery via various processes: combustion, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery • Benefits of Waste-to-Energy (WtE) when compared to traditional landfilling	• Similar to biomass, the carbon content in the waste that is burned for energy is emitted as CO_2 • Public financing might be complicated, e.g., European Regional Development Fund, Cohesion Fund and JTF do not support investments that aim to increase residual waste incineration capacities
OPPORTUNITIES	**THREATS**
• WtE technologies can achieve reductions in GHG emissions when compared to waste landfilling • Future-oriented WtE might be able to recover nutrients and other valuable materials, • Possible application of the integration of carbon capture and storage (CCS), yet with strong limitations	• Improved waste management practices, including waste prevention, reuse and recycling can significantly reduce residual waste in the future • The EU is gradually turning away from WtE, as demonstrated by its ambitious targets to achieve carbon neutrality by 2050, and to halve residual waste by 2030. • New projects could end up as stranded assets.

Proponents of WtE solutions suggest that there will always be a significant fraction of residual waste material that is non-recyclable and must be dealt with in a different way. However, improved waste management practices, including waste prevention, reuse and recycling can significantly reduce residual waste and contribute to the transition towards circularity.

WtE technologies can achieve reductions in GHG emissions when compared to waste landfilling. Most municipal and commercial waste contains a significant share of biogenic content (reaching 60% or more in some cases). The energy derived from this biomass fraction can be considered a substitute for fossil fuels, and therefore seen as contributing to a reduction in the overall CO_2 emissions from energy production. Additional savings come from avoided methane emissions from landfills and the recovery of ferrous and non-ferrous metals from municipal solid waste, reducing the demand for such primary materials and avoiding emissions from extracting and processing raw materials.

Nevertheless, the carbon content in the waste that is burned for energy is emitted as CO_2. Plastics and other oil-based products, which are also burned in WtE, are equivalent to any other fossil fuel, and cause GHG emissions. After coal, waste incineration represents the most polluting source of energy.

Changes in waste management legislation, such as the phasing out of landfilling, have caused a dramatic increase in WtE incineration in the EU – the quantity of MSW incinerated rose from 32 million tonnes in 1995 to 70 million tonnes in 2018. However, the EU is gradually turning away from WtE, as demonstrated by its ambitious targets to achieve carbon neutrality by 2050, and to halve residual waste by 2030 (as defined by the new Circular Economy Action Plan (CEAP)). Waste incineration is a carbon-intensive process that undermines efforts to reduce carbon emissions, and harms the transition to a circular economy. The construction of new waste incinerators is presented as an example of non-compliance

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with the EU Taxonomy Regulation and "Do No Significant Harm" principle. Thus, major European financial institutions are excluding WtE from financial support. Instead, higher environmental performance waste management solutions that embrace a zero-waste goal, such as waste prevention, reuse and recycling are now encouraged and being financed.

The European Regional Development Fund and the Cohesion Fund do not support investments that aim to increase residual waste incineration capacities, with the exception of the outermost regions and technologies for material recovery. As for the Just Transition Fund, it is clearly stated that waste incineration is excluded from financial support, because it "belongs to the lower part of the waste circular economy hierarchy".

The EU's climate, recycling, and circular economy plans mean that most energy production from waste could eventually become obsolete. The European Parliament's report on CEAP calls for minimising waste incineration, and calls on the Commission to define an EU-wide approach for the management of non-recyclable residual municipal waste that ensures its optimal treatment. It warns about building an overcapacity of waste incineration that could hamper the development of the circular economy.

Energy recovery from waste is done through a variety of processes, including mature technologies such as combustion, gasification, pyrolysis, anaerobic digestion, and landfill gas recovery. Combustion-based waste to energy systems are the most common, and at the current state of development are able to generate energy from landfill-bound waste while meeting stringent environmental requirements. However, the chemical composition of the waste makes it challenging to increase electrical efficiency, and there remains large, and often untapped potential to supply heat from WtE. Investment costs in WtE can vary significantly, and for high-income countries they amount to €380-570 per yearly tonnage capacity.

There are benefits of WtE when compared to traditional landfilling. However, as the principles of circular economy become increasingly important and mainstream, the expectations of these technologies are changing, driving innovation and technology development. Future-oriented WtE focuses on the recovery of nutrients and other valuable materials, production of energy carriers such as hydrogen, increasing the efficiency and quality of heat produced, and consideration of the integration of carbon capture and storage (CCS) with a waste combustion facility.

COPENHILL

Probably the most famous waste inceneration facility, CopenHill in Copenhagen has been showcased as a shiny best practice example for many years and been praised for its integration into the urban area and gaining great social acceptance. However it has also been criticised for being way over-dimensioned and importing waste from overseas, as well as unaddressed environmental concerns.

Source: CopenHill

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CARBON CAPTURE AND STORAGE IN PRACTICE

Hafslund Oslo Celsio project in Norway is arguably the most advanced project developing carbon capture and storage (CCS) for waste-to-energy.

Hafslund Oslo Celsio is Norway's largest district heating supplier and delivered 36% of the district heating produced in Norway in 2021. Its WtE plant in Klemetsrud, Oslo, is the largest in Norway, with capacity to treat 315,000 tonnes of waste per year – mostly residual household waste, but also waste from industry and enterprises. The plant incinerates residual waste that cannot be recycled, and recovers energy for electricity production and district heating. Around 50% of the waste incinerated at the plant comes from biogenic sources, such as unsorted or contaminated food waste, textiles, wood, paper, and cardboard.

Hafslund Oslo Celsio is planning to equip its WtE plant with an amine-based carbon capture facility to capture up to 400,000 tonnes of CO_2 per year. The plant is currently responsible for 17% of Oslo's total CO_2 emissions. The large-scale implementation of CO_2 capture is therefore critical to Oslo's ability to reduce its CO_2 emissions and reach its ambitious climate target of 95% reduction in GHG emissions by 2030.

Source: EINAR ASLAKSEN, Hafslund Oslo Celsio AS

European Commission

7. Excess heat

The usage of excess heat[17] is one of the most promising opportunities for the decarbonisation of district heating systems around the globe. Using excess energy is a clear energy efficiency measure, as it uses surplus energy that is an unavoidable by-product of several activities. If done right, using excess energy will not only result in lower costs, but also has benefits for the environment, ranging from lowering overall GHG emissions to reducing thermal stress on freshwater bodies currently used by many power plants and industries for cooling. The potential amount of heat that can be generated using this excess is tremendous. In the EU alone, the accessible amount of excess heat is estimated to be, at best, 2,860 TWh/y, which almost corresponds to the total energy needed to heat all homes in the EU. That means the usage of excess heat alone could theoretically heat all EU homes.

There are, however, two major limitations to this solution, as well as some lesser ones outlined in the SWOT table, above. First, the potential excess heat described above stems from sources like power plants, heavy industry, and other energy-intensive economic activities that produce a lot of unused surplus heat. Many of these processes will themselves undergo a major transition towards carbon neutrality (e.g., the steel industry switching from fossil fuels to direct reduction with hydrogen or alkaline iron electrolysis), and will therefore invest in efficiency measures to reduce how much

STRENGTHS	WEAKNESSES
• (On the balance sheet) CO_2-free and free/low-cost heat source, provided it arises as an unavoidable by-product of a process that is anyway necessary • Very large theoretical potentials from energy production (power plants, electrolyser…) municipal (wastewater, sewage plants…), commercial (data centres…) and industrial (process heat) sources • Only relatively small (additional) area required for heat exchangers, filters, pumps and pipes	• Source-sink relationship: - Cost-intensive transport lines may be required - Mismatch of temperatures or load profiles (e.g. due to shift or intermittent operation) may require investments in heat storage, booster and/or backup systems • Possibly abrasive or corrosive waste heat flows may demand expensive heat exchangers or filters • Radiant heat technically difficult to use
OPPORTUNITIES	**THREATS**
• Waste heat use can reduce active and cost-intensive cooling and thermal stress on waterbodies • Innovations for the use of radiant heat such as thermo-electric generators (TEG) • Very large low-temperature potentials can be raised with heat pumps • Opportunity to improve the image of a company that supplies waste heat • High political and social acceptance	• Detailed potentials on-site are often unknown • Potential risk of default (in terms of quantity, thermal output or temperature) due to loss or relocation of production or change of product or process • Lack of interest on the part of industry to supply waste heat (as long there is no obligation to use waste heat)

17 To avoid confusion with waste incineration technologies, which is also sometimes referred to as 'waste heat', we prefer to use the term excess energy (or as a synonym, surplus heat).

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excess energy they produce[18]. Nonetheless, even if these industries are completely excluded from potential calculations and only low temperature surplus heat is taken into account, this could still supply 10% of the heat demand in the EU. Second, available excess heat is not necessarily located near to where there is demand for this heat. It thus becomes crucial to consider whether it is possible and makes (economic) sense to connect excess heat production with demand via heat networks and associated infrastructure.

Even with these limitations in mind, there is still great potential to use excess heat for district heating in many regions, especially in areas that have a lot of industry and energy-intensive economic activities. The map in figure 22 (also available as an interactive map) shows the excess heat potentials of industrial sites in Europe that are in close proximity to district heating systems, and could therefore be relatively easily exploited. Overall, a study based on the corresponding data calculates a total potential of 118 TWh (425 PJ) of relatively easy-to-access excess heat that is available at a temperature of 95°C, and 267 TWh (960 PJ) available at a lower temperature of 25°C.

Despite this overarching technology assessment, the potential for individual district heating systems depends on the local economy and the available heat sources that exist in the region (the closer to the district heating system, the better). Furthermore, the temperatures that the district heating system uses are important, as there is much higher potential for mid-to low temperature grids when compared to classic high temperature systems.

The following examples of waste heat recovery projects from municipal, commercial and industrial sources should serve as inspiration for finding valuable sources of excess energy:

Wastewater (municipal)

In Vienna, which has one of the largest district heating systems in Europe (2,500km of pipes), construction has begun on a new sewage water heat pump that uses heat from wastewater. The wastewater in Vienna has average temperatures of around 12-23 °C, which may seem low. But with the help of an 110 megawatts electric heat pump the combination of large volume flow and cooling down of 6 degrees Celsius is nonetheless sufficient to be used to generate 880 GWh/a of heat at a temperature level of 90°C. It is expected that the new large-scale heat pump will be capable of fulfilling the heat demands of around 112,000 households. According to authorities, the plant will be complete in 2027. The investment costs are expected to be €70 million.

A similar project is also under construction in Utrecht, the Netherlands.

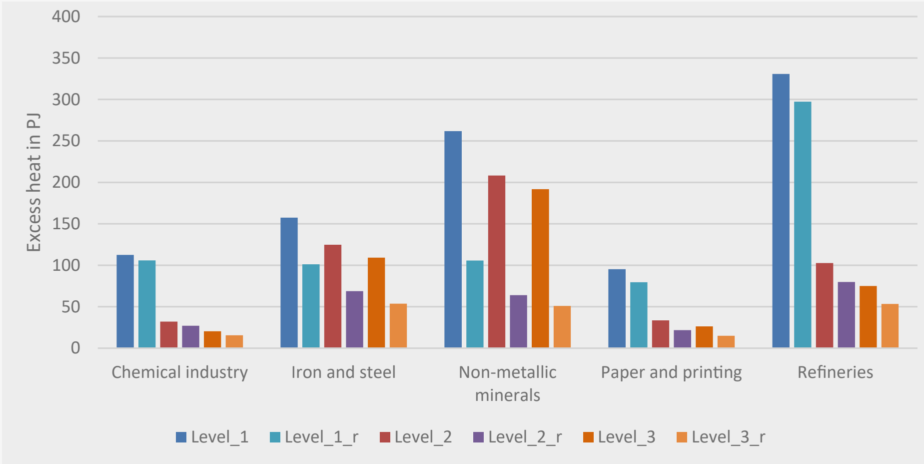

FIGURE 21: TOTAL EXCESS HEAT POTENTIALS OF THE MAIN ENERGY-INTENSIVE INDUSTRIAL SECTORS IN THE EU, SEPARATED BY HEAT UTILISATION LEVEL, CONSIDERING BOTH STATUS QUO AND MAXIMISED USE OF INTERNAL SURPLUS RECOVERY.

