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The Future of Heat Pumps in China

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The Tsinghua University Building Energy Research Center (BERC) was created in 2005. The mission of BERC is devoted to the development of energy-efficient and environmentally responsible buildings in China, in accordance with national and international energy and environmental targets, including buildings research and innovation.

The principal research activities within BERC include:

- Assessment of the current buildings status in China and strategic outlooks on buildings energy consumption and efficiency.
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- Research and development (R&D) of innovative high - efficiency buildings technology and systems.
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BERC is involved in international exchange and co - operation projects, including its ongoing collaboration with the International Energy Agency. BERC is also responsible for the Annual Report on China Building Energy Efficiency (in Chinese), which has been published annually since 2007, and China Building Energy Use and Emission Yearbook (in English), which has been published annually since 2016.

The latest annual report, entitled Decarbonize Urban Heating System-China Building Energy and Emission Yearbook 2023 (in English), can be downloaded free from:

https://link.springer.com/book/10.1007/978-981-99-7875-5.

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Executive summary

Heating is a fundamental service to society that needs to be decarbonised further

Heating accounts for almost 20% of energy use in industry and buildings globally, and about one-quarter of energy-sector emissions. China's buildings and industry sectors account for about one-third of global heat consumption and therefore have a major influence on global trends. Heat consumption in buildings has grown faster in China than in any other country over the past decade, making China the second-largest market for space and water heating in buildings today, just behind the United States, with an energy demand for both these uses of around 12 EJ. This trend shows no sign of slowing down as uptake of heating equipment in China continues to increase. In Chinese industries, heat consumption grew by 13% between 2010 and 2022, reaching 38 EJ. Nearly 20% is accounted for by low- and medium-temperature heat, below 200 °C, which is the most suitable range for heat pump applications. Consumption of heat below 200 °C grew by 7% over the same period, and its share in overall demand will increase as China shifts to higher value-added industries.

Today, heating provision in China is heavily reliant on coal. The direct use of coal for heat supply accounts for around half of final energy use for heating in buildings and industry. If coal used in district heating and to generate electricity for heating in buildings and industry is included, heat provision is responsible for 40% of national CO_2 emissions and coal use in China. However, this share has fallen by more than 5% over the past decade, thanks to policies to improve air quality, reduce CO_2 emissions and maximise energy efficiency.

Heat pumps offer a proven solution for decarbonising low- and medium-temperature heating

Heat pump sales are seeing unprecedented momentum worldwide. Global heat pump sales have increased by almost 30% since 2020, although there was a 3% decline in 2023. China – currently the world's largest market for heat pumps for buildings – accounts for more than one-quarter of global sales, and in 2023 China was the only major market where heat pump sales grew, by a robust 12%. Heat pumps that are already on the market in China offer one of the most efficient options for decarbonising heat in district heating networks, buildings and industry. Heat pumps accounted for 8% of heating equipment sales for buildings in China in 2022, and they are already the norm in new and existing buildings in some areas of central and southern China, where they are used for heating and cooling. The use of heat pumps for domestic hot water production is emerging, primarily in urban areas and commercial buildings, but the water heating market is still dominated by conventional electric heaters and gas boilers. Heat pumps consume on average three to five times less energy than electric heaters or fossil fuel-based solutions, though use in industry and district heating is still uncommon, in part due to low awareness and upfront costs.

Purchasing a heat pump typically pays off in the long run compared with other solutions, but high upfront costs remain a barrier. In China, air-to-air heat pumps are already the most cost-competitive heating option over their lifetime in some colder climates, and in cities with hot summers and cold winters, where they meet both heating and cooling needs. Air-to-water heat pumps, meanwhile, offer lifetime savings when compared to electric heaters, which cost less upfront but have low efficiencies. In contrast, air-to-water heat pumps are more expensive than gas boilers and only offer savings over their lifetime in areas with a competitive electricity-to-gas price ratio. The upfront costs for industrial heat pumps are over six times higher than for gas boilers, but over their lifetimes they are already far cheaper than gas and electric boilers, and nearly cost-competitive with coal boilers, thanks to their high efficiency.

The buildings sector and light industries have the greatest potential to expand heat pump deployment

Decentralised heat pumps installed in Chinese buildings currently account for one-quarter of the global installed capacity. The combined capacity is more than 250 GW, covering around 4% of heating needs in buildings. In the Announced Pledges Scenario (APS), which takes into account China's carbon neutrality target, this capacity reaches 1 400 GW by 2050, meeting 25% of heating needs. About 100 GW of heat pumps would need to be installed in buildings every year until 2050 to meet the ambition of the APS, equivalent to the capacity deployed in the United States, China and the European Union combined over 2022.

The greatest potential for decentralised heat pumps in buildings is in rural China and in urban areas in southern and central regions, although growth is also expected in new buildings in northern urban China. In the APS, heat pump capacity in these areas is projected to more than double by 2030 and increase fivefold by 2050. In areas with a temperate climate, or hot summers and cold winters, the share of reversible air-to-air heat pumps is expected to grow with increased uptake of heating equipment. The market for air-to-water heat pumps is also expected to grow, particularly in new buildings in northern China, where more stringent building energy codes favour heat pump uptake. In rural areas, sales of air-to-water heat pumps increase seven-fold by 2050 in the APS, and air-to-air units designed for space heating see even larger growth. Increased awareness of heat pump technologies and their applications, together with skilled installation, will be required to ensure efficient operation.

Across all industrial sectors, the greatest potential for heat pumps is to meet demand for heat at temperatures lower than 200 °C. Use of low- and medium-temperature heat is widespread in light industries, in pulp and paper production, and in the chemical sector. Today, such sectors represent over a third of industrial heat consumption in China, but they account for more than three-quarters of heat consumption below 200 °C. A potential 175-280 GW – enough to cover about 15% of current heat demand in such industries – could theoretically be supplied by heat pumps already today. In the APS, about 1.5 GW of heat pumps are installed in light industries every year between 2025 and 2050 to supply about 20% of heat demand in 2050. However, today there is a limited focus on heat pumps in industry decarbonisation plans, and a difficulty in standardising them, as they need to be tailored to specific industrial processes, which results in a more limited scope to reduce equipment costs. Further support to develop advanced heat pump designs for industrial applications at lower costs will be important in this regard.

Large-scale heat pumps can be integrated into existing district heating systems and optimise use of waste heat

Heat pumps applied to district heating networks provide opportunities to further decarbonise heat. Some large-scale heat pumps have already been deployed in district heating networks in urban areas in northern China, though networks still rely on coal for more than 80% of heat production. Heat pumps can increase the overall efficiency of the system by reducing network return temperatures, as well as providing opportunities to avoid curtailment of variable renewables when coupled with thermal energy storage. North urban China is reliant on district heating, and large-scale heat pumps are attracting interest as a solution for decarbonisation, in line with expansion and modernisation plans.

Heat pumps also provide opportunities to recover waste heat. China has systematically promoted waste heat recovery in industrial sectors like cement, and has other waste heat resources with temperatures below 50 °C which could be exploited by integrating large-scale heat pumps in district heating systems and industrial clusters. Nearly 20 EJ of waste heat from thermal power plants, industries, data centres and wastewater plants will be available by 2050, two-thirds of which would be suitable for heat pump integration – corresponding to a heat pump capacity of 650 GW, 20 times the potential within light industries. Currently, small industrial players find it particularly challenging to develop an economic case for implementing waste heat recovery strategies and effectively co-ordinating with other thermal users and producers to identify opportunities to connect to common district heating networks. Government action to overcome these barriers will be key to exploit further the waste heat recovery potential.

Heat pump deployment must go hand in hand with the decarbonisation of electricity grids

Decentralised heat pumps account for around 30% of direct emissions reductions for heating in buildings in China in the APS to 2050. Direct emissions for heating in buildings are reduced to 70 Mt CO_2 in 2050, down from 290 Mt CO_2 in 2022, thanks to greater efforts on electrification and energy efficiency. A switch to heat pumps and phase-out of coal and traditional biomass for heating could also substantially reduce local air pollutants, cutting $PM_{2.5}$ emissions from residential heating by nearly 80% by 2030. In light industries, direct emissions from heating are reduced from over 110 Mt CO_2 today to less than 10 Mt CO_2 in 2050 in the APS. Electrification accounts for two-thirds of emissions reductions for heating in light industries by 2050, of which one-third results from heat pumps.

Annual emissions from a heat pump installed in China are on average already more than 30% lower today than those from a gas boiler when taking into account both direct and indirect emissions. In the APS, indirect emissions from power generation decrease by over 40% by 2030, mainly due to the increased deployment of solar, wind and nuclear power. By the same year, annual emissions from heat pumps are nearly 60% lower than a gas boiler. While increased deployment of heat pumps inevitably increases electricity demand, their peak load impact is two times smaller than that of electric appliances in buildings in the APS in 2030.

Expanding the deployment of heat pumps creates growth and employment along the supply chain

China is the largest manufacturer of decentralised heat pumps for buildings and could quickly ramp up production to support further growth. China is a global leader for heat pump technology innovation and manufacturing, and produced around 35% of all heat pumps sold worldwide in 2022. More than 300 000 people are currently employed in China's heat pump sector, and numbers are set to double by 2050 in the APS. This is likely to create a need for vocational training and upskilling of practitioners such as heat pump installers.

In the APS, investment needs in industry and buildings continue to rise to accelerate the deployment of heat pumps. In buildings, annual investments need to triple to USD 30 billion (CNY 200 billion) in 2030 and to almost quadruple by 2050, equivalent to investments in wind power in the European Union and the United States combined in 2022. In the light industry sector, scaling up large-scale heat pump capacity to 30 GW in the APS by 2050 would require around USD 20 billion (CNY 140 billion). For comparison, Chinese light industries spent an equivalent amount on natural gas for heating in 2022.

Policy recommendations to drive up heat pump deployment in China

Set a national action plan for heating decarbonisation, including detailed actions for heat pump deployment

BUILDINGS

SHORT-TERM

- Strengthen energy efficiency standards
- Revise and unify labels across heating devices and launch awareness campaigns
- Strengthen upfront cost support for heat pumps

LONG-TERM

- Integrate more stringent performance requirements in regulations for new buildings to prepare for heat pump adoption
- Support large-scale retrofit packages for existing buildings as part of a co-ordinated heat pump rollout
- Phase out subsidies for fossil fuel-based heating to free up financing for cleaner, more efficient heating solutions

INDUSTRY

SHORT-TERM

- Increase awareness and support selection of heat pump solutions
- Promote heat pump research and demonstration projects
- Provide support to overcome installation, operations and maintenance costs

LONG-TERM

- Expand actions to drive waste energy recovery through heat pumps in light industries and district heating
- Introduce heat pumps as a recommended technology choice for decarbonising heating in selected industries

SUPPLY CHAINS

SHORT-TERM

- Establish clear criteria for the classification of clean heating
- Set targets to increase sales and deployment of heat pumps
- Promote heat pump rollout in line with expansion of renewable energy

LONG-TERM

- Promote job opportunities and skills in manufacturing, installation, operations and maintenance
- Enhance data oversight to better understand opportunities for heat decarbonisation
- Consider strengthening standards for lifecycle emissions to inform energy efficiency improvements, including considerations around HFCs and the use of alternative refrigerants
- Consider electricity system and demand flexibility implications in future electrification of heating and heat pump deployment

Introduction

Heating choices in the People's Republic of China (hereafter, "China") have a major influence on global heating trends. China is responsible for nearly 33% of global heat consumption, with the share of the industrial sector accounting for as much as 40%, and the buildings sector for around 20%. Today, heating in China is heavily reliant on coal, though its share in the heating mix has declined over the past decade as part of a policy-driven shift away from coal for heating.

Electrification through heat pumps can provide a key lever for decarbonising heating, and sales have increased in recent years in China, driven by growing demand for space and water heating, and clean heating policies. China is the largest manufacturer of heat pumps in buildings and heat pumps installed in Chinese buildings today have a combined capacity of more than 250 GW, with significant potential for further growth. While uptake in industry remains limited, several industrial sectors hold potential for heat pump deployment in the near term. Deployment of heat pumps in district heat networks is also gaining attention.

This report provides an overview of the status of heat pumps in buildings, industry and district heating in China, and examines potential to further accelerate deployment. Heat pumps can play an important role towards meeting China's goal of CO_2 emissions peaking before 2030 and achieving carbon neutrality before 2060, and this report highlights key opportunities to increase adoption.

Ahead of the 15th Five-Year-Plan period, this report considers the key policy measures that can address barriers to uptake and further accelerate deployment.

The report is structured as follows:

- Chapter 1 begins with an overview of heating in China today, including perspectives on heating decarbonisation across China's diverse climate zones and in buildings in urban and rural areas, and in different industrial processes. It describes the current policy landscape for heating in China.
- Chapter 2 considers the outlook for further deployment of heat pumps over the period to 2050, including within China's district heating networks. It describes the detailed projections of the uptake of heat pumps in buildings in each climate zone, the potential for uptake in different industrial processes and an outlook for light industries. It also includes a special focus section on heat pumps for integrating waste heat in industry and district heating networks, as well as other possible applications of this technology within district heating networks.

- Chapter 3 focuses on the implications of heat pump deployment in terms of emissions reductions and air quality, as well as the impacts for China's extensive heat pump manufacturing industry, job creation, investment needs and power sector flexibility.
- Chapter 4 provides a series of recommendations on combined policy measures to address challenges for heat pump deployment in China and to support development of a sustainable heat pump supply chain.

Scenarios, data and sectorial boundaries used in this report

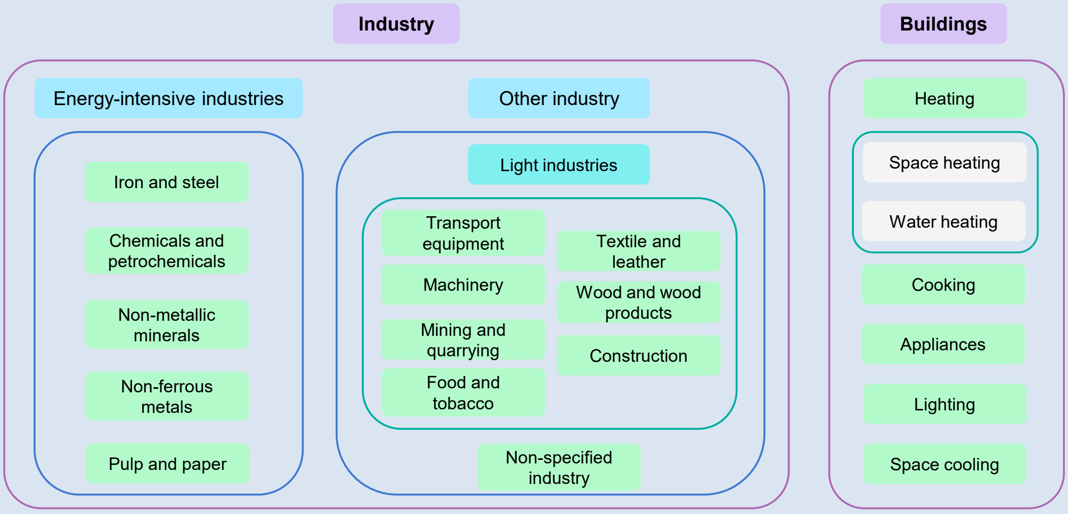
The outlooks to 2050 provided in this report by IEA are based on the following scenarios:

- **IEA Stated Policies Scenario (STEPS)**: A scenario which reflects current policy settings based on a sector-by-sector and country-by-country assessment of the energy-related policies that are in place as of the end of August 2023, as well as those that are under development. The scenario also takes into account currently planned manufacturing capacities for clean energy technologies.
- **IEA Announced Pledges Scenario (APS)**: A scenario which assumes that all climate commitments made by governments and industries around the world as of the end of August 2023, including Nationally Determined Contributions (NDCs) and longer-term net zero targets, as well as targets for access to electricity and clean cooking, will be met in full and on time.

IEA scenarios are developed using the IEA Global Energy and Climate (GEC) model, a large-scale bottom-up, partial-optimisation modelling framework. All data that are not otherwise referenced in this report are derived from IEA Energy Balances and IEA Global Energy and Climate model.

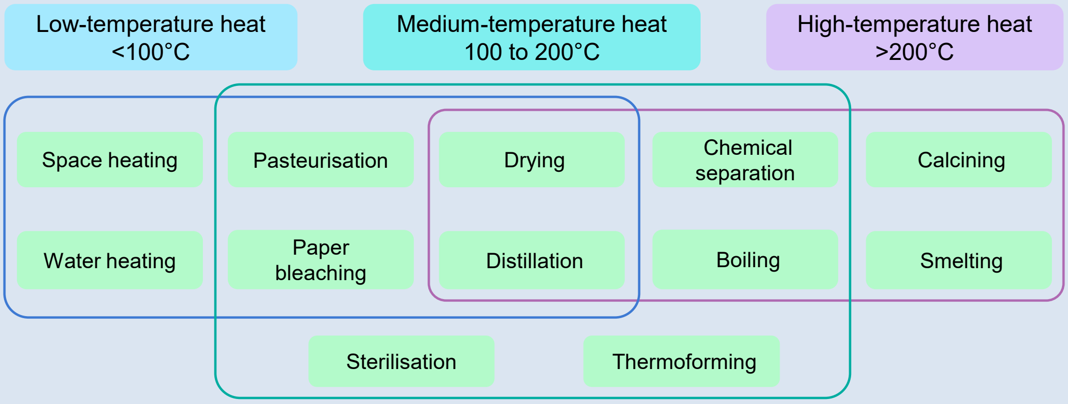
This report also includes assessments by Tsinghua University in China, which are based on their simulation-based China Buildings Energy and Emissions Model (CBEEM). The model projects space heating loads at the county level in northern urban areas, taking into account factors such as resident population, urbanisation rate, per capita building indicators, evolution of building energy efficiency levels and load indicators. In addition, Tsinghua University's energy consumption forecasting model also projects the heat demand of light industries based on the future restructuring of China's industrial sector and its processes.

Boundaries of industrial sub-sectors and buildings end-uses



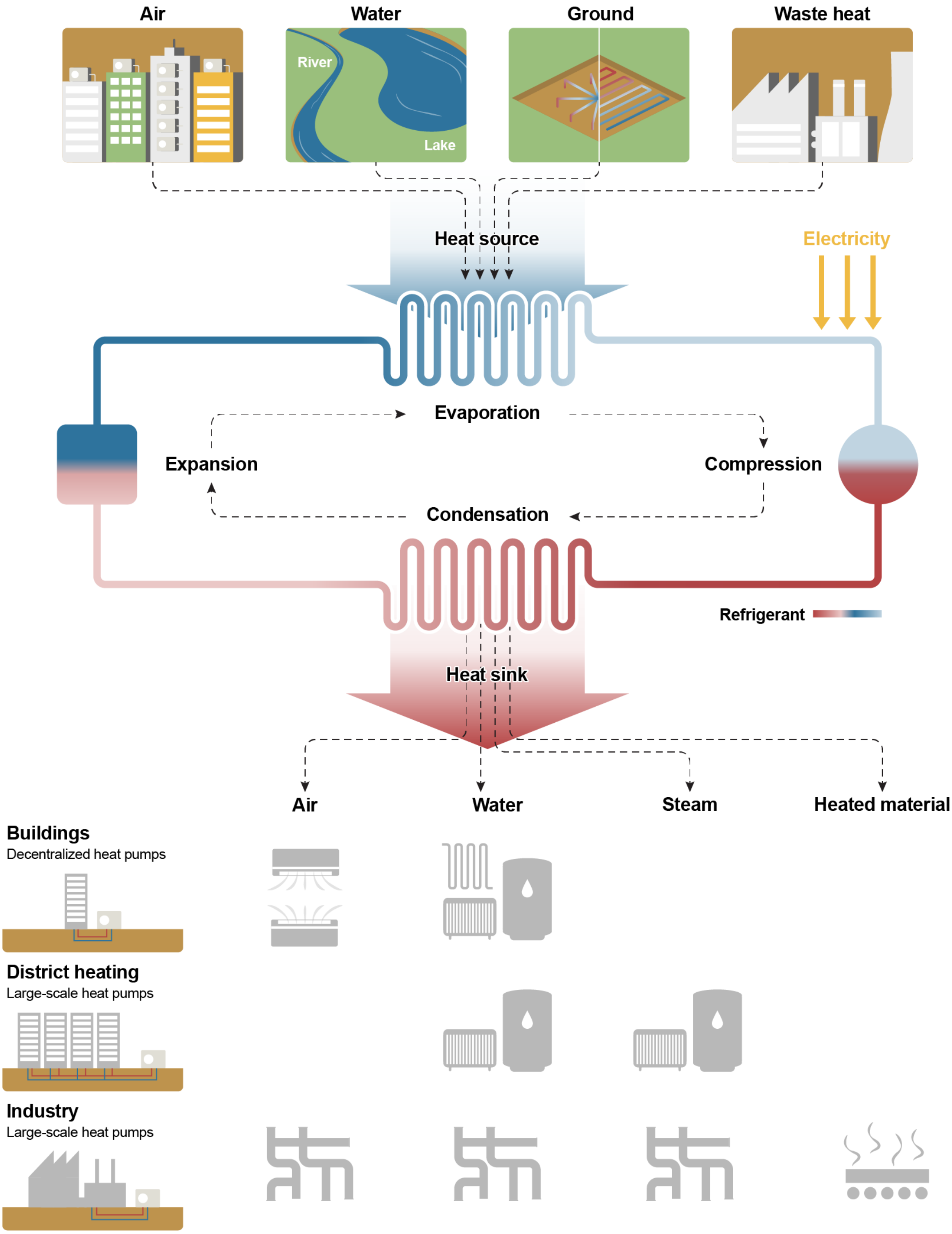
Notes: Pulp and paper also includes printing. Refineries are not considered as part of industry but instead as part of the energy supply sector in the GEC model. It is to be noted that the IEA's definition of industry categories differs from the 31 categories used by the China Energy Statistical Yearbook; specifically, the latter considers paper production and parts of the chemical sector to be light industries.

Industrial process and buildings heating end-uses by temperature levels



Source: IEA based on data from Beyond Zero Emissions (2018), Zero Carbon Industry Plan – Electrifying Industry; Mateu-Royo C. (2021), Development of High Temperature Heat Pumps for Industrial Waste Heat Recovery, accessed 13 March 2024.

Heat pump types and applications



Chapter 1. Heating in China

Highlights

- China is a major driver of global heat demand, with its industry and buildings sectors accounting for about one-third of global heat consumption. Heating in China is dominated by coal and responsible for 40% of coal fuel use nationally, down from more than 45% in 2010 following a series of air quality, clean heating and energy conservation policies.
- Heat consumption in buildings has surged by almost 75% since 2010 – faster than in any other country – due to an expansion in floor space and a growing need for heating in central and southern China. District heating is the dominant solution in urban areas of northern China, which has a colder climate, while decentralised solutions are common elsewhere.
- Industrial activity has grown considerably in China, and industrial heat demand has grown 13% since 2010 as a consequence. Heat below 200 °C – the temperature range in which state-of-the-art heat pump technology operates today – represented about 20% of industrial heat demand in 2022, primarily in light industries, pulp and paper, and chemicals.
- Alternatives to fossil fuel-based heating are set to make inroads in China. Electrification – including through heat pumps – is a key strategy for decarbonising heat. About 40% of heat consumption across buildings and industry in China could theoretically be supplied by state-of-the-art heat pumps.
- China had an estimated 45 EJ of waste heat resources in 2021, nearly as much as the heating demand of buildings and industry combined. Heat pumps are a viable option for integrating part of this heat into district heating networks and industrial processes.
- Air-to-air heat pumps are already the default option for heating and cooling buildings in mild climates where district heating is not deployed, and use of air-to-water units is emerging in colder climates and for the production of domestic hot water. Heat pumps provided a small share of heat in industry and district heating in 2022.
- In the long term, improving living standards and projected growth in floor area are expected to drive the share of heated floor area in buildings to 80% by 2050 – up from 65% in 2022. In the Announced Pledges Scenario (APS), electricity covers 25% of heating energy consumption in buildings by 2050 – up from about 15% in 2022.
- In industry, heat demand decreases by 40% to 2050 in the APS, and demand for high-temperature heat decreases most, as cement, iron and steel production peaks and then declines. However, heat demand from light industries grows by 15% to 2050 as the country shifts to higher value-added industries. Electrification also progresses in industry, supplying 80% of heat consumption in light industries by 2050 – up from 35% in 2022.

Introduction

Heating – an energy service required by the buildings and industry sectors – currently represents one-third of the world's total final energy consumption, or nearly 145 EJ, of which around 75% is from fossil fuels. Heating is responsible for 24% of global energy-sector emissions. In buildings, heat is needed for warming spaces and heating water.[1] In industry, heat is needed for various applications, which in terms of energy use are predominantly fluid heating, drying and metal smelting, but myriad other heat applications exist, such as catalysis, incineration, calcining, curing and so on.

Heat demand is driven by many factors. In buildings, heat demand is largely driven by climate, cultural and personal preferences, occupancy patterns, building performance and total floor area. In industry, the major driver of heat demand is the industrial activity per sector, such as steel smelting or paper drying. Importantly, heat demand in industry is generally stable over the year, whereas space heating needs in buildings tend to be seasonal.

China is responsible for 33% of global heat consumption, with shares as high as 40% for the industry sector, and around 20% for the buildings sector –significantly influencing global trends. Heat demand below 200 °C, the range most suitable for heat pump applications, makes up about 20% of total heat demand in Chinese industries. Heating in China is also responsible for 40% of global direct CO_2 emissions for heating.

Final energy consumption for heating in the industry sector was double that of the buildings sector in China in 2022. However, 60% of heat demand below 200 °C comes from the buildings sector. Levels of heat consumption are also developing at different rates. Driven by a 50% increase in floor area, decreasing use of non-commercial energy such as firewood, and increased demand for heating in central and southern China, heat consumption in buildings has increased by nearly 75% since 2010, faster than in any other country. Over the same period, heat demand in light industries and pulp and paper[2] decreased by 5%, thanks to efficiency improvements, while in other energy-intensive industries it increased by about 15%, as efficiency improvements were not sufficient to offset the increase in demand (Figure 1.1). However, total heat consumption for temperatures below 200 °C within the industry sector saw little change, with an increase of around 5% since 2010. Furthermore, over the past decade, the energy intensity[3] of Chinese industry decreased considerably, falling from 14.4 MJ per USD of industrial value added in 2010 to 8.6 MJ per USD in 2022.

Final energy consumption for heating in China is heavily reliant on fossil fuels, which accounted for about 70% of the total heat consumption in 2022. For

[1] Although technically heating, energy for cooking is not included in the definition of heat in this report.