Source: sEEnergies 2019

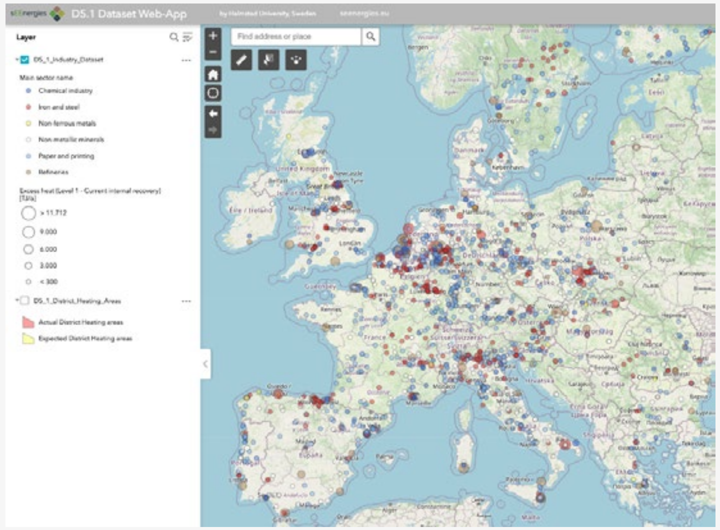

FIGURE 22: EXCESS HEAT POTENTIALS OF INDUSTRIAL SITES IN EUROPE

Source: sEEnergies

18 Surplus heat recovery and internal usage is already commonly used in almost all industrial processes to increase efficiency. Studies that aim to project the potentials for excess heat usually either take that status quo as a basis, or define multiple scenarios, including one that assumes that the potential for internal heat recovery is maximally implemented, in order to formulate a rather conservative, future-proof projection.

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Data centres (commercial)

Data centres are a growing source of waste heat. The CELSIUS initiative has produced a study that proposes strategies for improving energy efficiency in data centres, showcasing available technologies and examples of best practice. Three cases from the City of Stockholm showcase heat recovery as part of a pilot project for an open district heating network.

Other examples of good heat recovery practices hail from the City of Odense, Denmark and heat recovery from data centres in Braunschweig, Germany.

Pulp and paper mills (industrial)

The paper mill in Skjern, Denmark, Skjern Papirfabrik, sells low-temperature surplus heat to the local district heating company Skjern Fjernvarme. The paper mill installed a 4MW heat pump that raises the temperature level slightly so that it can be used in the city's DHS. The paper mill delivers more than half of the annual heat production for the DHS of the small city, with the exact amount varying according to the production intensity of the mill. The paper mill invested €3 million and the district heating company €670,000 to put in place the transmission connection – an investment whose amortisation took only five years. For the district heating system, buying the excess heat from the mill is always the cheapest option.

Breweries (commercial)

In 2013, Puntigam Brauquartier, a residential complex with 800 apartments, was developed in Graz, Austria. The complex was set up as an innovative quarter that includes facilities such as car-sharing, public transport stops, an open space area, and an information centre for residents. The district uses waste heat from the neighbouring Puntigam Brewery, generated during the fermentation process, for both heating (at 45°C) and hot water (70°C). As the district was designed with well-insulated buildings and low energy needs for heating (mostly floor heating), the full quarter is therefore self-sufficient with regards to heat and warm water.

Steel industry (industrial)

In Brescia, Italy, a steel mill heat recovery system was implemented. The project recovers heat from the smelting furnace and converts this into steam, which is then converted into electricity and thermal energy, and fed into Brescia's district heating system. As high levels of heat are needed for steel production, surplus heat from steelmaking can be implemented in 3rd generation DHS that run on high temperatures.

Supermarkets (commercial)

Keeping food fresh in cooling displays and freezers accounts for most of the energy consumption in a supermarket. Refrigerators generate heat during the process of cooling, which is often released as a byproduct. In Høruphav, Denmark, a supermarket pilot is reusing that heat, first and foremost for its own heating needs, with some surplus energy also sold to the local DHS. From August 2019 to April 2022, the supermarket had a total heat consumption of 668 MWh, and reused 523MWh through the new heat recovery system. An additional 133MWh has been sold to the district heating provider.

WHERE DOES EXCESS HEAT COME FROM?

Excess heat can be extracted in several different forms and requires specific methods that vary based on the following different types of excess heat transport mediums (see figure 23):

- Gases (e.g., flue gases)
- Solid streams (e.g., hot coke, steel, clinker)
- Liquid streams (e.g., wastewater in paper production)
- Cooling water (e.g., in power plants and many industrial processes)
- Radiation (e.g., furnace openings)
- Conduction (e.g., from surfaces of machines)

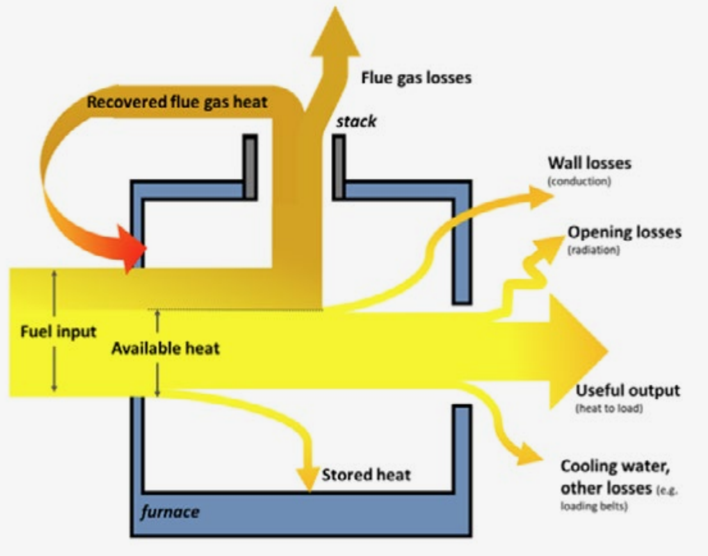

FIGURE 23: TYPICAL HEAT LOSSES IN INDUSTRIAL FURNACES.

Source: sEEnergies 2019

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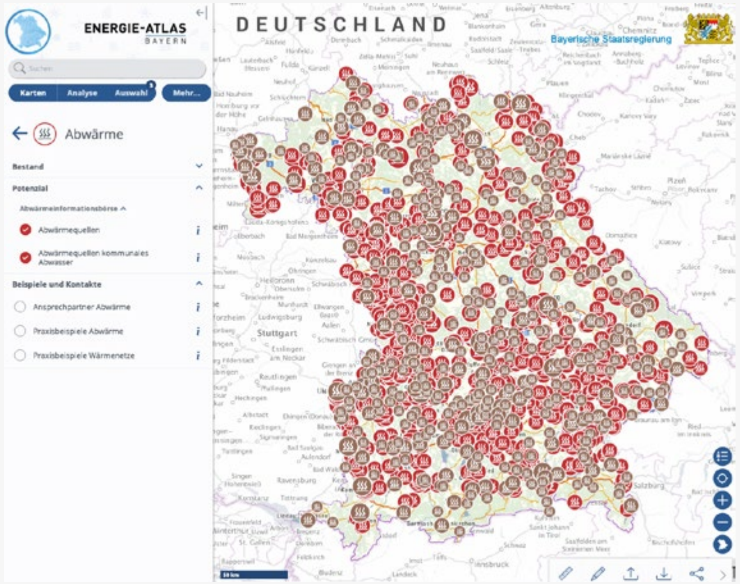
Metro tunnels (municipal)

While potentially less relevant for coal+ regions, metro tunnels are another source of excess energy that could be utilised via heat pumps. The only such system that is currently operational is in London, England. Bunhill Energy Centre uses a 1 MW heat pump to upgrade warm metro air from 18-28°C (in heating periods) to 80°C to be fed into the DHS. Several other metropolitan areas around the world are currently exploring this option as well.

Further examples have been also gathered by the ReUseHeat project.

All these examples require not only an initial investment and technological solution, but also a legislative framework that brings together all relevant – often private – companies that can serve as potential providers of excess heat, alongside the DHS operators. Most regions will face a number of market barriers that prevent DHS from leveraging the potential of reusing excess heat. Regulation can help by, for example, making it mandatory for industries to make a plan to exploit excess heat (see also chapter on Strategic H&C planning). Partnerships between local authorities, energy suppliers, and potential energy sources (such as supermarkets, data centres, wastewater facilities, and industries) can further help to exploit excess heat's full potential. An important tool for bringing local actors together can be the provision of **regional excess heat maps**, such as those developed in some German states like North Rhine-Westphalia or Bavaria (see figure 24).



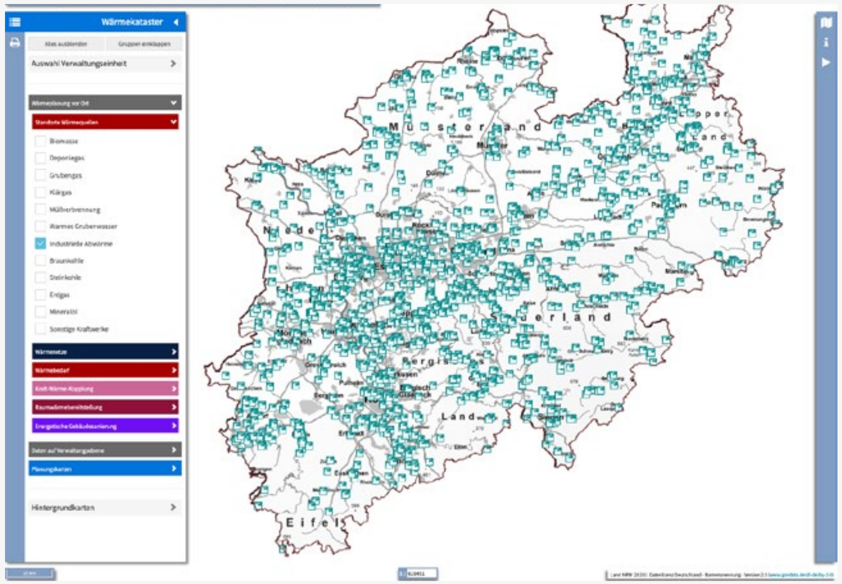


FIGURE 24: EXAMPLES FOR EXCESS HEAT MAPS THAT WERE DEVELOPED AS A POLICY TOOL TO INCENTIVISE THE USE OF EXCESS HEAT.

Source: Energieatlas NRW and Wärmekataster Bayern

European Commission

8. Combined heat (cooling) and power technologies (CH(C)P)

Combined heat and power (CHP), also known as **cogeneration** or **trigeneration** (**combined heat**, **cooling and power**, or CCHP), is an efficiency technology that makes use of the waste heat generated by thermal power plants during electricity generation. Compared to the uncoupled generation of electricity and heat using the same fuel in two separate plants, this saves primary energy and CO_2 emissions. The overall efficiency (sum of electric and thermal efficiency) is in the range of 80 - 90%, depending on technology, size, fuel and temperature level. CHP plants come in a variety of technical forms (see Info box: Technical description of CHP technologies and their market outlook), covering a wide range of temperatures and outputs (see Overview of different CHP technologies).