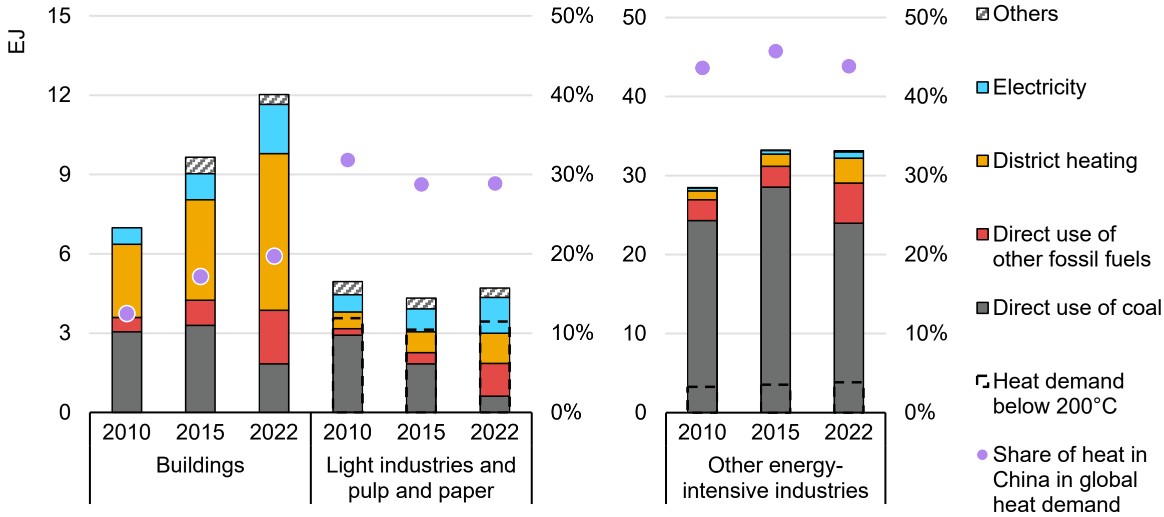
[2] Light industries include the following sectors: construction, mining and quarrying, food and tobacco, textile and leather, machinery, transport equipment, and wood and wood products. The pulp and paper sector is categorised as an energy-intensive industry, alongside iron and steel, chemicals, non-metallic minerals and non-ferrous metals. For more detail, see the sector boundary definition in the introduction.

[3] The amount of energy consumption per unit of value added.

industry, the share of fossil fuels jumps to around 80%, while for buildings it is about 30%. Overall, coal accounts for about 55% of direct use of fossil fuels for heat in China. If coal inputs to produce district heat[4] and electricity used for heating in buildings and industry are included, the heating sector is responsible for more than 40% of total coal use in China.

However, a look at the heating fuel mix of today reveals the structural change underway compared to just a decade ago, when coal made up about 75% of fossil fuels used directly for heat. This shift is related to successive policies put in place by the Chinese government since 2013 – firstly, to improve air quality, and more recently, to expand clean and low-carbon heating. Compared to 2010, direct coal consumption for heating has decreased by nearly 15% overall. Direct natural gas consumption almost quadrupled over the same period, while electricity almost doubled, leading the fuel shift away from coal at the consumer level. However, coal use in district heating increased 150% over this period, albeit with technological improvements and a shift from coal boilers to combined heat and power (see Box 1.2).

Figure 1.1 Final energy consumption for heating for the buildings and industry sectors in China and respective share of the global total, 2010-2022



Notes: Other energy-intensive industries include iron and steel, non-metallic minerals, non-ferrous metals and chemicals industries. Non-specified industries are not included. District heating and direct use of other fossil fuels in buildings – including both residential and non-residential - are derived from Tsinghua University's China Buildings Energy and Emissions Model, which are different to district heating statistics in China (see Box 1.1). Total final energy consumption for buildings matches the 2023 edition of the IEA Energy Balances and excludes the traditional use of biomass and other non-commercial energy. Total final energy consumption for industry matches the 2023 edition of the IEA Energy Balances.

China accounts for 33% of global heat consumption, and the heating sector is responsible for 40% of coal use in China – over 5% less than a decade ago, reflecting an emerging shift away from coal.

[4] District heat is often referred as central heating in this context.

This chapter provides an overview of current and future heat demand and what drives it, the heating fuel mix and decarbonisation opportunities, and recent policies relevant to heating. It sets out the basis for discussion of the role that heat pumps can play in industry and buildings, as well as within district heating systems which supply heat to both sectors, with special attention to the heating segments where heat pumps have most potential.

Box 1.1 District heating and coal statistics in China

Collecting heating statistics is a complex process, particularly given the large number and variety of stakeholders involved, difficulties with tracking unsold heat, and potential differences in data classification. During the preparations of this report, the IEA has worked closely with Tsinghua University as well as the National Bureau of Statistics, and has had exchanges with the Ministry of Housing and Urban- Rural Development to assess the historical final energy consumption by fuel for heating purposes in China. The insights and implications for this report are presented below.

A greater harmonisation of heating statistics within and among countries will be important to effectively inform policy decisions about decarbonising heating. The IEA will continue to work closely with relevant stakeholders to support a better understanding of heating statistics in China and globally, and to continue to improve its statistics and update its analytical insights progressively moving forward.

Heat demand in buildings

District heating: In official Chinese statistics, district heating for buildings is often referred to as “Centralized Heating”. The Urban and Rural Construction Statistical Yearbook of the Ministry of Housing and Urban-Rural Development and the China Statistical Yearbook of the National Bureau of Statistics report a national urban centralised heating area of about 11 billion m^2 in 2021 and 2022. Tsinghua University’s Annual Report on China Building Energy Efficiency in 2022 suggests that the district heating area accounted for by this statistic excludes a large amount of district heat supplies provided by small-scale heating enterprises. Private networks of this kind typically provide heat to universities, institutions and compounds. Some large-scale enterprises that manage their own independent district heat network are also excluded from the official statistics. For example, in the case of Beijing, the China Statistical Yearbook counted a centralised heating area of 660 million m^2 in 2020, while Beijing's “14th Five-Year Plan” heating development and construction planning documents estimated 895 million m^2 of centralised heating – a 25% difference with respect to the official statistics. When including these additional networks across northern China, the estimated floor area connected to district heating is around 14 billion m^2. The definition of “National Urban Centralized Heating” is also different from the “Heat” definition within national energy balances, which only includes a part of the district heat produced, while heat-only plants are accounted for in part within final energy consumption of the buildings sector. IEA Energy Balances are based on data from the National Bureau of Statistics, and final district heating consumption for buildings refers to the components of residential and services sectors.

For the purpose of this report, it was decided to use district heating energy demand numbers for the buildings sector from the assessment of Tsinghua University, which is about three times higher than IEA statistics in both 2010 and 2022. This difference is corrected at final buildings energy demand level by reallocating the corresponding quantities of direct fuels use from buildings to district heat supply. Thereby, consistency of total final energy consumption in buildings with IEA Energy Balances and public statistics is ensured.

Coal: The work on this report also identified differences in coal use in buildings between IEA statistics and the analysis of Tsinghua University, which takes into account coal used in rural areas that is extracted from small coal mines and not accounted in official statistical data. In energy terms, Tsinghua University analysis suggests that coal use in buildings is 95% higher in 2010 than reported in official statistics, and 65% in 2015. However, this mismatch closes towards 2022, the base year of analysis used in this report. Data on coal use for buildings used in this report is therefore kept consistent with IEA Energy Balances (based on data from the National Bureau of Statistics), with the difference that coal quantities within final consumption not specified elsewhere are, in part, allocated to buildings in this report.

Heat demand in industry

Industrial heat demand and utility-level heat supply reflected in IEA’s Energy Balances are reported by the National Bureau of Statistics. This data could not be compared with third party bottom-up independent public data surveys within the context of this report. Therefore, district heating energy demand data for the industry sector used in this report are taken directly from IEA’s Energy Balances, as reported by the National Bureau of Statistics.

Current status and perspectives on heating decarbonisation

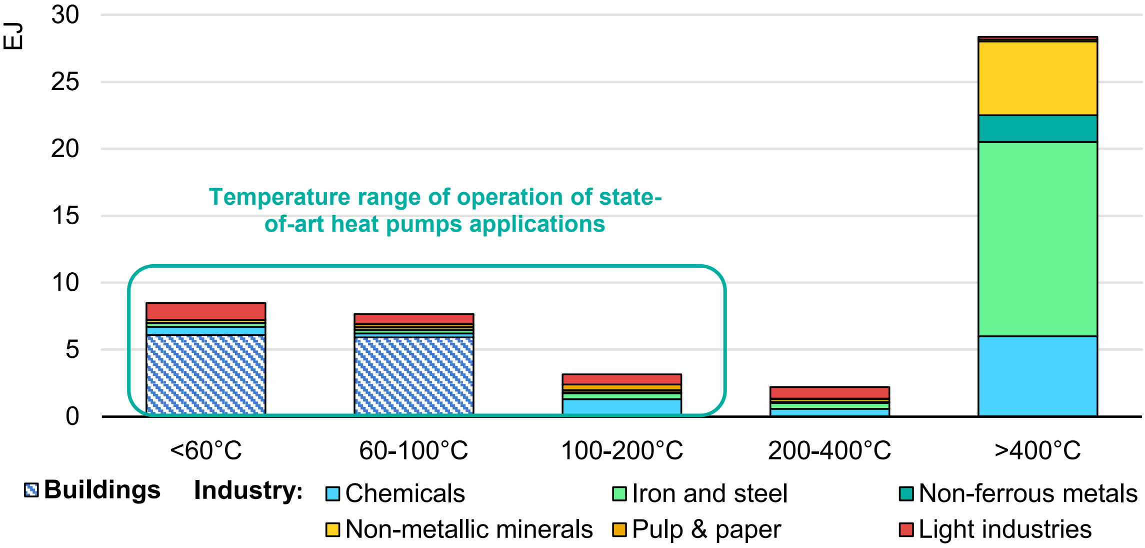
In buildings, the key decarbonisation levers are, firstly, avoiding demand by reducing the need for heating through improvements in building design and envelope performance, changes to cultural norms and practices[5] towards energy conservation, shifting away from fossil fuels, and improving the efficiency of heating equipment. In addition, buildings and thermal networks can exploit the capability to shed, shift and modulate electricity demand to provide flexibility to the electricity grid, facilitating integration of variable renewables in the power system.

The key decarbonisation levers for industry are, firstly, material efficiency, including avoiding demand for raw materials through efficient product design and manufacturing techniques, shifting to less energy- and resource-intensive and more durable products, combined with progress in reuse and recycling. At a broader level, action to decarbonise manufacturing processes includes increased energy efficiency and fuel switching within existing production routes, and deployment of innovative near-zero emission production routes based on hydrogen, direct electrification, carbon capture and storage, or innovative use of alternative raw materials. Electrification – in particular through highly efficient heat pumps – is a fundamental pillar of strategies to decarbonise heating in both the buildings and industry sectors.

Used in parallel to a progressive decarbonisation of power generation (see Box 3.2), heat pumps can contribute to a shift away from fossil fuels, and with energy consumption three to five times lower than alternative equipment, heat pumps can help reduce the overall energy required to provide heat. In addition, when coupled with thermal or electric storage, heat pumps can be operated to increase the flexibility of the electricity grid and/or district heating networks. In China, the use of heat pumps for industrial heat production is marginal today, though the use of heat pumps for space heating and domestic hot water production is more common (see Chapter 2). Today, state-of-the-art[6] heat pumps operate within temperature ranges below 200 °C, while heat pumps for higher temperatures are at lower levels of technology readiness, depending on the temperature range and process.

[5] Including consumers' actions to reduce energy consumption, such as changing the indoor temperature set point, using equipment part-time and part-space, and ventilating appropriately.
[6] Commercially available, first-of-a-kind applications and pre-commercial demonstrations.

Figure 1.2 Final energy consumption for heating per temperature level per sector in China, 2022



Notes: Energy use outside of heating applications is not included. State-of-art heat pumps applications refer to commercially available heat pumps, first-of-a-kind heat pump applications and pre-commercial demonstrations.

About 40% of current final energy consumption for heat holds the potential for heat pump integration over the short term, mainly in the buildings sector and for industrial applications below 200 °C.

The buildings sector in China requires heat at temperatures below 85 °C, and the lower the temperature required, the easier it is to integrate higher efficiency heat pumps. However, integrating heat pumps in buildings also involves other considerations beyond technology availability, such as affordability, compatibility with the surrounding built environment (space, aesthetics, noise) and overall building design, including compatibility with the heat distribution system, grids and networks. Scaling up heat pump deployment requires consumers and installers to be aware of the most suitable types of heat pumps in a given context, and how they compare with possible alternatives.

In contrast, in the industry sector, only about 10% of the heat required is at temperatures below 100 °C, half of which is in light industries (Figure 1.2).[7] About 8% of total industry heat consumption requires temperatures between 100 °C and 200 °C, for which first-of-a-kind commercial heat pump applications (up to 140 °C), and pre-commercial demonstrations and large prototypes (up to 200 °C) are emerging. However, more than 80% of heat demand for industry – of which about half is for the production of iron and steel – relies on temperatures above 200 °C. Applying heat pumps for this temperature range appears to be more challenging

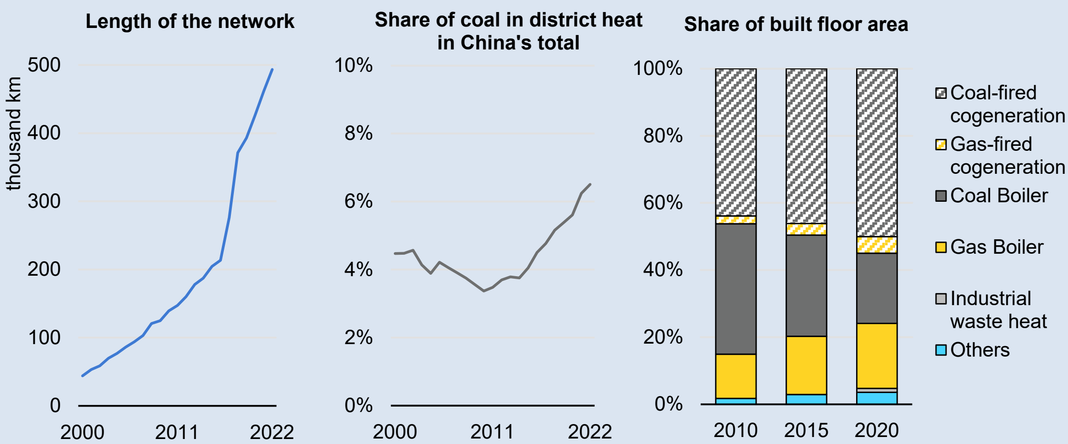
[7] Describes a range of sectors with lower specific energy use than energy-intensive industries. This includes diverse sectors handling the production of machinery, food, textiles, vehicles and timber, as well as mining and construction.

(see Chapter 2). For higher temperatures, heat pump technology is at an earlier stage of development than other low-carbon alternatives such as induction heaters, electric-arc furnaces or hydrogen and bioenergy heaters. In addition, even for low-temperature industrial processes, heat pump deployment faces obstacles such as high upfront costs and a lack of awareness among potential users.

Box 1.2 District heating: the world's largest network for providing heat to industry and buildings

District heating systems have been built in China since the 1950s, initially to connect industrial sites. Residential and non-residential buildings started to be connected in the 1980s, but large-scale deployment in north urban China happened only in the 1990s and is still continuing. Over the past decade, China has become the leading district heating market worldwide, followed by Russian Federation (hereafter, "Russia") and Europe. District heating grew both due to build-out of new urban buildings in cities already served by district heating, and to a large push to provide district heating to regions still using distributed coal boilers.

District heating network length, coal used in district heating as a share of China's total primary coal supply, 2000-2022, and share of district heated floor area by source, 2010-2020



Notes: Share of built floor area supplied by heat source is based on an assessment by Tsinghua University. "Others" include heat pumps and electric boilers, nuclear heat and renewable energy sources (solar, geothermal, bioenergy).

Source: IEA based on data from China, Ministry of Housing and Urban-Rural Development (2022), Urban and Rural Construction Statistical Yearbook; and Tsinghua University (2023), Annual Report on China Building Energy Efficiency.

The length of the district heat network has increased by 250% since 2010, of which the large majority is in the north, though some networks have been developed to the south of the Qin-Mountains-Huai-River line more recently. Network losses average around 12%, which is comparable with other countries, but can reach 20% in some less efficient networks. In some cases, there are problems of overheating and poor heat management. High subsidies for district heating occasionally lead to the curtailment of renewables to operate combined heat and power (CHP) plants for power generation, which can also result in inefficient operation of heat generation sites.

Coal consumption in district heating represents about 7% of China's total coal use. Coal plays a dominant role in Chinese district heat generation, especially via coal-fired CHP plants, and is closely coupled with the power sector.

However, China has taken action towards cleaner and more efficient heating in recent years, such as through the "Energy Production and Consumption Revolution Strategy" (2016-2030) and "Clean Winter Heating Plan in Northern China" (2017-2021) (see Policy landscape section), and this has had a visible impact. According to Tsinghua University's Annual Report on China Building Energy Efficiency 2023, coal-fired cogeneration in district heating rose 6% from 2016 to 2020, while coal-fired boilers fell by 13% over the same period. Excluding CHPs, the proportion of gas-fired heating reached a similar level to coal-fired boilers.

The potential to reduce the carbon intensity of district heating systems has been demonstrated in several district heating systems around the world, for instance in northern European countries such as Sweden and Denmark, where the combined share of renewables, heat pumps and waste heat reached over 90% and 75%, respectively, of district heat energy supply in 2021. China could seek to replicate such emission reduction pathways, given the potential to upgrade heating infrastructure and management, and integrate renewable energy sources, heat pumps and storage, as well as the high availability of waste heat from nuclear and other power plants, industry, data centres and wastewater. The 2021 potential for waste heat in China is estimated by Tsinghua University to be larger than 45 EJ, most of which is from thermal power plants (see Chapter 2).

Buildings

Current status of final energy consumption for heating

In 2022, China's combined energy demand for space and water heating in buildings was the second largest globally, surpassed only by the United States – making it one of the world's major heating markets. China is also the largest CO_2 emitter[8] for space and water heating, accounting for almost 1 Gt CO_2 or about one-quarter of global carbon emissions associated with heat consumption in

[8] Including both direct and indirect emissions.

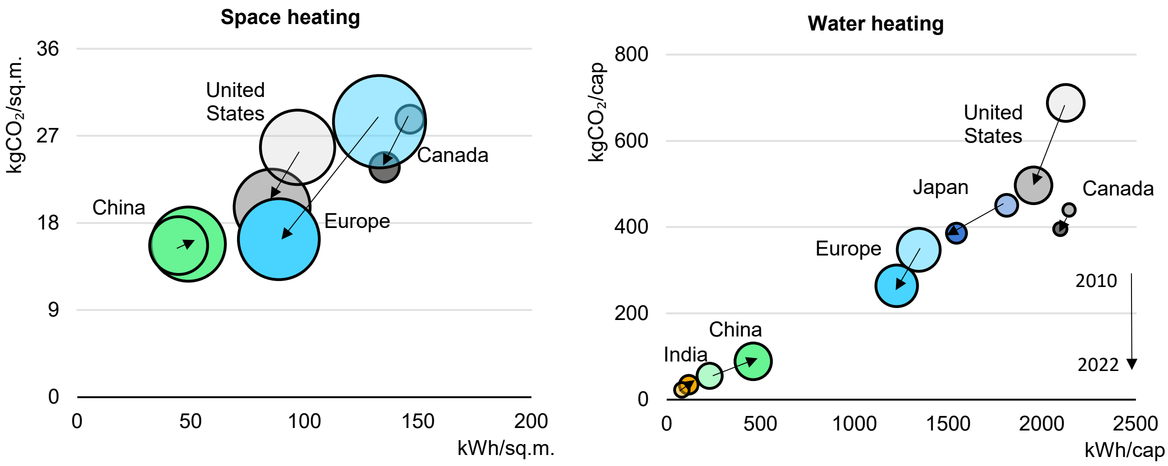
buildings in 2022. Heating consumptions per capita (kWh/person) and by floor space area (kWh/m^2), however, are on average 65% and 50% lower, respectively, than in other major heating markets.

This is driven by two main factors. Firstly, to low – but increasing – penetration and usage of space and water heating equipment in central and southern China, as well as in rural areas, and to the use of part-time and part-space equipment (i.e. heating just one room for part of the day), which is not common elsewhere. These areas represent nearly 70% of all floor area needing heating (see Box 1.3), and with improvements in living standards and changing cultural norms and practices, heating demand is likely to grow in central and rural China.

Secondly, China has several climate zones, and a large share of built floor area is in areas with mild winters, reducing the overall average heating intensity. However, north urban China, which is characterised by cold climates, has space heating intensities comparable to other major heating markets.

All advanced economies have reduced their space and water heating intensities since 2010 thanks to progress in energy efficiency policies. This is not the case in China due to the important increase in demand, but policies associated with energy efficiency, and coal-to-electricity and coal-to-gas shifting (see Policy landscape section) have contributed to limiting the growth of space heating intensities by 10% since 2010. Per capita consumption for water heating continues to increase in China due to growing demand (Figure 1.3).

Figure 1.3 Cross-country comparison of CO_2 emissions associated with space and water heating per square metre of floor area and per capita, 2022



IEA. CC BY 4.0.

Notes: CO_2 emissions include both direct and indirect emissions. Bubble size is proportional to energy consumption. On the left graph, floor area of China refers to floor area that requires heat. Final energy consumption for residential water heating has been calculated by Tsinghua University assuming 50 litres/household/day, while non-residential consumption is derived from the IEA Global Energy and Climate model.

Despite recent policy changes, energy and emission intensities for heating are still increasing in China, due to increasing equipment penetration and usage

In China, space and water heating represent nearly 40% of CO_2 emissions of the buildings sector, and about half of its final energy demand, primarily for space heating, which is responsible for 80% of energy demand for heating and of 85% emissions from heating in buildings. Direct and indirect emissions associated with space and water heating have nearly tripled since 2000, as a result of space and water heating consumption increasing by three-and-a-half times, and have increased 50% since 2010. This substantial increase is linked not only to the growth in built floor area (which has doubled since 2000), but also to the shift from non-commercial fuels (e.g. the use of traditional biomass) to commercial ones (e.g. electricity) in rural areas, and to the increasing uptake of heating equipment in areas without district heating, such as within the hot summer-cold winter (HSCW) climate zone and in rural areas (see Box 1.3).

Box 1.3 Climate zones and impact on space heating equipment choices

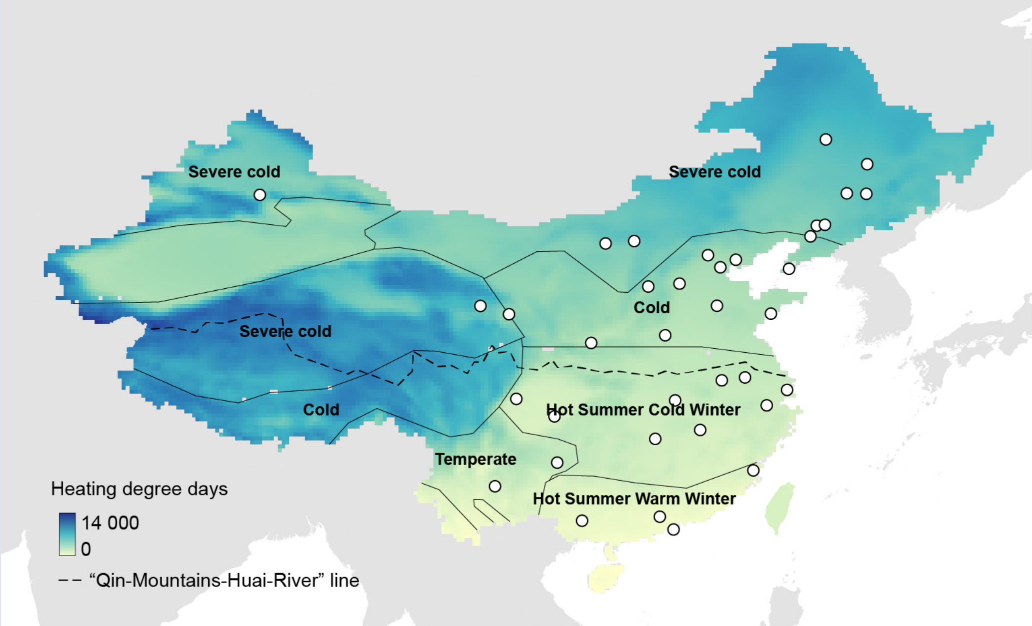
China's climate can be characterised as having five thermal climate zones for buildings design, which significantly impacts choices about the level of building insulation and deployment of heat equipment across provinces.

The Qin-Mountains-Huai-River line has been long considered the dividing line between northern and southern Chinese provinces. Until recently, this line also divided those with access to district heating (in the north) from those who did not. To the south of the line, and in rural areas, residents need to provide for heat on their own.

The north of China falls within the **cold and severe cold climate zones** characterised by low winter temperatures and long winter periods (90-180 days per year). District heating networks are the most common solution for space heating in northern urban areas, distributed across 15 provincial units, including provinces, municipalities and autonomous regions. Buildings' energy performance has been improving in recent decades thanks to the increasing stringency of buildings' energy codes (see Policy landscape section).

Immediately to the south of the line is the **hot summer-cold winter (HSCW)** climate zone, which has an average heating season that lasts about 1-3 months. District heating has not been centrally planned by municipalities in this area, and buildings are increasingly investing in heating systems and relying on a decentralised heating system. Demand for space heating is increasing in this area, together with rising living standards. In urban areas, building envelope performance is poorer than in buildings in north urban China, as less attention has been devoted to heating needs within buildings' energy codes.

Map of Chinese climate zones, heating degree days and distribution of selected Chinese cities with more than 1 million inhabitants



Notes: Heating degree days are derived from the IEA Weather for Energy Tracker, calculated with base temperature 20 °C.

Source: IEA based on data from China, Ministry of Housing and Urban-Rural Development (2016), Thermal Design Code for Civil Buildings (GB50176-2016).

Space heating is also used in some parts of the **temperate climate zone**, where the average winter temperature falls below 5 °C for a maximum of 90 days per year. Decentralised heating solutions are prevalent in this area.

The demand for space heating is very low in the **hot summer-warm winter** zone.

Space heating needs, built floor area, and dominant space heating equipment by different climate zone, 2022

	Severe cold and cold zone	Hot summer and cold winter	Temperate	Hot summer and warm winter
Thermal needs	Heating dominated; cooling optional/secondary need based on location.	Cooling dominated; heating secondary need.	Heating needed in some parts.	Cooling dominated; heating optional.

	Severe cold and cold zone	Hot summer and cold winter	Temperate	Hot summer and warm winter
Mean monthly temperatures (°C)	Severe cold: coldest < -10 °C Cold: coldest -10-0 °C	Coldest: 0-10 °C Hottest: 25-30 °C	Coldest: 0-13 °C Hottest: 18-25 °C	Coldest: >10 °C Hottest: 25-29 °C
Heating equipment (urban areas)	District heating; bulk coal boilers; various types of electric heaters; gas wall-hung boilers; geothermal/ground-source heat pumps.	Electric heaters (including underfloor heating, radiator, electric blanket, infrared heater, fan heater); air-source heat pumps; natural gas boilers; oil boilers.		/
Heating equipment (rural areas)	Coal, natural gas and biomass boilers; air-source heat pumps and electric heaters; solar thermal.			/
Share of built floor area (%, billion m^2)	~34% (23 billion m^2) Of which urban: 66%	~45% (31) Of which urban: 67%	~9% (4.5) Of which urban: 55%	~12% (10) Of which urban: 62%
Building codes targeting heating	since 1986	since 2022		

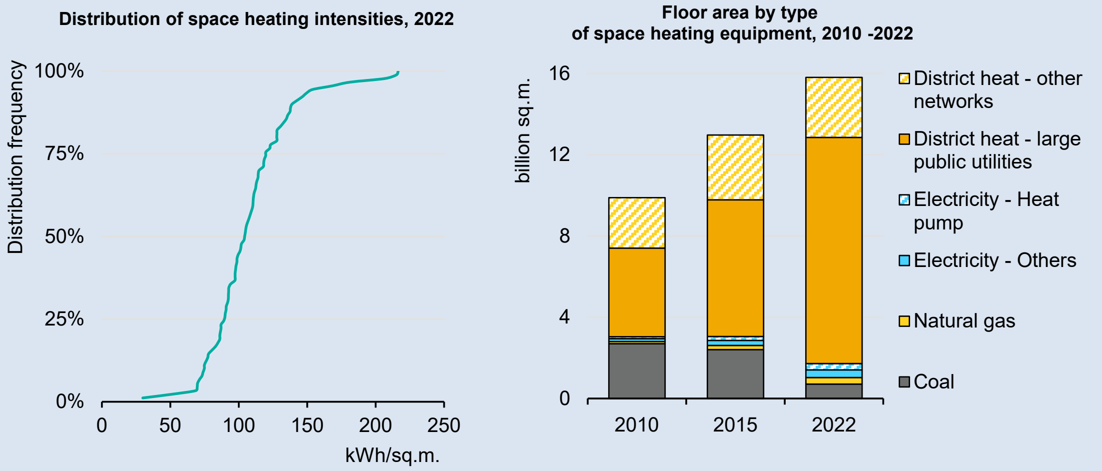
Notes: In some milder climates, air-air heat pumps are often bought with the purpose of air conditioning during the summer period (reversible air conditioners) but are also used during winter to warm up rooms quickly, either independently or coupled with other equipment. In 2022, the General Code for Energy Efficiency and Renewable Energy Application in Buildings was introduced in all climate zones. In the cold and severe cold zones, the JGJ 26 was introduced in 1986.