STRENGTHS	WEAKNESSES
• Efficiency technology (waste heat utilisation) for thermal power plants across a wide range of applications and performance • Technology diversity (internal combustion engine, gas turbine, steam turbine, combined cycle, fuel cell, organic rankine cycle) and good combinability with other heat supply options (especially PtH, bioenergy, and solar energy) • Contribution to secure generation capacities (high flexibility, provision of positive and negative residual load or balancing power) • Technical potential for switching from fossil to renewable gases (biogas, biomethane, RE hydrogen and RE methane) and solid fuels (solid biomass) • Increasing market maturity of fuel cells as a technology with high electric efficiency and direct (i.e. efficient) utilisation of H_2	• Still predominantly dependent on (cheap) fossil fuels • Combustion technologies (especially motor CHP) have disadvantages in terms of noise, vibrations, pollutant emissions, maintenance requirements, service life, and methane slip
OPPORTUNITIES	**THREATS**

• Increasing demand for controllable power plants and flexibility, as well as sector coupling
• Remaining heat demand for space and process heat that cannot be covered by alternatives (especially in winter)
• Increased potential and economic efficiency for CCHP due to increasing air-conditioning demand (climate change)
• Conversion of gas supply (generation and gas infrastructure) to biomethane, RE hydrogen, and RE methane
• Imports of RE gases from countries with lower-cost RE electricity generation potentials
• Synergetic use of H_2 feedstock pipelines in industry
• Use of existing power plant sites for renewable thermal storage power plants (PtH + CHP)
	• No more use of fossil fuels (natural gas, oil, coal) in the long term
	• Economic viability made more difficult by:
	  - More expensive, low-CO_2 energy sources (H_2, SNG)
	  - High cost reduction potentials in alternative technologies of renewable electricity (electrification of space and process heat with heat pumps and direct electric applications) and renewable heat
	  - Decreasing refinancing margins on the electricity side (due to increasingly cheap RE electricity in the base load)
	• Dismantling of gas distribution pipelines due to declining demand in the building sector
	• Uncertainty about new gas supply (potentials and costs of RE hydrogen or RE methane)
	• Increased competition for use due to significantly increasing H_2 demand in industry (e.g. due to direct reduced iron (DRI) in the steel sector) and transport (heavy duty, aviation, ships)
	• Uncertain and complex energy policy framework conditions (funding, tenders, levies, taxes, CO_2 prices, ETS, etc.)

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Overview of different CHP technologies

In the past, CHP was – and in fact still is – a widely used technology for generating and feeding heat into large and small heating networks. One of its strengths is that it can provide electrical and thermal power at base load. However, the current business model is usually based on the combustion of (cheap) fossil fuels, such as coal, natural gas and heating oil. These are becoming increasingly expensive due to rising CO_2 prices and, in some cases, physical shortages in the markets. In addition, in order to comply with global and European climate protection targets, these fuels must be taken off the market in the EU by 2050 at the latest.

In principle, CHP plants can be converted to use renewable energy sources (especially solid biomass, biogas and green hydrogen). However, this conversion is associated with a number of risks and uncertainties with respect to energy prices, potentials, timely availability, and infrastructure development, especially for renewable synthesis gases. At the same time, other competing technologies based on excess heat or renewable energy sources, such as power-to-heat, solar thermal, or geothermal energy, are becoming more mature and thus economically competitive. With respect to electricity generation, CHP plants are also coming under increasing economic pressure in view of the expansion of, and persistently high learning curves associated with, renewable electricity generation plants (especially PV and wind), which primarily feeds into the electricity grid. Due to their growing share, the operating times of CHP plants are decreasing, thus jeopardising their economic viability.

CHP TECHNOLOGY	CAPACITY [MWEL]	POWER TO HEAT RATIO	TEMPERATURE LEVEL	FLEXIBILITY	LCOH (TODAY)	MARKET OUTLOOK
Gas Turbine + Waste heat boiler	0.2 – 300	0.3 – 0.6	Hot water: < 200°C Steam: < 550°C	+	+	+
Steam Turbine	10 – 1000	0.6 – 2.5		-	o	o
Combined cycle power plant (CCPP)	80 – 850	0.7 – 2.0		+	+	+
Combined heat and **power unit**	0.005 – 10	0.6 – 0.9	< 130°C	+	+	+
Organic Rankine Cycle (**ORC**)	0.1 – 10	0.1 – 0.25	70°C - 130°C	+	o	-
Fuel Cell (FC)	0.001 – 4	0.7 – 3.25	Hot water: < 150°C, Steam: > 500°C	++ (LT) + (HT)	- -	o

LCOH: Levelized cost of heat
+(+): (strongly) above average
LT/HT: Low/High Temperature
o: average
ORC: Organic Rankine Cycle
-(-): (strongly) below average

Source: LANUV 2021, own translation

On the other hand, there are great opportunities for secured power to cover the residual electrical and thermal load that remains in systems whereby renewable electricity and heat sources are fed-in with priority, but unsteadily. The hybrid provision of heat from combined CHP and PtH (see chapter on Power-to-Heat) plants, alongside solar thermal support or CHP low-temperature waste heat that can be raised to a usable temperature level with the help of heat pumps, is also referred to as **innovative CHP**. These hybrid systems are also discussed in the section Integrated energy systems. They offer synergy effects in terms of costs, security of supply and efficiency, especially with the integration of thermal storage.

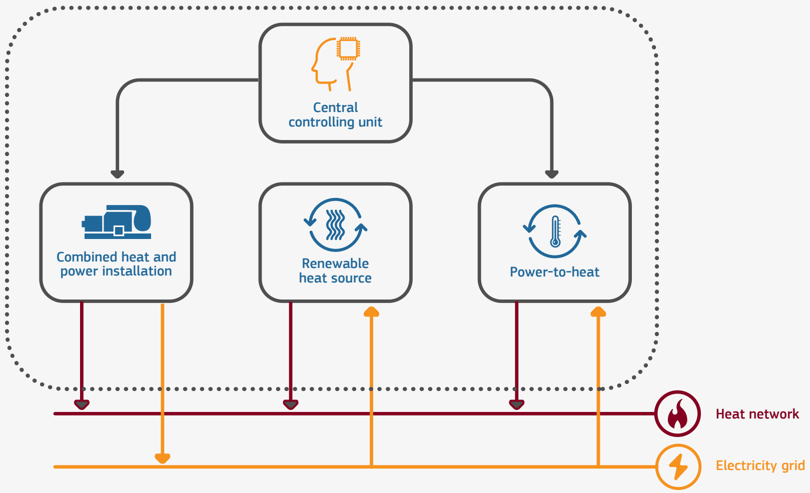

FIGURE 25: PRINCIPLE OF THE CHP TECHNOLOGY CONCEPT

Source: VK Energie

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INFO BOX: TECHNICAL DESCRIPTION OF CHP TECHNOLOGIES AND THEIR MARKET OUTLOOK

Gas turbine + Waste heat boiler

Natural gas or renewable gases are burned in a gas turbine (GT). The hot combustion gases drive a turbine whose mechanical rotational energy is converted into electricity by a generator. The exhaust gases from the gas turbine, with temperatures between 450°C and 600°C, are used in a waste heat boiler to heat hot water or steam. Direct use of the hot exhaust gases in production processes (e.g. drying) is also possible.

Due to their low electrical efficiency (30 - 39%), gas turbine CHP plants have efficiency disadvantages compared to combined cycle plants. However, gas turbines are quite favourable in terms of CAPEX costs and are among the most flexible of all CHP technologies, so there are still market opportunities for this technology to cover peak loads in future energy systems with high shares of renewable energies, and consequently short operating times for CHP plants.

Steam Turbine

By burning fossil fuels, renewable energy sources, or waste in a steam boiler, fresh steam is produced resulting in electricity production in a steam turbine with a connected generator. Geothermal heat can also be used to drive a steam turbine. The turbine can be designed as a *backpressure system* whereby the pressure level, and therefore the temperature of the exhaust steam, is predetermined (usually for heat recovery in steam networks or industrial processes). Alternatively, steam turbines can be designed as *condensing systems*. In this case, the steam is expanded to negative pressure and the residual heat is released to the environment at a low temperature level (about 95 °C) in the condenser. In addition, heat can be extracted from steam turbines by tapping at any pressure level. Hot water for district heating can be provided by heating condensers.

Due to the relatively low electrical efficiency (35 - 46%) compared to combined cycle power plants, paired with high investment costs, there has been no significant expansion of this process in recent years. Instead, a steady reduction of steam turbine power plants is expected in the course of the energy transition and the phase-out of coal. These power plants do not have the flexibility of gas turbines, Combined Cycle Gas Turbines (CCGTs), combined heat and power units, or fuel cells, and are therefore at a disadvantage in the face of future challenges in an electricity market dominated by fluctuating renewable energies.

Combined cycle power plant (CCPP) / Combined Cycle Gas Turbine (CCGT)

In a combined cycle plant, a generator is first driven to produce electricity by burning gas or oil in a gas turbine. The exhaust gases from the gas turbine, at temperatures between 450°C and 600°C, are used in a waste heat boiler to heat hot water or steam. The downstream steam turbine process produces additional electrical power so that an high overall electric efficiency of 35 - 60% is achieved. The steam turbine can again be designed as a *backpressure system*, whereby the pressure level and therefore the temperature of the exhaust steam is predetermined, usually for heat recovery in steam networks or industrial processes. Alternatively, steam turbines can be designed as *condensing systems*. In this case, the steam is expanded to negative pressure and the residual heat is dissipated at a low temperature level in the condenser. In addition, heat can be extracted from steam turbines by tapping at any pressure level. Hot water for district heating can be provided by heating condensers.

As coal is phased out, the development of natural gas-fired combined cycle power plants is being discussed as a replacement for coal-fired CHP. In general, CCGTs are well suited to provide the residual load for the increasingly intermittent renewable electricity generation. The technology is flexible enough to accommodate a switch from fossil gas to renewable gases. Biomethane and synthetic natural gas (SNG) can be used in such plants without converting the gas turbine, and hydrogen (depending on the proportions) is usable with gas turbine conversion.

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Combined heat and power unit

A gas- or oil-fuelled internal combustion engine (ICE) drives a generator to produce electricity with an efficiency of 34 to 41%. Waste heat from the engine's cooling water, intercooler, oil cooler and exhaust is extracted by heat exchangers up to a temperature of 130°C. Compared to gas and steam turbines, the advantages of a CHP unit are the relatively low cost of CHP system technology in the low power range, and its potential for fast start-up and shut-down under fluctuating load conditions. In addition, the serial connection of several modules and a flexible mode of operation can cover a wide power range.

Because of their flexibility and modularity, combined heat and power units are a complementary technology to renewable energy. Therefore, further market expansion is expected, but with lower operating hours in use. The first hydrogen-powered CHP units are already in operation, making carbon-neutral operation possible.

Organic Rankine Cycle (ORC)

The basic principle of an ORC is similar to that of a steam turbine power plant. However, unlike a conventional steam turbine, which uses steam as its working medium, an organic liquid with a lower evaporation temperature is used as the working fluid in an ORC. This makes ORC systems suitable for power generation from low temperature sources such as geothermal, solar thermal, or waste heat. The ORC process is also used for biomass CHP plants in the medium power range (from about 200 kW_{el}). If a thermal oil or hot water circuit with a temperature of approx. 300°C is connected between the biomass combustion plant and the ORC process, virtually pressureless boiler operation is possible. This eliminates the need for a steam boiler operator, which is common in Germany for the steam power process, so that there is little manual labour required.

Due to its low electrical efficiency of 10-20%, and comparatively high plant investment, the use of an ORC power plant is only economically viable if there is a low-cost heat source (e.g. waste heat) and high avoided electricity costs thanks to own consumption. However, the heat source (e.g. geothermal energy) may compete with the direct use of heat.

Fuel Cell

In a fuel cell (FC), gaseous hydrogen reacts with oxygen to form water. The hydrogen can either be supplied directly, produced from natural gas in an external reformer (low-temperature FC), or produced in an internal reformer (high-temperature FC). Unlike combustion in a heat engine, the reaction takes place in a chemical energy converter, so exergy losses are low, and electrical efficiencies (35 - 65%) are high. The heart of the fuel cell is the single cell in which the chemical reaction takes place, emitting electricity and heat. For high power generation, several single cells are connected in series to form stacks, and several stacks are connected together to form the FC system. As the fuel cell does not require combustion and has almost no mechanical components, it operates very quietly and low-wear. Depending on the chemical converter used, different types of fuel cells are available. The most common types are

- Phosphoric Acid Fuel Cell (PAFC)
- Polymer Electrolyte Membrane Fuel Cell (PEMFC)
- Solid Oxide Fuel Cell (SOFC)
- Molten Carbonate Fuel Cell (MCFC)

The high electrical efficiency of fuel cells and their ability to generate electricity and heat from hydrogen in an emission-free and controllable manner make fuel cell technology suitable as a climate-neutral complement to intermittent renewable electricity generation. At present, however, fuel cells are relatively expensive to purchase, so reducing investment costs will be crucial to increasing their market share (over combustion-based CHP) in the future. In addition, the use of fuel cells as CHP depends on the amount of hydrogen available for electricity and heat generation (given competition for use with industry and transport).