Source: IEA based on data from China, Ministry of Housing and Urban-Rural Development (2022), Urban and Rural Construction Statistical Yearbook (for thermal need) and from National Bureau of Statistics (2022), China Statistical Yearbook (for split of floor area).

Space heating in north urban China

District heating systems (see Box 1.2) are used as the main space heating method in northern Chinese cities and towns, and connected floor area (11-14 billion m^2 in 2022) had an average annual growth rate of 11% from 2010 to 2022. The remaining heated floor area relies on distributed equipment: coal boilers (41%), electric heaters (22%), gas boilers (19%) and electric heat pumps (18%).

Space heating intensity, 2022, and district heated floor area from large public utilities in north urban China, 2000-2022



Notes: Heat consumptions per unit area come from Tsinghua University and China Urban Heating Association. District heated floor area from large public utilities is derived from the 2022 Urban and Rural Construction Statistical Yearbook, and on 'other networks' from Tsinghua University. Geothermal/ground-source heat pumps are not counted.

Floor area, space heating energy intensities and temperature set points in north urban China

	2022	2030	2050
Floor area, billion m^2 (% of national total)	16 (23%)	20 (26%)	22 (26%)
Space heat intensities, and potential reduction (%)	75-140 kWh/m^2	Potential reduction from 2022: 30-35%	
Temperature set points (°C)	18-28	18-24	18-22

Notes: Space heat intensity refers to final energy consumption. Potential reduction includes measures targeting both the envelope and the heating equipment from an assessment by Tsinghua University.

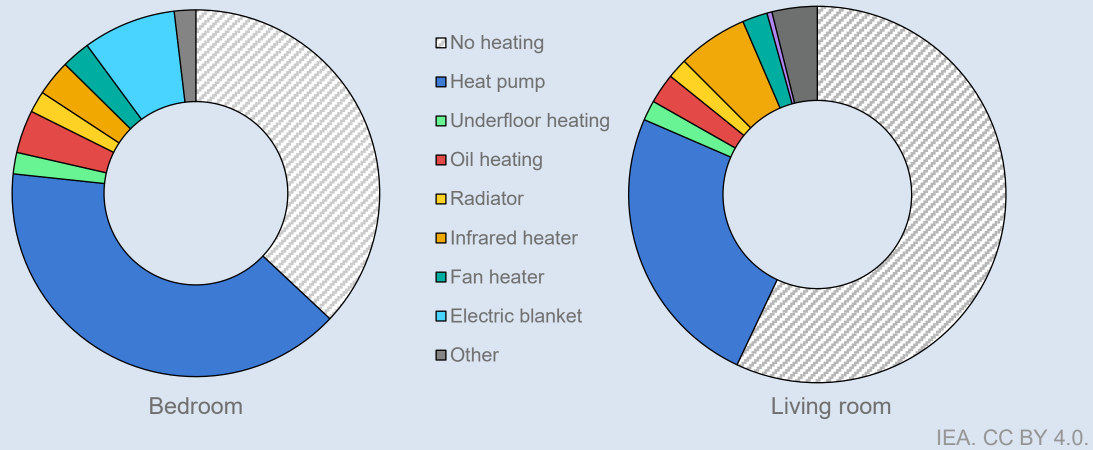
Source: IEA based on data from Tsinghua University (upcoming), China Building Energy Use and Carbon Emission Yearbook 2024 (for temperature set points and space heat intensities for 2022).

Key future considerations: Building envelope performance improvements and retrofitting of equipment, together with heat management strategies to reduce temperature set points and overheating, will be fundamental to reduce heating needs and provide opportunities to integrate heat pumps in both buildings and district heating networks. Campaigns to raise awareness among consumers and heating professionals along the value chain on the available heating options and how to operate them will also be critical.

Space heating in the urban hot summer-cold winter zone

Residential buildings in this area are heated and equipped with a variety of decentralised devices operated on a part-time and part-space basis over the winter period (lasting up to-3-4 months). Many households still do not possess heating equipment, and the majority of households typically open windows for more than 3 hours per day for ventilation, which might lead to energy losses if heating equipment is run continuously.

Distribution of heating equipment in the urban hot summer-cold winter zone, 2018



Note: "Other" include gas boilers.

Source: IEA based on data from Jiang et. al, (2020) How do urban residents use energy for winter heating at home? A large-scale survey in the hot summer and cold winter climate zone in the Yangtze River region.

Floor area, space heating energy intensities and temperature set points in the hot summer-cold winter zone

	2022	2030	2050
Floor area, billion m^2 (% of national total)	21 (30%)	23 (30%)	24 (29%)
Space heat intensities	0-20 kWh/m^2	Use and uptake of heating equipment expected to increase	
Temperature set point (°C)	14-18	18-20	18-22

Note: Space heat intensity refers to final energy consumption.

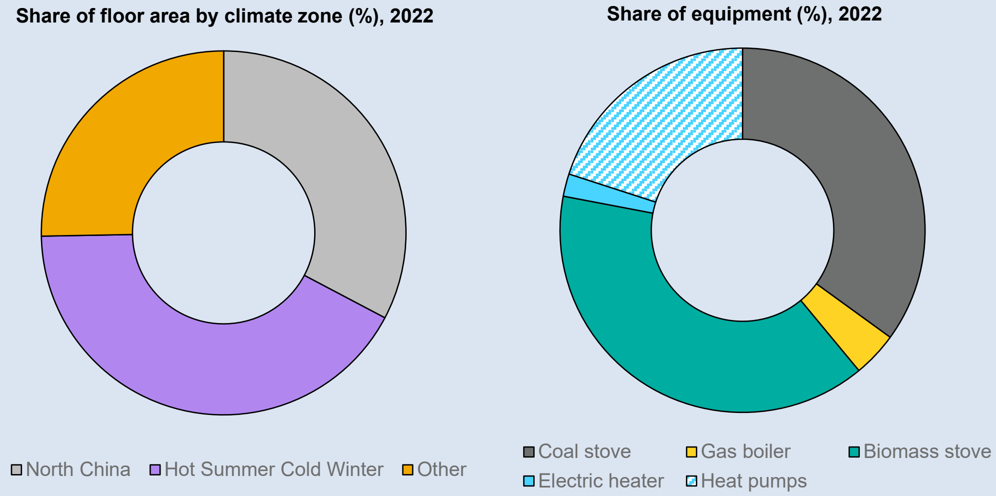
Source: IEA based on data from Tsinghua University (upcoming), China Building Energy Use and Carbon Emission Yearbook 2024 (for temperature set points and space heat intensities for 2022).

Key future considerations: Due to the milder climate and short winter periods, district heating is not likely to be cost-effectively deployed at scale in these areas. Reversible air-to-air heat pumps will potentially become a crucial technology to provide both heating and cooling, although depending on preferences and specific climate, air-to-water units with underfloor heating are also viable options. Building envelope performance improvements for heating and cooling, and the availability of equipment with high energy efficiency and heat management, will be critical to limit the increase in energy consumption in the region. Maintaining current habits around low-temperature set points and adopting best practices associated with ventilation will also be key.

Space heating in rural areas in all climate zones

On average, rural buildings have lower energy performances than those in urban areas, with consumption two to three times higher with respect to energy-efficient standards. Poor indoor air quality has been a target of government action on clean heating for the past decade, leading to a reduction in coal use by 60% from 2015 to the end of 2021. Natural gas and electricity are leading the fuel shift.

Share of floor area by climate zone and share of equipment in rural areas, 2022



Note: Share of equipment is derived from Tsinghua University modelling and refers to share of equipment among households owning equipment.

Floor area, space heating energy intensities and temperature set points in rural areas

	2022	2030	2050
Floor area, billion m², (% of national total)	24 (35%)	25 (32%)	26.5 (32%)
Space heat intensities, and potential reduction (%)	0 – 105 kWh/m²	Potential reduction in the North: 25 – 45%	
Temperature set points (°C)	12-15	15-18	15-22

Note: Space heat intensity refers to final energy consumption.

Sources: IEA based on data from Tsinghua University (upcoming), China Building Energy Use and Carbon Emission Yearbook 2024 (for temperature set points and space heat intensities for 2022).

Key future considerations: Compared to urban areas, rural areas have more space to enable the integration of heat pumps and renewable energy sources. Increasing the affordability of clean heating solutions will be of critical importance for continuing the shift away from coal and avoiding future lock-in to gas infrastructure. This should also include measures to improve the quality of the building envelope to reduce energy losses (and bills for consumers). Raising awareness of clean heat options, renovation practices, and financial support available could also support consumer decision-making

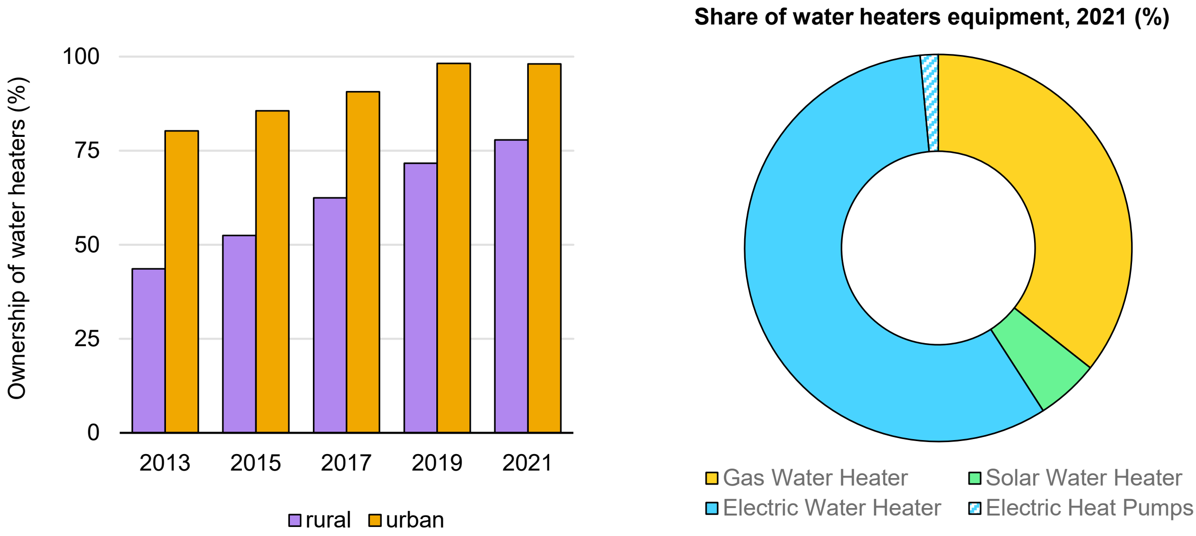
Hot water production

Domestic hot water consumption in China is currently around 50 litres per household per day, predominantly used for bathing and showering. Hot water is also needed in non-residential buildings such as restaurants, hospitals and office buildings.

In contrast to in many other heating markets, emissions and consumption intensities associated with water heating are still increasing in China, with trends that might approach levels similar to Europe (Figure 1.3) due to increases in equipment ownership and use, especially in rural areas (Figure 1.4). This trend can also be seen in other emerging and developing economies, such as India. Spurred on by population growth, energy consumption for water heating in China has been growing fast and has more than doubled since 2010 – about twice as fast as for space heating.

Water heating in residential buildings is largely supplied separately to space heating today. Electric water heaters account for about 60% of all residential water heaters, and the market for heat pumps is still emerging (see Box 2.2).

Figure 1.4 Ownership of residential water heaters, 2013-2021, and main type of residential equipment installed, 2021



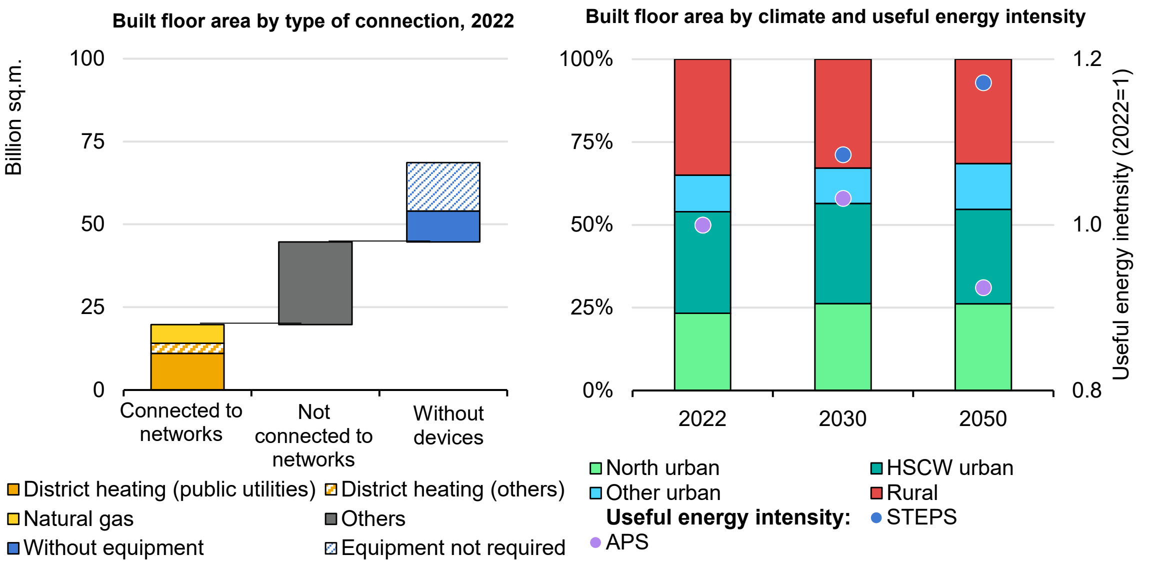
Notes: Ownership of water heaters (left) is based on the average number of units per households. The share of water heaters by type of equipment is based on analysis from Tsinghua University. Share of heat pumps is IEA analysis.
Source: IEA based on data from the National Bureau of Statistics (2022), China Statistical Yearbook (for ownership of water heaters).