9. Nuclear energy

STRENGTHS	WEAKNESSES
• Low-carbon emission technology • Base load capable • Low operation costs • Using excess heat from a nuclear power plant to supply DH not only increases the plant's overall efficiency (to ~80%), it also (somewhat) reduces its ecological footprint, as the heat is utilised instead of released into the environment	• Production of radioactive waste • Very capital intensive, which does not allow for market economy realisation (without strong governmental subsidies and guarantees) • Very long construction periods • Inflexible operation that is not compatible with fluctuating power generation (e.g. solar and wind power) • If not utilising the excess heat, electricity-only nuclear power plants are not the most efficient (~33%) and release large amounts of heat into the nearby ecosystem • Environmental and health hazards in the upstream production chain of nuclear fuel (extraction and preparation of uranium) • Centralised technology with no small (<300 MWel) units available on the market • Need for large cooling units, though this need can be reduced in case of DH supply • Nuclear plants are typically located far away from the large population centres that could benefit most from such a DH supply; plant locations are usually not concurrent in coal+ regions
OPPORTUNITIES	**THREATS**
• Potential to produce large quantities of electricity for new low-carbon applications like power-to-heat, power-to-gas and e-mobility • Most nuclear power plants are not yet equipped to supply DH, meaning it is a largely untapped resource (at least for those communities nearby)	• Generally poor acceptance among the public, including a strong NIMBY effect associated with constructing new nuclear plants • Risk of cost explosion and time delay during construction phase • Dependence on few manufacturers and nuclear fuel suppliers, partly dominated by unreliable third countries (especially Russia and China) • Still no viable and secure concepts for final disposal of nuclear waste • Costs of monitoring and safely storing nuclear waste will be passed onto future generations (for well over 10,000 years) • Risk of proliferation of nuclear materials (plutonium) for nuclear weapon production • Risk of a maximum credible accident with radioactive contamination that leads to extensive, disastrous and long term impacts on human beings and biosphere

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Nuclear-based DH systems are relatively uncommon, covering only about 0.2% of DH worldwide, the overwhelming majority of which are found in Russia (with ~4.5 GW_{th} of total DH capacity via nuclear CHP plants), as well as a few other parts of eastern Europe (e.g. České Budějovice, Czech Republic has aDH system that was recently retrofitted and linked to the relatively-nearby Temelin nuclear power plant). At the moment, this approach remains rather rare in western Europe, though nuclear-philic countries like France and Finland are considering exploiting it as an option as they phase out coal.

From a certain point of view, nuclear DH may seem only minimally different from other forms of large-capacity CHP plants that focus primarily on electricity generation, rather than heat production. Considering that roughly two thirds of the heat produced by a normal nuclear power plant is discharged into the environment, there certainly seems to be a decent case for utilising this rather steady base-load type of "excess heat".

Some are looking into still-emerging technologies, like small modular reactors, as an option for energy production, including DH, though detractors claim that these technologies are actually "too late, too expensive, too risky and too uncertain". In any case the (severe) challenges posed by using nuclear plants for DH remain nearly identical as for electricity. The many valid concerns raised around exploiting nuclear energy (e.g. generally poor public acceptance, long time-lag from planning until operation, high costs, environmental and health problems in uranium mining, disaster risks, terrorism threat and very long-term radioactive waste disposal) do not disappear simply because a CHP nuclear plant operates more energy-efficiently than an electricity-only one. The only real positive difference between these two is a slightly smaller ecological footprint derived by utilising excess heat, rather than releasing it into the environment.

A distinct obstacle for nuclear DH is that such power plants are generally located far from major population centres, which tend to be the most cost-effective areas for DH. Unless building long (expensive) pipelines to these heat-dense cities, exploiting a nuclear power plant for DH would usually be rather limited to only surrounding areas, which are typically more sparsely populated, meaning a relatively low impact on overall heating decarbonisation. Furthermore, considering that it is relatively uncommon to have already-built nuclear power plants in the same areas where coal+ mines and coal power plants have operated, the vast majority of coal+ regions considering nuclear DH would have to start from scratch, building a new nuclear power plant. Other (renewable) alternatives are almost universally cheaper to deploy, and can begin operating with clean DH before any new nuclear facility could even manage to get past its own planning stages, much less supplying heat.

Integrated energy systems

District heating has a long tradition, with DH networks with simple coal- or waste-fired boilers already established in the 19th century. This first generation of district heating (1GDH) was characterised by a high temperature level and low energy efficiency. figure 3 in chapter on Energy Efficiency illustrates the development from this first generation to the target state of fourth generation (4GDH), representing a highly-efficient, flexible, climate-neutral, and fully digitally integrated energy system. This integrated concept is characterised by:

- High energy **efficiency** (see chapter Energy efficiency: The guiding principle)
- Low **temperature level** up to Cold Heating Networks (see "LowEx" infobox)
- **Diversification** and integration of **excess heat**, **renewable** energy sources (see chapter Energy supply options for decarbonising district heating systems), new **technologies** and **thermal storages**
- **Flexibilisation** to use energy at the most efficient time (and to most efficient costs)
- **Decentralisation** (including sub networks)
- **Sector coupling** (CHP and PtH) and **cold** integration (CCHP)
- **Digitalisation** and interaction between **demand** (building efficiency) and **supply**.

LOW-TEMPERATURE HEATING GRIDS AND COLD LOCAL HEATING (LOWEX)

LowEx systems are systems for heating and cooling of buildings that are designed to be supplied with energy sources at a low temperature (and thus exergy) level. In thermodynamics, "**exergy**" refers to that high-value portion of energy (which depends on the ambient conditions) that is capable of delivering work. Examples of low-exergy forms of energy are heat sources at a low temperature level, such as near-surface geothermal heat, ambient heat, (low-temperature) solar heat, and waste heat from industrial processes or CHP plants.

Low-temperature heating grids – also called **LowEx** grids – have the advantage of making low-exergy and renewable heat efficiently usable for the heat supply. They are thus central pillars of a decarbonisation strategy for the heating market, and have been applied in a few places, such as Bjerringbro, Denmark and Heerlen, the Netherlands. LowEx networks are characterised by low network temperatures, usually <50°C (these are also called *Cold Local Heating* at temperatures below approx. 20°C, see also figure 3 in chapter "Energy Efficiency"). This allows heat sources to be tapped whose temperature levels are not sufficient for direct integration into conventional heating networks. Thermal CHP plants can increase their electricity generation at constant heat output, and the use of heat pumps becomes more efficient and economical due to significantly lower temperature spreads compared to conventional heating systems.

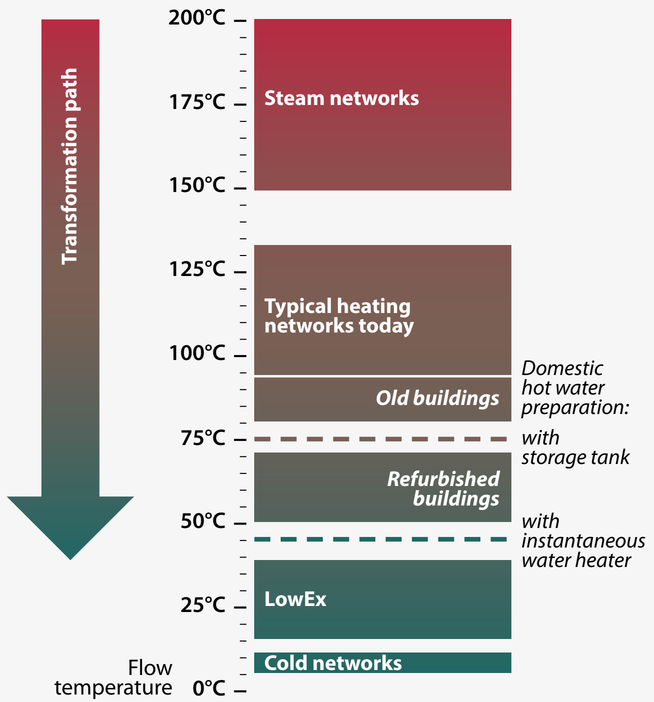

FIGURE 26: NECESSARY FLOW TEMPERATURE LEVELS FOR DIFFERENT KIND OF DISTRICT HEATING NETWORKS.

Source: Wuppertal Institute

Other advantages of *cold local heating* include a reduction in heat distribution losses thanks to flow and return temperatures being close to the ambient temperature, and the reduction of material and installation costs thanks to lower insulation thicknesses (up to largely dispensing with pipe insulation) and through the use of inexpensive plastic jacket pipes.

Diversification and the integration of new technologies and thermal storages are key elements to fully develop the local potential of renewable energy sources to cover heat demand in times of low renewable energy input (e.g. low solar irradiation), as well as to lower the heat generation costs in times of high fuel (e.g. gas, biomass or waste) or electricity prices and to reduce risks of shortage of a single energy carrier (e.g. natural gas, biomass, or renewable hydrogen).

Energy storage

Thermal storage can help to bridge periods of missing or excessive heat production, e.g. by solar thermal or by power-to-heat applications (e.g. in times of very low or very high electricity prices), thus adapting heat production to the actual thermal load.

Many suppliers have already added an *above-ground thermal storage tank* to their heating network to optimise system costs. Such heat tanks can be, for example, 44 cubic metres large, with their thermal capacities of about 1500 MWh for several hours up to a few days.

A special innovation is the so-called *Atmospheric Two-Zone Storage Tank* (see figure 27). Its storage volume is divided by an intermediate roof into an upper and a lower zone, which are connected to each other via pipes. The upper zone contains water at 60-90°C, which generates pressure due to its own weight. This ensures that the water in the lower zone, which is over 100°C, does not start to evaporate. Thus, the two-zone design allows for the storage of water with temperatures slightly above 100°C (e.g. 115°C) in a pressureless container.

Underground seasonal storage tanks are suitable for storing heat over a period of several weeks or months. There are four technical options to consider when pursuing underground seasonal storage (see figure 28):

1. ***Tank*** *thermal energy storage systems* (**T**TES) usually consist of an underground reinforced concrete tank that is filled with water.
2. ***Pit*** *thermal energy storage systems* (**P**TES) begin by creating an artificial 'pond', filling it with storage material, and covering it with a lid (e.g. a foil or floating insulation balls).
3. ***Borehole*** *energy storage systems* (**B**TES) use the rock underground to store heat with the help of geothermal probes through which water flows.
4. ***Aquifer*** *energy storage systems* (**A**TES) use underground, water-bearing rock layers for heat storage, which are tapped through boreholes.

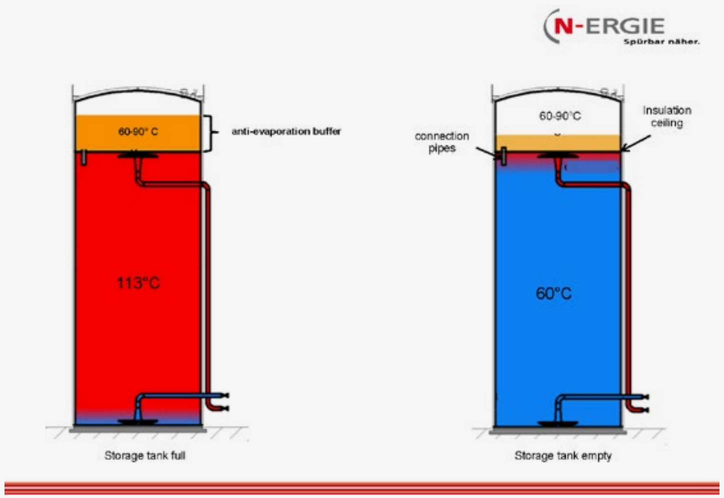

FIGURE 27: PRINCIPLE OF AN ATMOSPHERIC TWO-ZONE STORAGE TANK.

Source: N-ERGIE AG 2018

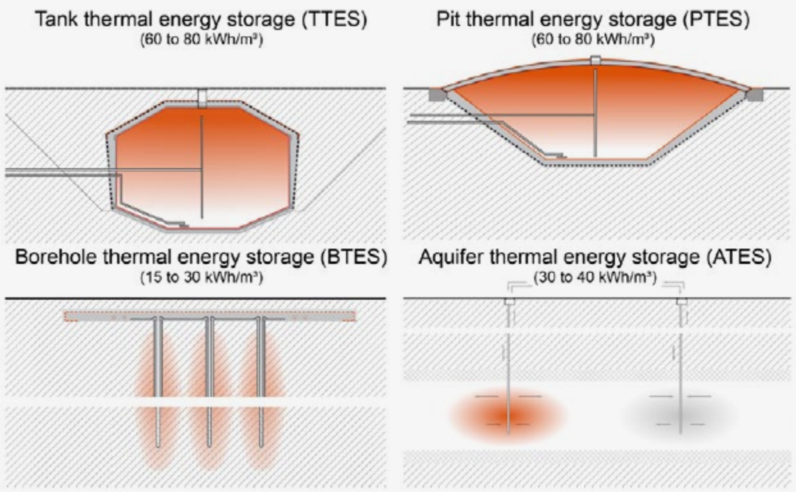

FIGURE 28: OVERVIEW OF DIFFERENT PRINCIPLES OF SEASONAL UNDERGROUND THERMAL STORAGE

Source: Solites

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PIT THERMAL ENERGY STORAGE SYSTEMS (PTES)

The technology for pit storage tanks has been used in several countries on a commercial stage for many years. However, the main challenge posed by these tanks is that the insulated lids accumulate moisture, resulting in high heat losses. To address this, Aalborg CSP, a Danish company, developed a new lid design (figure 29), which features evenly sized squares with slopes directing rainwater towards pumping wells, efficiently draining water, and minimising heat losses.

This new technology results in reduced heat losses of only 8% over the course of a year. The storage pits at Høje Tåstrup near Copenhagen are considered "one-of-a-kind", featuring the first operational pit with multiple charging/discharging cycles within a year (e.g., 26 cycles). It is charged with heat from the Greater Copenhagen transmission grid and is intended to reduce expensive peak loads in the district heating network.

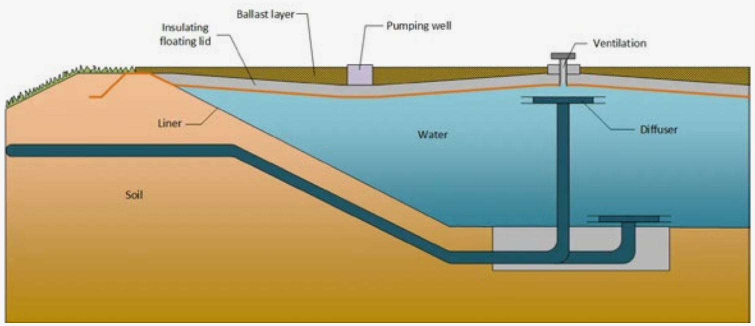

FIGURE 29: THE NEW INSULATED LID TECHNOLOGY AUTOMATICALLY HANDLES RAINWATER AND PREVENTS MOISTURE ACCUMULATION INSIDE THE INSULATION.

Source: Aalborg CSP

Flexibilisation

Flexibilisation (also referred to as hybridisation) of District Heating & Cooling (DHC) generation systems allows for the use of the cheapest available energy source at any time, notably including solar radiation or electricity (via power-to-heat) in times of abundant renewable energy. This strategy is a **flexible response** to both the variability of renewable energy potential, and price signals from the energy market. Thus, the use of storable and normally high-priced energy resources like biomass, renewable gases, or (with limitations) waste can be limited to cover residual heat demand, and – in the case of CHP plants – residual electricity demand.

Sector coupling

Sector coupling (see chapters Combined heat (cooling) and power technologies (CH(C)P) and **cold integration** are further elements of future DHC networks. Cold can be generated by electric chillers, or by absorption/adsorption chillers, driven by renewable electricity or by sustainable heat from CHP plants (*trigeneration* or *Combined Cooling Heat and Power* CCHP), from waste heat, or from renewable heat. If a heating and cooling network is operated simultaneously, heat pumps can highly-efficiently shift heat from the cooling to the heating line. In this case, the Coefficient of Performance (COP) of the heat pump is almost doubled.

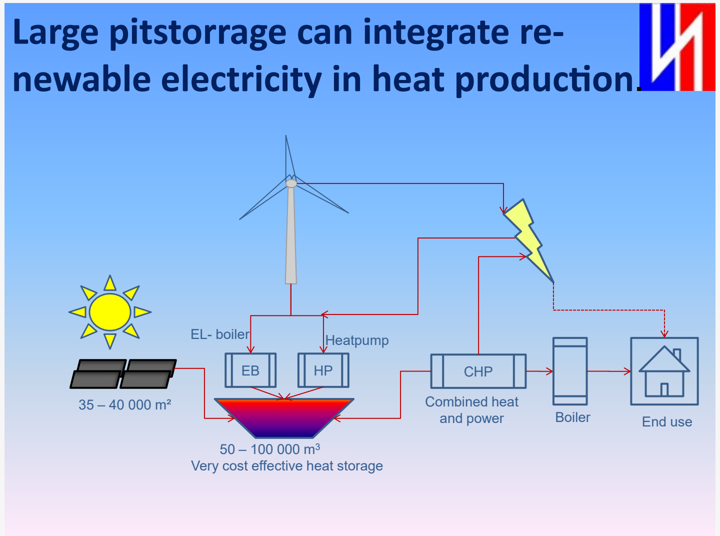

FIGURE 30: FLEXIBILISATION/HYBRIDISATION OF DIFFERENT RENEWABLE HEAT GENERATION SYSTEMS WITH A STORAGE TANK AND CHP.

Source: Dronninglund Fjernvarme 2014

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4G AND 5G DISTRICT HEATING SYSTEMS AS THE GOLD STANDARD? AN EXAMPLE OF THE INTEGRATED ENERGY SYSTEM OF HEERLEN, NETHERLANDS

A 4th or 5th generation district heating system (also referred to as 4GDH or 5GDH) is a type of district heating system that operates at low temperatures, typically between 5-35°C for 5G, and 35-70°C for 4G. This is significantly lower than the operating temperatures of traditional district heating systems, which typically operate at temperatures of 70-120°C.

The lower operating temperatures of these systems make them more efficient, and allow them to use a wider range of heat sources. These 4G and 5G systems largely follow the energy-efficiency-first principle introduced in chapter 2. They not only use highly efficient technologies, but also exchange thermal energy between buildings according to their H&C needs. Integrated storage for heating and cooling also buffers fluctuations and allows more flexibility than traditional district heating systems.

The Mijnwater project was initiated and built by the municipality of Heerlen, the Netherlands as a 4th generation DHC network. The idea was to use warm water in an abandoned and flooded local coal mine as a sustainable source. In the winter, 28°C water was fed from the mine into the grid to deliver warmth, while in the summer, cool water of 16°C from a shallower source was distributed.

This grid started by serving one large office building (national statistics bureau CBS) and a housing project in Heerlen. In 2013, the grid was upgraded to a fully functioning 5th Generation Heating & Cooling grid, which is now able to exchange heat and cold between all customers, simultaneously, while the mine water system is used to store heat and cold. The upgraded second stage of the Mijnwater project provided heat for 200,000m^2 of building equivalents in four connected cluster grids, with a newly installed capacity of 4 MW for heating and cooling.

Mijnwater B.V. plans to further invest €430 million between now and 2030 to further expand the system to connect to approximately 30,000 homes. The application of the 5GDHC concept is continuously improved and has been also used as a blueprint for DHS development in other municipalities in Europe.

A more in-depth overview can be found in a separate case study developed by the CRiT initiative.

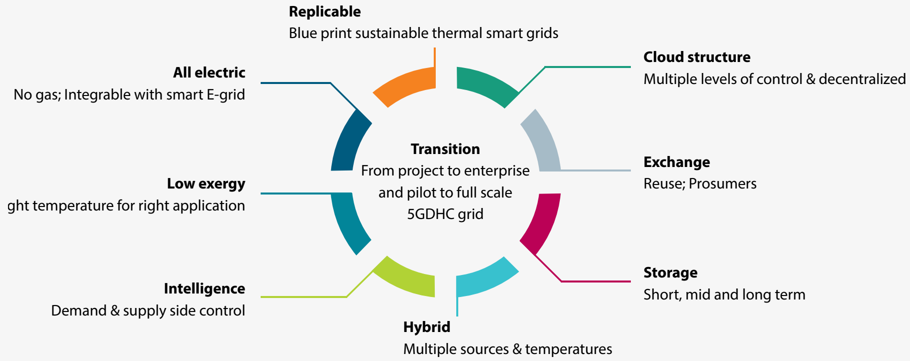

FIGURE 31: ELEMENTS OF A FULL-SCALE FIFTH GENERATION DISTRICT HEATING SYSTEM

Source: Fraunhofer IEG

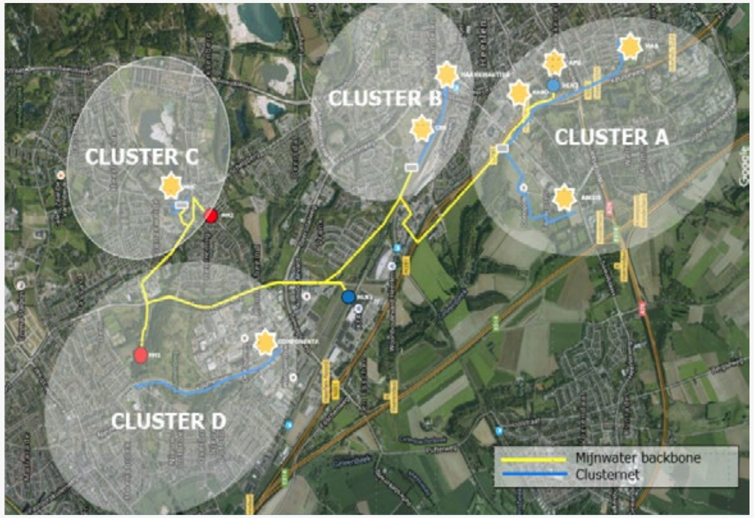

FIGURE 32: A MAP OF HEERLEN MUNICIPALITY SHOWING THE CLUSTERS, PIPE NETWORK AND HOT & COLD DRILLING WELLS, THE LATTER INDICATED BY RED AND BLUE DOTS.

Source: Van Oevelen Vanhoudt 2020

Digitalisation

Digitalisation is a key enabler of all the strategic elements described above, such as energy efficiency, diversification, hybridisation, flexibility, sector coupling, and storage management. For example, digital infrastructure can manage bidirectional systems, and the interaction between H&C demand (building efficiency) and supply.

In Denmark, digital billing systems exist with a return-temperature-dependent bonus-penalty system that rewards lowering temperature levels using thermal insulation measures or panel radiators. Both the supplier and the consumer benefit from this: Lower return temperatures increase the temperature spread, and thus the thermal capacity of existing networks. Lower flow temperatures make it easier to integrate low-temperature sources such as waste heat or renewable heat.

Decentralisation

A further step on the way to 4GDH systems is **decentralisation**. Large DHC systems are usually characterised by high flow temperatures and high heat losses. However, networks in large cities are coming to realise that decentralising their DH and instead operating smaller, (somewhat) partitioned systems can end up being more efficient and reliable.

Dividing large networks into several small ones – e.g. by means of substations – allows the network to lower the temperature level, and thus reduce energy losses, and more easily integrate bidirectional (two-way flow) systems, such as decentralised solar thermal collectors.