Ownership of water heating equipment is rising fast, and about 60% of equipment is comprised of electric water heaters that are separate to technologies used for space heating.

Demand drivers and evolution of heating needs

Following projected demographic trends, the number of Chinese households will continue to grow until the end of this decade, and then slightly decrease to reach a level similar to that of 2021 by 2050. The recent contraction of real estate is expected to bounce back in the medium term, and floor area to continue to expand in line with urbanisation, though at a much slower pace than in recent years. We estimate that built floor area in China will reach about 85 billion m^2 by 2050 – up from 68.5 billion m^2 in 2022. Growth in floor area in the non-residential sector is expected to outpace growth in residential floor area, increasing 65% by 2050.

Figure 1.5 Built floor area by type of network connection, 2022, and evolution of built floor area and useful space heating intensities in the Announced Pledges and Stated Policies Scenarios, 2022-2050



Notes: APS = Announced Pledges Scenario; STEPS = Stated Policies Scenario; HSCW = hot summer-cold winter zone. Useful energy intensity refers to the ratio of useful energy for space heating and heated floor area.

While about two-thirds of existing heated floor area is not locked-in to an existing network connection, any fuel-switching strategy should be combined with action to improve heating energy performances.

As much as 75% of existing floor area will still be standing by 2050. While all types of new heating equipment can be easily integrated in new floor area developments, there may be limitations for existing floor area. The quality of the building envelope and existing heating and distribution systems have an impact on the size and type of heating equipment. Today, about two-thirds of buildings that need heating are not locked-in to existing infrastructure (district heat and natural gas) and could potentially shift to heat pumps (Figure 1.5). In addition, the floor area yet to be built by 2050 has the potential to choose their heating technology. However, attention to the thermal quality of the buildings is needed to enable the most efficient operation of heat pumps. There are significant opportunities to increase the average heating energy performance of floor area by increasing renovation rates of existing buildings and building high-performing new buildings.

These two measures will be crucial to meeting China's target of carbon neutrality before 2060 and limiting growth in energy consumption, especially given the increasing penetration and use of heating equipment. In the APS – the scenario compatible with the carbon neutrality target – at least 70% of built floor area by 2050 meets energy efficiency standards,[9] allowing for a reduction in useful space heat intensities of about 10% compared to today (Figure 1.5). In the STEPS, which reflects the impact of current policies, only about 45% of built floor area meets such a target by 2050. In the APS, retrofit rates also jump from less than 0.5% today to 1.5% by 2030.

In both scenarios, improving the performance of the building stock eases the integration of efficient and clean heating technologies, such as heat pumps, and renewable-based technologies, at the same time as increasing the overall resilience of buildings to extreme weather events.

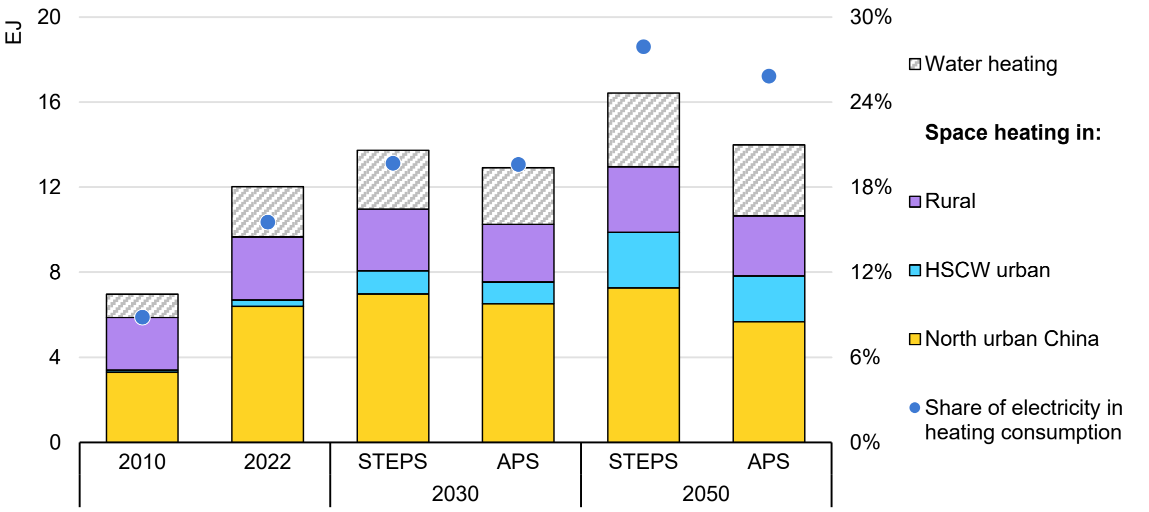
Perspectives on heat decarbonisation in buildings

Under the APS, energy consumption for space and water heating is projected to continue growing to 2050, albeit considerably slower compared to the previous decade, thanks to energy conservation and fuel switch measures. In the APS, the increase in final energy consumption for heating is limited to just 4% by 2050 – 20% less than in the STEPS (Figure 1.6). North urban China is responsible for the majority of space heating consumption in all scenarios, though the share of consumption in the HSCW zone continues to increase, covering 20% of the total by 2050 – up from about 5% in 2022. The share of rural areas in buildings' final energy consumption for heating slightly decreases to 2050 in all scenarios, although consumption stays nearly flat, as increased equipment penetration and usage is offset by energy efficiency improvements and population decrease.

In the APS, direct coal use for heating is reduced by 75% by 2030 and almost completely phased out by 2040. The share of direct natural gas is cut in half by 2050, with use concentrated in areas with an existing gas network. In the STEPS, the share of natural gas in final energy consumption by 2050 is double that in the APS, as buildings' energy performances are lower and more buildings in central China and rural areas operate heating systems continuously (instead of part-time, part-space).

[9] Standards that are at least as ambitious as the 2022 General Code for Energy Efficiency and Renewable Energy Application in Buildings, and progressively moving towards ultra-low energy and zero-carbon-ready buildings.

Figure 1.6 Final energy consumption for space and water heating in the Announced Pledges and Stated Policies Scenarios, 2010-2050



Notes: APS = Announced Pledges Scenario; STEPS = Stated Pledges Scenario. HSCW = Hot summer-cold winter climate zone. Split of final energy consumption for space heating by climate and urban/rural assessed by Tsinghua University. Beyond the technology mix, water heating demand is assessed by assuming achievement of 100% ownership of equipment in both urban and rural areas, and an increased use, from 50 l per day per household to 75 l per day per household for the residential sector by 2050; for the service sector, the assumed evolution is driven by floor area increase.

On the basis of announced pledges, around 25% of final energy consumption for heating will be met by electricity in 2050. Rural areas across China and urban areas in central and southern regions have the greatest potential.

The share of final energy delivered at the buildings border by district heating slightly increases in both the APS and STEPS by 2050, concentrated in north urban China and mostly relying on existing large infrastructure. Electricity jumps to a 26% share in the APS and 28% in the STEPS. In the STEPS, electricity consumption is higher in both 2030 and 2050 due to the overall lower energy performance of buildings, and more limited uptake of electric heat pumps in favour of other less-efficient electric heaters. In contrast, in the APS, electricity is widely consumed by electric heat pumps (covering 25% of heating needs in 2050; see Chapter 2), though some electric resistance heaters are still used for domestic hot water production,[10] particularly in urban areas where space constraints can limit the uptake of alternative technologies.

In the APS, the combination of avoided demand and fuel switching at the buildings level, coupled with the progressive decarbonisation of power generation (Box 3.2) and district heating, reduces emissions associated with heating buildings by about 75% by 2050, down by about 650 Mt CO_2[11] compared to 2022, and 60% lower than in the STEPS in 2050.

[10] Some are used as part of power-to-heat systems, where possible.
[11] Including direct and indirect emissions.

Industry

Current status of final energy consumption for heating in industry

Chinese industry has grown considerably over the past decade: aluminium production increased by 150% and steel by 60%. In comparison, over the same period, global aluminium production increased by 75%, and steel production by 30%, with a 20% decrease in Europe. Industrial development has contributed to the growth of the Chinese economy – GDP per capita has doubled since 2010 – and positioned China as a leader in different industrial segments. China now represents 50%, 51% and 54% of global aluminium, cement and steel production, respectively.

Despite this substantial expansion, Chinese industrial emissions grew by only 8% over the same period. In monetary terms, the emissions intensity of Chinese industry has decreased considerably in the past decade, falling from 2.4 kg CO_2 per USD of industrial value added in 2010 to 1.2 kg CO_2 per USD in 2022.

This is due to a combination of factors. First, energy intensity has decreased considerably. China is home to some of the world's most efficient aluminium smelters, with an energy intensity of 48.4 GJ per tonne of primary aluminium – 13% lower than it was in 2000 – compared to the world average of 50.8 GJ/t.

The second key factor is fuel shifting: Most of the increase in energy demand in the past decade has been in the form of electricity, which has grown from 17% of industrial energy demand in 2010 to 26% today. This happened at the expense of direct coal use, which has fallen from 65% to 45% of the industrial energy mix over the same period, thus lowering the emissions intensity. Natural gas has also played an important role, with its share growing from around 3% to 8% of industrial energy demand. This shift is partly driven by the changing composition of Chinese industries, with the chemicals sector growing considerably faster than steel, for instance, leading to an evolution in fuel use. These developments have been encouraged as part of the pivot to high-quality development and in an effort to improve air quality.

Heat is the main end use of energy in industries, accounting for about 60% of energy demand (Box 1.4). The other main industrial energy uses are the production of mechanical energy, lighting and cooling, all of which primarily consume electricity, whereas 80% of industrial heat in China is sourced from direct use of fossil fuels. Nonetheless, as a result of the shift away from coal, the average emissions intensity of heat generation for industry decreased by 15% over the past decade. However, despite this decrease in emission intensity, industrial emissions overall in China have continued to increase over the same period.

Box 1.4 IEA methodology to estimate heat demand in industry

To estimate heat use by industry sub-sector and by temperature level, we start from the industrial energy demand by fuel.

We assume that most fuels are used for heating applications, with only two exceptions: fuels used as feedstock and as electricity. This assumption is made on the basis that around 90% of fossil fuels used in industry are used for heating purposes and the rest is for mechanical energy or other non-specified applications.

For feedstock, no fuel used is counted in heat production.

For electricity, we apply a share for the portion used in heating applications, as opposed to that used for mechanical energy, lighting or cooling. The share of electricity used for heating is specific to each industrial sub-sector and is extracted from the MECS (Manufacturing Energy Consumption Survey) survey published by the US Energy Information Administration.

This heat demand is split by temperature level using values from various scientific articles and reports. These sources display heat use per temperature level for diverse industrial sub-sectors in different regional contexts and it is assumed that their levels of temperature splitting can be applied globally, given that process thermal energy requirements are mandated by the nature of the industrial processes in a given sub-sector rather than the region in which it operates. Furthermore, values from those sources are harmonised on ranges within a common temperature scale (<60 °C, 60-100 °C, 100-200 °C, 200-400 °C and >400 °C).

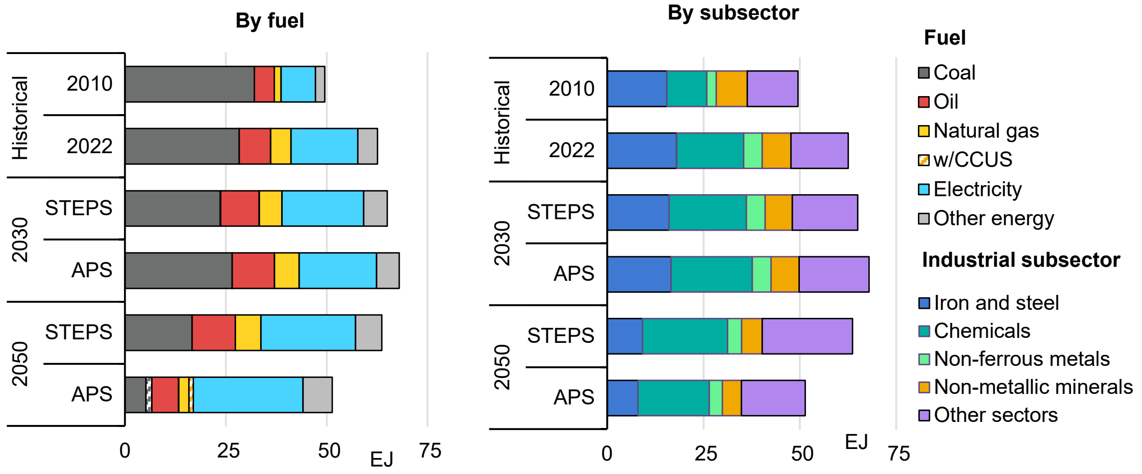
This method is applied for all sectors with the exception of non-specified industry as there is a higher level of uncertainty on the heat demand of this sector.