A recent study done on Beijing's coal-based DH network[19], for example, found that splitting up the whole system into separately-operated zones could theoretically reduce (unnecessary high) temperature levels to cover actual demand, improve heat distribution, decrease fuel consumption, and thereby save costs on the order of several million dollars within a single heating season. Some studies highlight that such a neighbourhood approach to DH can better exploit the potential of 5th generation DH. Beyond integrating heating storage or smart heating grids, this method may bring forth further benefits, such as more efficient peak-shaving, or shifting demand.

A European example for a decentralised or "neighbourhood" district heating concept has been developed for the colliery westerhold area ("Neue Zeche Westerholt") in the former coal-mining Ruhr area in Germany, which is currently at a planning stage for development. In a study, the best option identified was to create a separate new centralised cold network of 20°C and decentralised heating at 45°C, via decentralised heat pumps and heat storages (see figure 33).

19 To understand a sense of scale, Beijing's DH includes five plants (mainly coal-based CHP, but also fossil gas) providing a total 1.2 GWth of heat load and 230 substations over an area of ~1550 hectares.

FIGURE 33: HEAT AND COLD SUPPLY CONCEPT FOR THE NEW WESTERHOLT COLLIERY TRANSITION AREA, GERMANY.

Source: Wuppertal Institute

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Strategic H&C planning

The transition of the H&C system is a complex task with intertwined technical, socio-economic, and environmental aspects. This transition requires coordination between different sectors, and institutional and governance levels that enables all stakeholders to cooperate and reach a mutually agreed upon understanding and solutions. There is, therefore, a strong need for strategic H&C planning practices that can respond to the challenges of the local energy system.

Strategic H&C planning is a continuous process that aims to achieve energy and climate goals. It should be viewed as a dynamic and iterative process that requires an effective feedback mechanism. The outcomes need to be monitored in order to identify possible improvements and make adjustments to ensure the implementation of the optimal solutions.

Elements of strategic H&C planning

Regional/local H&C planning is needed to analyse which H&C options make the most sense for various consumer types and locations in cities and municipalities. The creation of appropriate framework conditions is of great importance for effective implementation of the planning process. This includes:

- Developing strategic H&C planning with the clear goal of local/regional decarbonisation, and with sub-goals and timeframes that are aligned with national and EU goals. This process should include regular updates and evaluation of its status.
- Embedding H&C planning in other local/regional policies.
- Making governance processes efficient, and linking strategic and operational levels. A more formal team can be established to handle overall processes.
- Involving stakeholders in the planning process – a step that is crucial for successful implementation. Co-creation with citizens, technical experts, politicians, and other stakeholders is necessary for H&C strategies to be socially legitimate, to create a sense of ownership over the plan's actions, and to increase acceptance and commitment to support its implementation (for further guidance, see governance toolkit).
- Formulating a common decarbonisation narrative to help raise awareness among citizens that the energy transition is: i) something to be realised together; ii) something that all can prosper from; and iii) something to which their community can meaningfully contribute.
- Removing unnecessary administrative burdens and providing certainty and predictability for investors in the H&C sector, so that they can feel secure in investing in sustainable solutions.

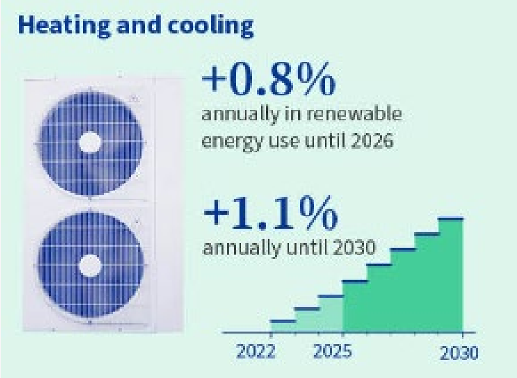

FIGURE 34. ANNUAL GROWTH RATES IN THE SHARE OF RENEWABLES FOR HEATING AND COOLING FROM THE RECENT EU FIT-FOR-55 PACKAGE.

Source: European Council 2023

EXAMPLE: INCENTIVISING ENERGY EFFICIENCY RENOVATIONS BY LINKING RENOVATION TO COMMUNITY GREEN URBAN PLANNING IN MILAN, ITALY

In 2020, the City of Milan, Italy approved an Air and Climate Plan, which serves as an action plan for the city to become carbon neutral, and to respond to the climate emergency.

Among the many instruments developed within the action plan was the Milan Transition Fund (MTF-2026), a financial model that aims to improve the efficiency of public and private buildings, promote urban development, enhance home quality, and reach zero energy consumption.

Interventions such as minor renovations, significant reorganisation, and local RES production will be implemented in neighbourhoods identified according to the city's objectives. The retrofit company pays for the interventions at no cost for residents and building owners. Because the contract is tied to the building rather than the individual homes, cash flow may be generated to pay back (and compensate for) the capital over time. By implementing green infrastructure, public spaces, and mobility initiatives, the community will benefit from some of the savings from energy efficiency operations.

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European Commission

EXAMPLE: ACT!ONHEAT WORKFLOW FOR INTEGRATED PLANNING

One of the most comprehensive examples of the strategic H&C planning process was developed within the European-funded Act!onHeat project.

The Act!onHeat workflow consists of 11 steps that address urban planning, implementation, and policies (figure 35). The starting point is the development of a vision (step 1), followed by the establishment of a working group (step 2). The working group coordinates the process and aligns with urban planning. Steps 3, 4, and 5 then involve an inventory analysis, zoning, and scenario development. Results of these steps are then fed into the formulation of a transition strategy (step 6). Here, the relevant local authority defines milestones and objectives. Based on this, strategies and/or measures are drafted (step 7). In an ideal scenario, implementation projects emerge directly from the process. These are then analysed for feasibility (step 8), and subsequently planned and implemented (steps 9 and 10). The workflow is followed by regular reviews that identify potential improvements, and thus intervene in an iterative way in the process (step 11).

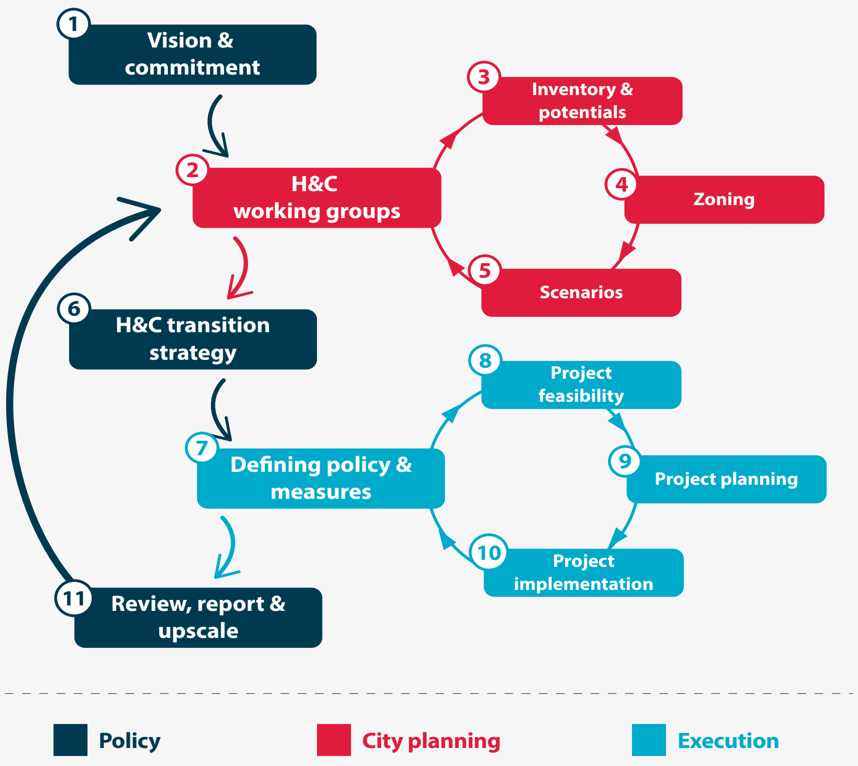

FIGURE 35: THE ACT!ONHEAT WORKFLOW.

Source: Act!onHeat

Three closely linked pillars are critical to facilitate the transition towards a low-carbon H&C system. These are improvements in:

1. energy efficiency (see chapter on Energy efficiency: The guiding principle),
2. thermal networks (see chapter system integration), and
3. efficient low-carbon energy supply (see chapter on Energy supply options for decarbonising district heating systems).

Strategic H&C planning can be very time intensive and costly when done from scratch, often needing to cover not only a local authority, but also the surrounding region housing the green energy sources. However, there are scientifically verified digital tools at hand that can help optimise the planning process, reducing the time and resources needed. For instance, the Hotmaps tool enables the rapid identification of "go-to areas" for H&C systems implementation, while the THERMOS tool helps to design thermal networks in a cost-effective manner.

Energy planning has to be developed in an integrated manner, assessing and coordinating all relevant stakeholders, considering interests of consumers and providers, as well as linkages with other sectors like the buildings and environmental protection sectors. H&C planning should be an integral part of urban planning, defining the future distribution of activities in space. Energy infrastructure has to be planned spatially, with locations and right-of-way determined and granted. Integrating H&C planning into urban planning processes in such a way that outlines the potential role and benefits of DHC in the context of wider social, environmental, and economic drivers is crucial, as it can pave the way for the deployment of sustainable DHC systems.

Role of regional and local political levels

Both national and local authorities play an important role in promoting the decarbonisation of the H&C sector. National and EU levels must set overarching energy and climate targets, which local levels can then translate into concrete projects, including H&C planning and projects.

Due to the local character of H&C – and of renewable technologies that are an important part of sustainable H&C – local authorities play a key role in initiating H&C planning and implementing sustainable H&C solutions. As the implementation of technological solutions becomes more concrete, however, local planning processes can become more complex. Municipalities and cities need to collect and utilise local data and knowledge in these processes, which cannot be acquired at the national level.

It is important for municipalities to envision their future energy system in an integrated manner, considering interactions with other assets (building stock, gas and electricity grid, etc.). Local authorities are in a position to encourage and facilitate community and industry engagement in this planning, by providing low-cost financing options, reducing the burden of administrative processes, and providing the platform for – as well as strategically steering – a stakeholder dialogue on H&C planning. Municipal leaders are, after all, well positioned to consider the diverse local interests and needs at play, and to derive common goals for the well-being of all.

Cities and municipalities can drive strategic H&C planning, and can link-up these policies and practices with climate action at the regional and (inter)national levels, ensuring that plans are aligned with scientific recommendations guided by the Intergovernmental Panel on Climate Change (IPCC). For many years, European local authorities' commitment and willingness to take action against climate change has

SUSTAINABLE COOLING

Sustainable cooling is a crucial topic in which municipalities lack adequate knowledge and action planning. Cooling demand has increased rapidly over the past three decades due to rising temperatures and other social and economic factors. Thus, local and national action is urgently needed to curb the unsystematic, rapid growth of individual – and often inefficient and unsustainable – cooling to promote sustainable solutions, including district cooling. European cities are expected to witness a rise in temperature close to 3°C by 2050 compared to the pre-industrial, reinforcing the critical need for sustainable cooling measures that ensure the liveability of urban settlements, especially in light of Europe's ageing population and continuing urbanisation.

EXAMPLE: AN INTEGRATED APPROACH THAT ACCELERATES CLIMATE ACTION, WHILE CREATING GREEN JOBS

ProjectZero is a public-private partnership established in 2007 in the Danish municipality of Sønderborg. The municipality is located near the Baltic Sea, close to the German border, and has a population of approximately 75,000 inhabitants scattered across rural areas and towns. The Sønderborg area is among the world's frontrunners in CO_2 reduction – through work done as part of ProjectZero, by 2020 CO_2 emissions had been reduced by 51% compared to 2007 levels.

The goal of the project is to achieve a carbon-neutral energy system by 2029, and to simultaneously become a role model for how other cities around the world can translate this coordinated approach to their local contexts in such a way that, at the same time, creates economic growth and green jobs.