The sources comprise: EcoHeatCool study (2012), Taibi et al. (2010), Vannoni et al. (2008), ARENA-ITP (2019). The result is an estimate of the heat demand per industrial sub-sector and per temperature level.

The evolution of Chinese industry and impact on heat demand

In line with measures to meet the Chinese carbon neutrality target, we estimate that the emissions intensity of Chinese industries per unit of value added will decrease by 30% to 2030 and 80% to 2050 in the APS – while the country retains more than 35% of global production of steel, cement and aluminium in 2050.

Figure 1.7 Energy demand by fuel and by industrial sub-sector in China compared to the Stated Policies and Announced Pledges Scenarios, 2010-2050



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario; CCUS = Carbon Capture, Utilisation and Storage. "Other energy" includes imported heat, bioenergy, non-renewable waste, solar thermal, geothermal, and imported hydrogen. "Other sectors" include pulp and paper, light industries, and non-specified industries. Fuel used as feedstock is included.

The share of coal in industrial energy demand has shrunk by 20% since 2010 thanks to economic restructuring and policy incentives, and continues to decline, opening the way to electrification.

Under the APS, industrial energy demand in 2030 is 4% lower than in the STEPS, and this gap widens to 20% in 2050 (Figure 1.7). Multiple factors explain how this is achieved. Firstly, material efficiency is more developed in the APS. To use building materials as an example, significant savings can be made by optimising design to use fewer structural elements while achieving the same level of comfort and safety in buildings, in addition to extending the lifetimes of existing buildings through better renovation. Further savings come from solutions such as lowering the cement to concrete ratio or using alternative construction materials like timber. Combined, such measures to avoid demand account for 30% and 10%, respectively, of the cumulative difference in steel and cement emissions between the STEPS and APS over 2022-2050.

Secondly, the APS includes an acceleration in recycling of materials such as steel, plastics and paper; output from scrap-based electric furnaces doubles by 2030 in China. Given that scrap-based steel production is around one-eighth as energy intensive as iron ore-based steel production, this has an important impact on energy demand.

Changes to the composition of materials also make a difference. For instance, the clinker-to-cement ratio in China goes from 65% today to 55% in 2050 in the APS, making the demand for clinker 22% lower in the APS than in the STEPS in 2050. Given that clinker is the active material of cement, and its most energy-intensive ingredient, this also has an important impact on the total energy demand.

In addition, energy efficiency is improving as deployment of state-of-the-art technology spreads and methods of production improve, such as through thermal energy intensity improvements in cement kilns, or energy intensity improvements in aluminium smelters.

Some technological changes can also impact energy demand. One such example is hydrogen production. Today, thermal-energy hungry coal gasification and steam methane reforming are the main production routes in China. In coming years, the development of electrolysis will reduce heat demand as this technology relies on non-thermal electrical energy.

Finally, economic and social factors also have an impact. The Chinese population started to decrease in 2022, and in combination with a slowdown in urbanisation, this is leading to a decrease in the need for bulk materials like cement and steel.

Such factors affect the different industrial sectors in differing ways, with varied impacts on heat demand. In total, about 30% of cumulative emission reductions between 2023 and 2050 in the APS are thanks to energy efficiency measures.

In addition, the evolution of different industrial sectors[12] will affect heat demand. The different sectors can be divided into two categories:

- "Energy-intensive industries" comprises the five most energy-intensive industrial sectors, which together are responsible for 90% of industrial heat demand in China. These include iron and steel, chemicals, non-metallic minerals, non-ferrous metals, and pulp and paper. In these industrial sectors, fossil fuels are used in industrial processes often requiring high temperatures (above 200 °C), and there are significant waste heat resources that can be exploited to further optimise heat flows in Chinese industries.
- "Light industries" describes a range of sectors with lower specific energy use than energy-intensive industries. This includes diverse sectors handling the production of machinery (accounting for 37% of light-industry energy use in China), food (17%), textiles (17%), vehicles (9%) and timber (2%), as well as mining (10%) and construction (9%).[13] Light industries tend to have lower-temperature heat requirements than their energy-intensive counterparts, with applications often needing steam or high-temperature water.

There are additional differences between these two groups. On average, in energy-intensive industries, a larger share of energy consumption is devoted to heating applications than in light industries. Furthermore, 60% of the energy consumed by light industries is in the form of electricity and only 30% fossil fuel, while for energy-intensive industry, those ratios are 20% and 70%, respectively.

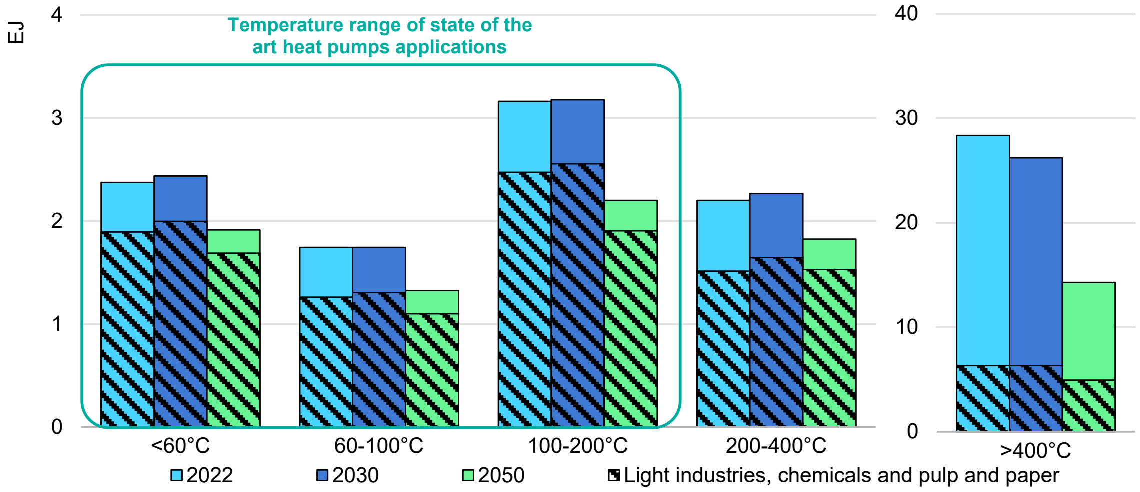
[12] All other industrial sectors, gathered under the name of 'non-specified industry', are excluded from energy-intensive and light industries.
[13] All other industrial sectors, gathered under the name of 'non-specified industry', are excluded from energy-intensive and light industries.

In both the APS and STEPS, the chemicals and light industries sectors are the industrial sectors in which the largest increase in the use of energy is expected (Figure 1.8).[14]

In the APS, the combination of activity increases and electrification make the need for low- and medium-temperature heat more and more prominent, up from 19% of demand in 2022 to 25% in 2050. In particular, chemicals and light industries represent half of heat demand in 2050 – up from one-third in 2022. These are also the sectors where 25% and 75% of the heat demand, respectively, is below 200 °C – and it is mainly in this range that heat pump technologies could be deployed (Figure 1.8).

In combination with these changes to individual sectors, there is progress in electrification in both the STEPS (+10%) and APS (+30%). Material and energy efficiency, fuel shifting, and carbon capture, utilisation and storage[15] (CCUS) help to limit emissions to 0.8 Gt by 2050 in the APS, 70% lower than in the STEPS.

Figure 1.8 Industrial heat demand by temperature level in China in the Announced Pledges Scenario, 2022, 2030 and 2050



Note: Includes iron and steel, chemicals, non-ferrous metals, non-metallic minerals, pulp and paper and light industries.

Between 2022 and 2050, in the APS, the share of low- and medium-temperature heat in overall heating demand in Chinese industries grows from one-fifth to one-quarter.

Perspectives on heat decarbonisation in light industries

Light industries have the largest potential to integrate heat pumps over the short term, due to their lower average process temperatures when compared to energy-intensive industries. In addition, light industries required about 10% of industrial

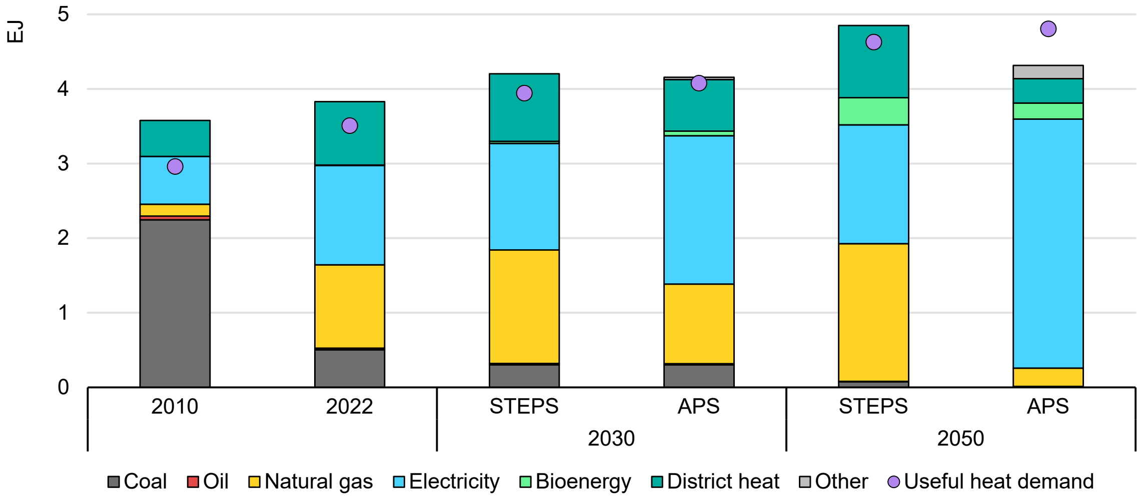
[14] Detailed explanation on how industrial activity is projected can be found in the IEA Global Energy and Climate Model documentation.
[15] 40% of direct emissions are captured in 2050 in the APS.

heat in 2022, and demand is expected to grow by 10% in the STEPS by 2030 and 30% by 2050 and, in the APS, by 15% by 2030 and 40% by 2050.

Over the past few years, coal use for heating in light industries has been dramatically reduced (Figure 1.9), mainly in favour of natural gas, in an effort to improve air quality. This trend continues in the STEPS, with natural gas representing 40% of heating needs by 2050, up from 30% in 2022. This goes hand in hand with the development of blended biomethane in the gas network, while the share of electricity remains constant.

The outlook in the APS has two major differences with STEPS. Firstly, activity is higher, as some light industry sectors are strongly mobilised for the energy transition, particularly mining, for critical minerals, and the machinery sector,[16] to produce clean technologies such as batteries, solar PV and heat pumps. As a result, the 2050 heat demand is 5% higher in the APS than in the STEPS. Secondly, electrification plays by far the most important role, supplying 80% of heat needs by 2050, with bioenergy, solar thermal, geothermal and hydrogen providing most of the rest. The deployment of heat pumps allows for a 20% decline in the energy intensity of heat supply by 2050 compared to today.

Figure 1.9 Energy for heating in Chinese light industries per fuel in the Stated Policies and Announced Pledges Scenarios, 2010-2050



Notes: Sectors covered comprise construction, food and tobacco, textile and leather, machinery, transport equipment, wood and wood products, and mining and quarrying. Bioenergy includes bioenergy, waste and blended biomethane. “Other” includes solar thermal, geothermal and imported hydrogen.

Thanks to electrification, the average energy efficiency of heat production in light industries increases by 7% to 2030 and 20% to 2050 in the APS.

[16] The machinery sector includes the manufacturing of metal products, machinery and equipment other than transport equipment. The mining and quarrying sector includes the extraction and beneficiation of ores, stone, sand and clay but excludes fossil fuel extraction.

The pulp and paper sector shares a lot of similarities with light industries: for processes such as boiling and drying, the sector required about 900 PJ of heat in 2022, three-quarters of which were under 200 °C. A notable feature of the paper sector is the important role of bioenergy, which alone satisfied about one-third of the energy requirements in 2022. Historically, coal was the main energy source of the pulp and paper sector in China, with 43% of the energy supply in 2010. However, coal use has since fallen to reach just 10% in 2022, thanks to a doubling in the share of electricity combined with a shift to natural gas. This trend continues in the APS, and coal use is almost entirely phased out by 2050 in favour of electricity and bioenergy. The pulp and paper sector therefore has significant potential for heat pump deployment (see Chapter 2).

Policy landscape for heating in China

Over the past decade, China's heating sector has been the target of policy action at the national, provincial, municipal and county level, with the aim of improving air quality and shifting to clean heat[17] solutions. Measures have also been introduced to improve energy conservation, raise building performance, increase the affordability of available heating solutions and improve understanding among consumers through energy labelling (Figure 1.10).

Since 2011, the ambition to transform the heating sector is also evident in successive Five-Year Plans, which play a leading role in China's energy development strategies. Initially, the focus was on reforming the metering system for heating in north urban China, and this then expanded to encouraging the implementation of energy savings measures, emissions reductions and the utilisation of clean energy. To promote action on energy efficiency and emissions reductions the government set targets for energy and carbon intensity per unit GDP improvements in its 14th Five-Year Plan (2021-2025) of 13.5% and 18% respectively.

In 2020, the central government announced that China would aim for carbon emissions to peak before 2030 and carbon neutrality before 2060. This has been followed by a series of sectoral blueprints, such as for the buildings sector, for which the blueprint sets targets including an electrification rate for buildings of 55% and 65% by 2025 and 2030, respectively. Carbon-peaking action plans have been issued for the industry sector, together with the promotion of energy savings and decarbonisation in key industries.

[17] In Chinese policies, "Clean" heating refers to a heating method that uses natural gas, electricity, geothermal, biomass, solar energy, industrial waste heat, clean coal (ultra-low emissions) or nuclear energy.

These measures combined contributed to driving up the uptake of heat pump technologies (see Chapter 2).

Clean heat supply

Heating policies were first introduced in 2013 to improve air quality, especially in the north of China, and since 2017 have expanded to target clean and low-carbon heating in line with national climate change strategies.