On behalf of the city council, ProjectZero coordinated the preparation of a new Masterplan 2029, which describes how the area will reach its goal. The plan has four main components:

- Energy efficiency and electrification in homes and businesses – renovations, conversion to district heating and heat pumps, as well as electrification of low and medium heat;
- Green transport and conversion to electric cars;
- Plant investments in biogas, a wind farm, Power-to-X (PtX) and district heating;
- Sector coupling – creating a unique and fully integrated energy system via optimal use of: i) surplus heat from production processes connected to district heating; and ii) PtX, where hydrogen and CO_2 can be converted into green fuel using electricity and biomass.

Three district heating companies in the area are working together to decarbonise the DHS. At the moment, they mostly use excess heat, biomass, and municipal waste, as well as other sources of excess heat, such as data centres and PtX plants. RES will be utilised in the future, once the existing DH systems are expanded and connected for their optimal use.

FIGURE 36: SCHEMATIC MAP OF THE PROJECTZERO MASTERPLAN IN SØNDERBORG, DENMARK.

Source: ProjectZero

been visible, notably through the Covenant of Mayors, and more recently the 100 Climate-neutral and Smart Cities Mission.

Policy instruments for H&C planning

Zoning is a method of urban planning in which the urban area is divided into so-called zones. Each of these zones has its own planning and building regulations, which may differ from those of other zones. For example, allowable size and dimensions of properties, their purpose (residential, commercial, etc.), and requirements for building construction may all be specified. Zoning therefore offers opportunities to influence the development of the H&C sector, and to identify zones that are particularly suitable for DHC.

Cost and supply stability, paired with some degree of local ownership, e.g. through energy communities, can increase public acceptance of H&C solutions. Involving companies and other stakeholders in this way means that all are working hand-in-hand with the municipality towards achieving energy and climate targets – and other environmental, economic, and social objectives – and thus that it is not only public buildings whose energy demands are decarbonised. The benefit for the suppliers is that their role is also somewhat ensured in the future energy mix, as long as they meet agreed upon requirements, thereby providing long-term security of investments.

Energy communities have already proven important in mobilising financing and public support for local energy projects. Although most renewable energy communities focus on electricity generation, they can also engage citizens in sustainable H&C initiatives. These can be facilitated through partnerships between profit-driven utilities and thermal energy cooperatives (TEC). Energy communities offer opportunities for Just Transition Fund (JTF) regions to rebuild the H&C sector in a way that provides environmental, economic, and social benefits to the local community.

There is a risk that an influx of large renewable energy infrastructure could create limited benefits for regional stakeholders beyond job creation for (initial) construction and management, and regional revenues via business taxes. In other words, there is a risk that the bulk of income may flow out of the region instead of into the hands of local communities. There is a growing understanding across Europe that locally-oriented deployment of renewable energies is a favourable approach to truly achieve a just transition. Moreover, energy communities should not primarily be developed as a means for well-off citizens to make additional profit; local and regional governments in JTF regions should consider energy communities as part of greater efforts to alleviate energy poverty.

Given the local nature of the H&C, one of the main tasks for policy makers, municipalities, DHC operators, and urban planners willing to promote H&C decarbonisation through DHC is to understand the main learnings from best-performers. Denmark is often presented as a best practice on how district heating can provide a sustainable heat supply (see box). DH has been promoted in Denmark through favourable financing schemes on non-commercial terms, the non-profit principle, or the principle of necessary costs; through mandatory connection to reduce investment

GUIDANCE TO SET UP ENERGY COMMUNITIES

Energy communities are a broad concept; but, they can be basically defined as collective initiatives of stakeholders like citizens, local authorities, and small and medium enterprises (SMEs) who jointly engage in energy-related activities. There exist several guides on how energy communities work and can be deployed at the local level:

1. Energy Community Guidebook by the Community Power Coalition, Friends of the Earth, EnergyCities and REScoop.eu
2. How Cities can back Renewable Energy Communities by EnergyCities
3. Guidebook for Developing Energy Communities in Rural Areas by the EU Rural Energy Communities Advisory Hub

DISTRICT HEATING ENERGY COMMUNITY IN BEAUVENT, BELGIUM

Beauvent is a Belgian energy cooperative from West Flanders working on wind production, solar production, and heating networks. The cooperative currently unites more than 8,000 equal shareholders who help build local, sustainable energy projects, and benefit from their proceeds. Since 2019, the cooperative has managed the heating network in Ostend. The length of the network route is 8.6 km, and its heat pipe system is 17.2 km long, connected to excess heat from a municipal waste incineration plant. The thermal capacity of the system is 7.5 MW and it supplies heat to industrial customers and public buildings, as well as households.

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risks, which was in force until 2019; and via H&C planning that has been institutionally anchored in Denmark since 1979.

Under the recast of the Energy Efficiency Directive (EED), EU countries will also have to promote local H&C plans in municipalities with populations above 45,000. H&C planning processes are highly dependent on legal and strategic frameworks, therefore more attention should be paid to them as indispensable bases for sustainable energy planning. National authorities are required to improve the process by formulating strategic objectives, providing a framework within which local planning is carried out and developing support structures.

Mandatory H&C planning has already been introduced in Member States and sub-national regions, such as the Netherlands, Scotland, and in Baden Württemberg (Germany). Based on the Danish experience, it is much easier and quicker to transition from fossil fuels to renewable technologies, especially via district heating, when the municipality already has a comprehensive plan of their future H&C systems.

While renewable DHC technologies often benefit from low operating costs, they are generally associated with higher upfront costs compared to alternatives. Therefore, a long-term investment horizon is required. Government support in the form of **financial and fiscal incentives** can be crucial in overcoming the barrier of high upfront costs. Relevant support schemes for DHC are structured and applied differently across the EU. The most commonly used instruments are financing grants, premium tariffs, low interest loans and tax exemptions. In particular, support schemes tend to include subsidies and financial incentives for: i) DHC grid infrastructure; ii) renewable and efficient DHC generation; iii) research, technology development and demonstration of innovative DHC systems; and iv) connecting end users to DHC networks. Subsidies and financial incentives targeting DHC grid infrastructure, as well as renewable and efficient energy generation, are available in most EU Member States. On the other hand, subsidies and financial incentives on research and innovation as well as for connecting end-users to DHC networks are less common.

Just Transition Mechanism (JTM) funds will support coal+ regions in economic diversification and reconversion of the affected territories, including the transformation of existing, or the construction of new, DH systems. A review of submitted Territorial Just Transition Plans (TJTPs) shows that many regional and local governments, e.g. in Poland, Slovenia, and Latvia, are eager to build and modernise their DHC networks.

EXAMPLE: THE FRONTRUNNER, DENMARK

The market share of district heating in Denmark is among the highest in the world. It supplies approximately two thirds of Danish private households with space heating and domestic hot water. The deployment of DHS in Denmark was thanks to a strong cooperative culture, lack of domestic fuel sources, the energy crisis in the 1970s, top-down heat infrastructure planning and, later, growing environmental awareness.

Most Danish district heating systems are owned by cooperatives or municipalities. Municipally-owned DH companies are typically located in more urban areas, and are larger in scale. In 2019, they supplied approximately 60% of the heat sold in Denmark. District heating companies operated as cooperatives are typically located in more rural areas, and are smaller in scale. In 2019, they supplied approximately 34% of the heat sold. District heating companies with other types of ownership, such as private, accounted for 6%.

Fuels used to produce heat include both fossil fuels (e.g. coal, oil, fossil gas), and non-fossil fuels (e.g. biomass, waste, solar). The Danish district heating sector has integrated large amounts of RES – mostly biomass, but also some solar thermal and excess heat from industry – within a relatively short time. Paradoxically, the policy focus on carbon emission reductions has led to the DH sector being dependent on fuel imports. This time, the fuel dependency is on biomass, with sometimes questionable sustainability of the production chain. However, the Danish energy system is still evolving and is currently undergoing significant changes, primarily the integration of more intermittent renewable energy resources (namely, wind power) in combination with (seasonal) heat storages, electrification and sector coupling. Danish scientists and stakeholders from the field have also played a decisive role in developing the strategic idea of 4th and 5th generation DH (4GDH and 5GDH, see figure 3 in chapter Energy efficiency: The guiding principle).

RENEWABLE POWER-TO-HEAT IN HAJNÓWKA, POLAND

The current district heating system in Hajnówka in eastern Poland relies heavily on a coal-fired power plant, providing heat at a high temperature (130°C).The heating network is operated by a local private company, which did not invest much into the network making it rather inefficient, and therefore heat in the region has been rather expensive.

However, as Hajnówka County holds great potential for the use of renewable energies, in particular for wind energy and photovoltaics, the Hajnówka county commissioned a feasibility study to explore options for a Power-to-Heat heating system.

The study was carried out by the German "110-prozent Erneuerbar" Foundation and has been funded by the European Climate Protection Initiative with an overall project value of €306,100. The study carried out a first scenario analysis, with two status quo scenarios (coal scenario 1 with PLN 1,221/ €270 per t coal and scenario 2 with PLN 676/ €150) and two renewable scenarios (heat pump and a heat pump with storage scenario).

The results of the study exemplified that annual operation costs of the network would be lower for the power-to-heat solutions, except prices for coal would be very low, which in the long-run would become more and more unlikely due to the rising CO_2 prices (see figure 37).

Despite the results itself, the study show how a decarbonisation process can be further backed by a local study can serve as a first orientation for municipalities for H&C planning and to gain further support from political levels. A similar study was conducted e.g., for the city of Sofia, Bulgaria.

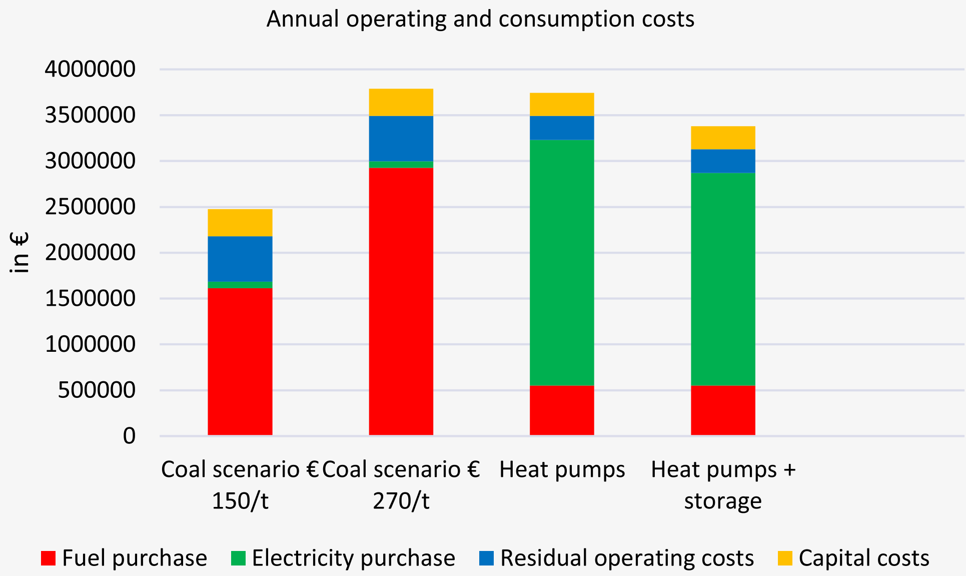

FIGURE 37: COMPILATION OF THE ANNUAL OPERATING AND CONSUMPTION COSTS IN EUROS ACCORDING TO THE CURRENT FRAMEWORK CONDITIONS FOR SCENARIOS.

Source: 100% Erneuerbar

Excursus: Decentralised heating

As has been made clear, DH represents an effective means of supplying heat to consumers, especially if it has been (at least partially) decarbonised. Its reliance on centralised heat production and a network for local distribution has proven to be reliable, efficient, and cost-effective in most cases.

However, DH is not the most suitable option in every case. There are certain terrain types (e.g. overly hilly, rocky underground, or subject to seismic activity), which may make it difficult or risky to install or expand DH systems. Of course, where climates are too warm, DH is not generally needed – but these areas should consider district cooling!

Furthermore, the built environment itself can present a challenge to DH deployment and renovations. For instance, it can sometimes be relatively problematic to install new, or retrofit existing, DH networks in culturally-protected neighbourhoods, or in densely populated areas. DH companies and public authorities under such circumstances may also have to contend with discord from the public, especially due to disturbances during installation or renovation phases. This should be interpreted as all the more reason to ensure that any efforts to introduce or renovate DH are done with sufficient engagement of local stakeholders and residents.

On the other side of the spectrum are more sparsely populated areas, where there is enough space to install the infrastructure, but expected DH revenues are lower. A common rule of thumb used by many DH experts (e.g. promoted by the Heat Roadmap Europe project) is that an area with heat demand density higher than 120 TJ/km^2 (~33 GWh/km^2) should be considered as quite profitable for DH. Having more disperse heat density certainly does not exclude DH as a viable option (e.g. IRENA has claimed even 36 TJ/km^2 (~10 GWh/km^2) could be reasonably cost-effective), but in these cases it may be more financially attractive to exploit other heating technologies.

For the most part, the suggested approach for individualised heating mirrors what has been previously written for DH, namely: **consider energy sufficiency, implement energy efficiency, decarbonise sources, and accelerate cleaner energy sources**. Most recommendations for individual heating would likely include the exploitation of heat pumps with corresponding heat sources such as ambient heat (ambient air, horizontal ground collectors) or near-surface geothermal heat (vertical ground collectors), combined with photovoltaics to power them. Both can be rather universally deployed (even though the former still often suffers from higher capital costs compared to simple gas boilers). Other common solutions depend on local conditions, but might include solar thermal (e.g. for hot water, if not space heating), deep geothermal (e.g. for larger buildings or for a spa), and/or biomass boilers (though sustainability concerns about this resource remain valid at smaller scales – see the chapter on Biomass).

European Commission

Further reading

KeepWarm "Learning Centre" (project's own and external materials), with many resources also being available in other languages: Data inputs; Business models and funding; Financing implementation; Technical solutions and cases; Sustainable energy sources; Policy recommendations; Thermal planning tools; Capacity Building materials in other languages; Training material

Celsius Toolbox (aimed especially at cities): Business & Finance; Policy & Planning; Stakeholder Engagement; Technical Solutions; Toolbox Glossary

Europe Beyond Coal: DH briefing and CHP/DH webpage

Renewable energy in district heating and cooling: A sector roadmap for Remap (IRENA, 2017)

RELaTED project (focused on DH in general, as well as Ultra Low Temperature DH)

Heat Roadmap Europe (focused on European H&C overall), with many resources useful for DH in particular, e.g.: Peta (Pan-European Thermal Atlas) 4.3; Country Heat Maps; Heat Roadmaps; Guidelines

Levelized Cost of Electricity- Renewable Energy Technologies (Fraunhofer ISE, 2021)

GeoDH project (focused on geothermal DH), e.g.: Guidebook, Map, Report on Potential and Resource Centre (Technology; Regulation; Financing/ Business Development; Training; Other)

ThinkGeoEnergy.com, including an article focused on eastern Europe

CrowdThermal project (focused on crowdfunding and social engagement for financing geothermal projects), including a set of tools and various useful publications

GeoEnvi project (focused on addressing the environmental concerns for deep geothermal energy), including life cycle assessment tools, a database and various published resources

DARLING-e project (focused on delivering data - and information services about deep geothermal energy within the southern Pannonian basin), including an interactive GIS-based map, library of resources and various useful tools looking at benchmarking, decision-making, risk mitigation and policy/ permits.

Bankwatch CEE's section on DH:

- briefings "Is Hungary and Slovakia's district heating future in hot water?" and "Getting gas out of district heating in the Baltics"
- Smoke and mirrors - Why the climate promises of the Southern Gas Corridor don't add up (2018)

Breaking free from fossil gas (Agora Energiewende, 2023)

Future of Gas (EASAC, 2023)

Hydrogen in the Future Energy System: Focus on Heat in Buildings (Fraunhofer ISE, 2020)

Clean Hydrogen Ladder (Michael Liebrich, 2021)

LIST OF ABBREVIATIONS

ATES	Aquifer energy storage system
BECCS	Bioenergy Carbon Capture and Storage
BTES	Borehole energy storage system
CCGT	Combined cycle gas-turbine
CCHP	Combined, Cooling and Heat power
CCPP	Combined cycle power plant
CCS	Carbon Capture and Storage
CEAP	Circular Economy Action Plan
CHP	Combined heat and power
Coal+	Coal, peat, lignite, and oil shale (region)
COP	Coefficient of performance
CST	Concentrated thermal collector
DE	Direct electric
DH	District heating
DHC	(Advanced) District Heating and Cooling
DHS	District heating system
EBRD	European Bank for Reconstruction and Development
EED	Energy Efficiency directive
EIB	European Investment Bank
ELHO	Extra light heating oil
EnEV	German energy saving regualation of 2007
EPBD	Energy Performance of Buildings Directive
ETS	Emissions Trading System
ExH	Excess Heat
FC	Fuel Cell
GHG	Greenhouse gas
GT	Gas turbine
GWP	Global warming potential
H&C	Heating & cooling
HP	Heat pump
HT FC	Internal reformer fuel cell
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
JRC	The Joint Research Centre
JTF	Just Transition Fund
JTM	Just Transition Mechanism
LCOE	Levelized cost of energy
LowEx	Low-temperature heating grids and Cold Local Heating
LUC	Land use change
MCFC	Molten Carbonate Fuel Cell
MENA	Middle East and North Africa
MSW	Municipal solid waste
NIMBY	Not-In-My-Backyard phenomenon
NT FC	external reformer fuel cell
OCGT	Open-cycle gas-turbine
ODP	Ozone-depleting potential
ORC	Organic Rankine cycle
PAFC	Phosphoric Acid Fuel Cell
PEMFC	Polymer Electrolyte Membrane Fuel Cell
PE	Primary energy
PH	Passive House
PTES	Pit thermal energy storage system
PtG	Power-to-Gas
PtH	Power-to-Heat
PtX	Power-to-X
PV	Photovoltaic
PVT	Photovoltaic thermal hybrid solar thermal collector
RE	Renewable energy
RED	Renewable energy directive
RES	Renewable energy sources
RNG	Renewable Natural Gas
SDH	Solar District Heating
SMEs	Small and medium enterprise
SNG	Synthetic Natural Gas
SOFC	Solid Oxide Fuel Cell
TEC	Thermal energy cooperative
TEG	Thermo-electric generator
TJTP	Territorial Just Transition Plan
TTES	Tank thermal energy storage system
WtE	Waste-to-Energy

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Annex: Overview of Technologies for District Heating Decarbonisation

	TECHNOLOGY		CAPACITY RANGE (THERMAL)	TEMPERATURE LEVEL	APPLICATION AREA	LOAD TYPE	COSTS A) INVESTMENT (€ PER KWTH) B) OPERATION (ENERGY COST € PER KWHTH)	SYNERGIES & OPTIONS FOR SECTOR COUPLING
1	**Solar Thermal**	Building / Ground mounted	Buildings: from ca. 4 kWpeak (small 6m2 DHW system) Solar DH: ca. 100 kWpeak - 50 MWpeak (ca. 140 - 71.000 m2)	ca. 60 to 110°C	Object supply Heat Networks Industry	Base load (but supply-dependent)	a. medium (open space: ca. 600 €/kWth or 350 €/m2) to high (buildings: ca. 1,500 €/kWth) b. low (own electricity pumps)	Good combinability with CHP (iCHP), as CHP power generation tends to be unprofitable in summer (high PV power feed-in & low power load)
2	**Geothermal**	deep (> 400 m, without HP)	ca. 100 kW up to ca. 75 MW (in Germany)	ca. 40°C to ca. 250°C	Heat Networks Industry	Base load	a. high (bore) b. low (own power pumps)	Base-load capable renewable heat source Potential for (seasonal) heat and cold storage in aquifers.
3	**Power-to-Heat (PtH)**	Direct electric (boiler/ heating rod)	Electric heater: ca. 1 to 3 kW Electric boiler: ca. 100 kW - 15 MW Electrode boiler: ca. 1 - 90 MW	up to ca. 240°C (with electr. steam superheater up to ca. 500°C)	Object supply (heating rod) Heat networks Industry	Peak load	a. low (300 €/kWth) b. high (electricity)	Potential to improve process efficiency (no flue gas losses, precise metering of energy quantities) and product quality (for process heat). Good combinability / flexibility with CHP (iCHP) e.g. for redispatch or provision of balancing power".
		Heat Pump	ca. 1.5 kW (passive house HP compact unit or for DHW) up to ca. 20 MW (DH network, cascaded if necessary)	Standard-WP up to ca. 60°C Large HP up to ca. 90°C HT-WP up to ca. 150°C	Object supply Heat Networks Industry	Base load	a. medium (700 - 1.000 €/kWth incl. development of heat source) b. medium (electricity - but in combination with an environmental heat source)	Base-load capable renewable heat source Potential for heat-cold coupling (heat swing) good combinability / flexibility with CHP Efficiency improvements possible by using low temperature waste heat in combination with solar thermal (lower area in solar storage) or CHP (waste heat from exhaust gases / engine cooling)
4	**Natural Gas Syngas Hydrogen**	Boiler	ca. 10 kW (small decentraliced boiler) up to some Megawatt (boilers for large buildings or peak boiler for heat networks)	up to ca. 500°C	Object supply Heat Networks Industry	Base load (buildings) Peak boiler (in heat networks or hybrid systems)	a. low b. high (gas)	Low investment option to cover peak load with renewable gases (H2, syngas, biogas / biomethane)
5	**Bioenergy**	Biomass / Biogas	about 10 kW (small pellet stove) up to ca. 500 MW (large biomass heating (power) plant).	up to ca. 500°C	Object supply Heat Networks Industry	Base load Peak load/backup (e.g. as a supplement to solar thermal)	a. low (biomass boiler: ca. 250 €/kWth) to medium (biogas CHP: ca. 1,050 €/kWth) b. low (solid biomass) to medium (biogas)	Storable renewable energy source In combination with CHP high efficiency and high decarbonization potential
6	**Waste incineration**	Boiler	about 15 MW up to > 100 MW	up to ca. 500°C	Heat Networks Industry	Base load	a. high b. low (depending on type and quality of waste)	In combination with CHP fairly efficient In combination with CCUS high decarbonisation potential
7	**Waste Heat**	industrial / municipal	some 100 kW to ca. 90 MW	municipal: 10 bis 15°C with HP: up to ca. 90°C industrial: 11% < 60°C 29% < 90°C 36% < 110°C Total = 61% < 150°C 39 % > 150°C	Heat Networks Industry	Base load (but supply-dependent)	a. individually depending on complexity of extraction, pressure and temperature level as well as distance to heat network b. low (own power pumps)	In combination with heat pumps (PtH) higher temperature levels achievable
8	**CHP**	ICE / CC / GT / ST / FC	ca. 1 kW (small fuel cell) up to ca. 500 MW (large combined cycle plant)	ca. 80°C to ca. 500°C	Object supply Heat Networks Industry	Base load (heat) Residual load (for fEE feed-in)	a. medium to high (1.000 - 5.000 €/kWth depending on technology and electricity ratio) b. medium (natural gas/coal/H2/biomass - allocation to electricity & heat)	Potential for combined heat, cooling and power generation (CHP)

Abbreviations:
ICE: Internal combustion engine
CC: Combined cycle
GT: Gas turbine
ST: Steam turbine
FC: Fuel cell

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This toolkit has been developed in close collaboration with the Members of the District Heating Working Group. We would like to thank all members for their contributions and feedback.

Initiative for coal regions in transition

Led by the European Commission, the Initiative for coal regions in transition assists EU countries and coal regions tackling challenges related to the transition to a low-carbon economy.

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