Between 2013 and 2017, several measures were introduced to promote a fuel shift in district heating from coal to gas and electricity, to establish the construction of clean coal distribution centres in rural areas, and to introduce heat metering. Since 2017, the focus of policies has expanded to encompass setting requirements for heat networks and buildings. This has included clean winter heating strategies targeted to local conditions in northern China, with the aim of improving the efficiency of district heat networks, including pilot projects in selected cities (Box 1.5). In parallel, other policies were implemented to replace coal in almost all households in the Beijing-Tianjin-Hebei provinces and surroundings areas, and the Fen-Wei Plain by 2020. Policies introduced since 2020 have encouraged the use of waste heat, heat pumps, clean biomass and other renewables sources, and CHP generation, as well as demonstrations of heating from nuclear power plants.

These policies have shown significant results. As of the end of 2018, a total of more than 13.5 million households[18] in the Beijing-Tianjin-Hebei region and surrounding areas, as well as the Fen-Wei Plain, had completed clean heating renovations. According to the mid-term assessment of winter clean heating in northern regions, at the end of 2018, the winter clean heating rate in the northern regions had reached about 51% – an increase of 12.5 percentage points compared to 2016. In 2018, the average $PM_{2.5}$ concentrations in the Beijing-Tianjin-Hebei region and surrounding regions, and the Fen-Wei Plain, were 60 micrograms per cubic metre (μg/m^3) and 58 μg/m^3, respectively, representing a nearly 12% and 11% decrease from 2017. During the same year, there were no continuous periods of heavy pollution lasting three days or more in Beijing for the first time in six years.

Since 2021, the "Plan for Carbon Peak Action by 2030" also includes heating considerations for the HSCW zone. Additional measures to accelerate the large-scale integration of industrial waste heat and renewable energy sources in urban heating systems, speed up the integration of renewables for heating in rural areas,

[18] Corresponding to a clean heat rate of 50.7% in northern China, distributed as 68.5% in northern urban area and 24% in northern rural area respectively.

phase out coal-fired boilers and upgrade CHP have been introduced in conjunction with the 14th Five-Year Plan (2021-2025).

Buildings energy codes, labelling and targets

Building efficiency standards are critical to the transition to clean heating, including with regards to heat pump integration. China has been taking action on energy efficiency since 1986, and more recently also on green buildings, ultra-low energy consumption buildings and prefabricated buildings. At the Conference of the Parties (COP) 28 in 2023, China joined the Buildings Breakthrough, pledging their commitment to “near-zero emissions and resilient buildings by 2030”.

China’s General Code for Energy Efficiency and Renewable Energy Application in Buildings (GB55015-2021) was implemented in April 2022, introducing mandatory quantitative requirements for energy efficiency and emissions in residential, non-residential and industrial buildings across all climate zones. The code covers new buildings as well as reconstruction, expansion and renovations of existing buildings, and the related energy efficiency calculations cover space heating, air conditioning, lighting, lifts, domestic hot water and share of renewable energy generation. All new buildings are required to install solar systems under this code. The requirements vary considerably across climate zones for aspects such as the thermal transmittance of walls.

China first initiated energy-saving design standards in 1986 (JGJ26-1986), initially focusing on residential buildings connected to district heat in severely cold and cold regions. These standards specify requirements for the thermal performance of various elements of the building envelope and were progressively strengthened[19] in 1995, 2010 and 2018.

Building codes were introduced later in other climate zones, without requirements for thermal performance. In the HSCW zone, energy-saving design standards specific to residential buildings (JGJ134) were issued in 2001 and revised in 2010. In the hot summer-warm winter zone, standards for energy-saving design in residential buildings (JGJ75) were issued in 2003 and revised in 2012. Non-residential public and commercial buildings (GB50189) have also been regulated since 1993, with standards updated in 2005, 2015 and 2019.

Also relevant to clean heating and heat pumps are targets for renovation. The plan for clean heating in winter in northern China (2017-2021) targeted renovation of urban buildings, energy efficiency improvements and the introduction of high-efficiency indoor heating terminals. The Three-year Action Plan for Winning the

[19] Including a progressive increase in the stringency of building codes by introducing a 50%, 65%, and 75% "energy-saving percentage" compared to the heating energy consumption of northern buildings in the early 1980s as a benchmark. In some northern regions, stretch codes were introduced ahead of national standards, such as in Beijing in 2012.

Blue Sky War (2018-2020) also encouraged renovation of rural housing. The 14th Five Year Plan for Buildings Energy Conservation and Green Building Development (2021-2025) targeted the renovation of more than 350 million m^2 of existing buildings by 2025, and the construction of more than 50 million m^2 of ultra-low energy consumption and near-zero energy consumption buildings, also including targets for the share of prefabricated new buildings.

Appliances and equipment labelling and standards

China's Minimum Energy Performance Standards (MEPS) were first initiated in the 1980s, and energy efficiency labelling programme for appliances in 2005. This currently includes household heat pump water heaters, multi-coupled air-conditioning heat pump units, water and ground-source heat pump units, and ground ambient temperature air-source heat pumps.

In January 2024, the National Development and Reform Commission (NDRC) revised the MEPS, expanding their coverage and setting higher 'Energy Saving' and 'Advanced' levels of equipment across 43 products, 8 of which are cooling products. For primary heating or heat pump water heaters with capacity below 10 kW, the revised MEPS set a minimum level for the Coefficient of Performance (COP) of 3.70 Watts/Watts (W/W), an energy-saving level of 4.40, and advanced level of 5.0. For multi-connected air-conditioning (heat pump) units, the notice sets COP value levels of 3.30 (minimum), 4.00 (energy saving) and 4.80 (advanced).[20] Updates will be released annually.

Box 1.5 Pilot demonstrations for clean heating in northern China

In May 2017, central financing was allocated to pilot work to replace dispersed coal burning with clean heating and to carry out energy-efficient retrofitting of existing buildings in northern China. Key support was provided to the "2+26" cities in the Beijing-Tianjin-Hebei region and surrounding areas. The first batch of funding for demonstration periods of three years in 12 pilot cities was determined through competitive review, assessing local factors such as the availability of clean heating sources, the feasibility of the proposed technical approach, investment and financing guarantees, pricing, local supporting policies and subsidies, regulatory measures, and so on. Direct-administered municipalities were allocated

[20] The range of levels set for multi-connected air conditioning (heat pump) units vary depending on the model. For CC≤14 000 W, the COP levels are: minimum (3.60), energy saving (4.40) and advanced (5.60), and for models 50 000 W＜CC≤68 000 W, the COP levels are: minimum (3.30), energy saving (4.00) and advanced (4.80).

USD 0.14 billion (CNY 1 billion)[21] per annum, provincial capitals USD 0.1 billion (CNY 0.7 billion), and prefecture-level cities USD 0.075 billion (CNY 0.5 billion).

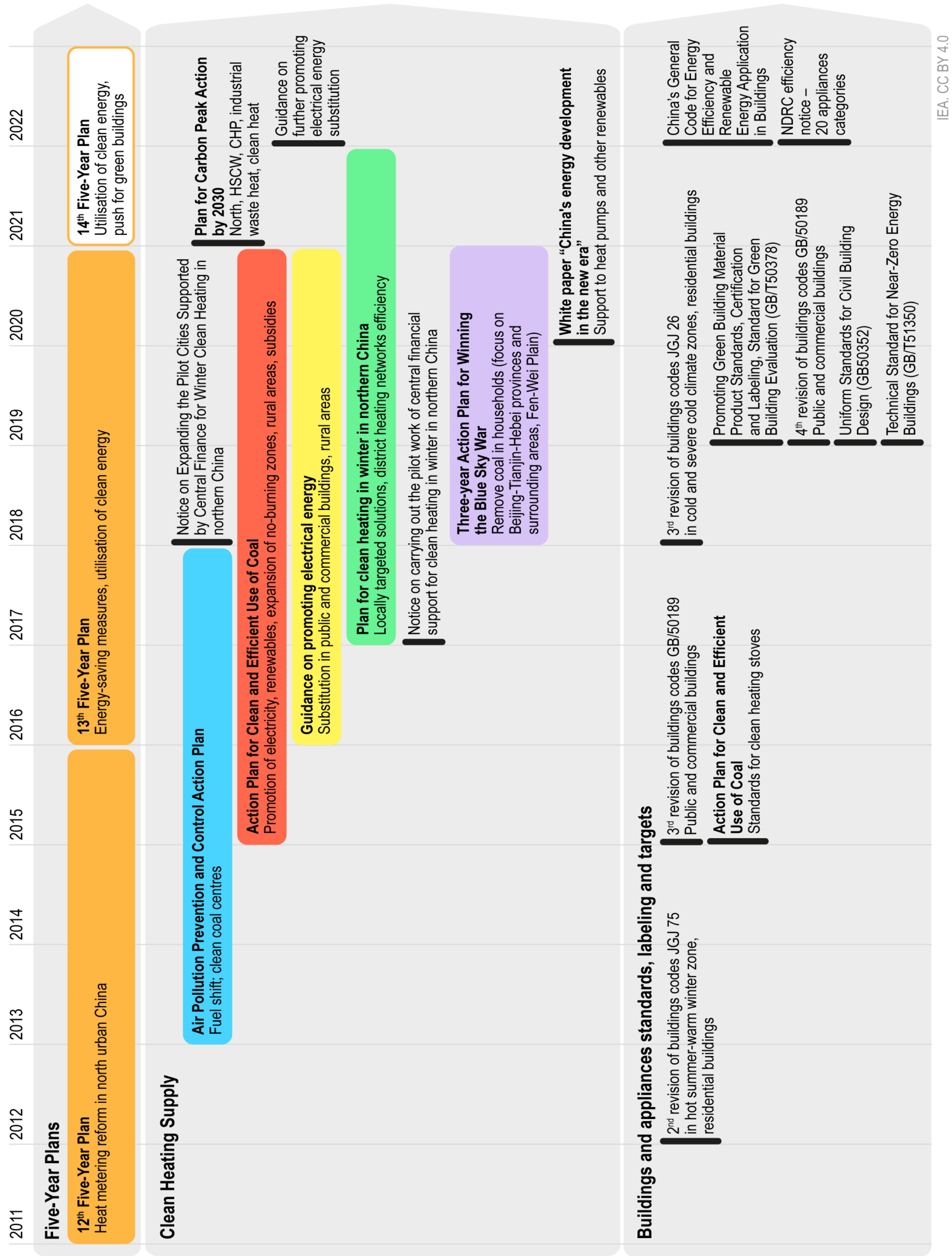
This was followed in July 2018 by a second round of funding for a batch of 23 pilot cities, with central financing for annual fixed-amount subsidies at different levels. In the years 2017-2018, the total local subsidy funds reached USD 8.2 billion (CNY 55.5 billion). The pilot cities primarily adopted "coal-to-gas" and "coal-to-electricity" technology switches as the main alternatives for clean heat sources, with only a small number of pilot projects involving other forms such as "coal-to-district heat" and "coal-to-biomass".

Other batches of pilot projects were announced in 2019, 2021 and 2022, bringing the total number of cities supported since 2017 to 88.

At the end of 2022, the clean heating area in northern China reached 17.9 billion m^2, achieving a clean heating rate of 75% and surpassing the established target of 70%.[22]

[21] Exchange rate: 1 Yuan Renminbi (CNY) = USD 0.148 (as of December 2022).
[22] Clean Heating Industry Committee (CHIC).

Figure 1.10 Policy landscape for heating in China, 2011-2023



Chapter 2. Outlook and opportunities for deploying heat pumps in China

Highlights

- Heat pump sales have increased steadily in China over the past decade, though they declined slightly in 2022. In 2023, sales of air-source heat pumps returned to growth, primarily driven by heat pumps used for space heating, with domestic hot water heat pumps remaining at 2022 levels. Air-to-air heat pumps are the dominant segment in China, accounting for about 60% of total installed capacity today.
- Heat pumps installed in Chinese buildings have a combined capacity of more than 250 GW. Capacity is set to grow to 1 400 GW by 2050 in the Announced Pledges Scenario (APS), in which national climate and energy security targets are assumed to be met.
- On the basis of both the Stated Pledges Scenario (STEPS) and APS, China is expected to remain one of the top three heat pump markets for buildings worldwide and to account for more than 25% of the global sales and installed capacity by 2050.
- In the APS, air-to-air heat pumps consolidate their market dominance by 2050 due to increased penetration in rural areas and in the hot summer-cold winter (HSCW) zone. Growth in demand for cooling in areas that have both cooling and heating needs could provide an opportunity to scale up the deployment of heat pumps in milder climates and reduce the costs of heating for consumers. The penetration of heat pump water heaters also increases in all Chinese regions, reaching more than 10% of all water heaters in the APS by 2050.
- Many high-temperature heat pumps are already commercially available in the industry sector, particularly with output temperatures below 140 °C. However, technologies up to 200 °C are at the first-of-a-kind application or pre-commercial demonstration stage.
- Heat pumps could theoretically supply up to 15% of today’s industrial heat demand, with most of the potential being in the chemicals, food and machinery sectors. Very few heat pumps are installed in Chinese industries today, but capacity is expected to reach 30 GW for the light industries sector by 2050 in the APS, covering 20% of its heating needs.
- China has abundant waste heat resources, and increased recycling of this waste heat, enabled by heat pumps, could provide heat for district heating and light industries. As much as 650 GW of heat pump capacity could be deployed by 2050 to integrate suitable waste heat from diverse activities.

Introduction

China's energy consumption for heating has undergone significant changes in recent years across the buildings and industry sectors (see Chapter 1), with a steady decline in the share of fossil fuels in final energy consumption and an increase in the share of electricity. In the **buildings sector**, heat pumps have already been responsible for the increasing electrification experienced over the past few years. The market share of heat pumps used for space heating in China increased from 4% in 2015 to 8% in 2022.

Heat pumps designed for use in buildings have achieved a relatively high technology readiness level (TRL)[23] and are widely used, not only in China, but also in other heating markets, such as the United States, Europe and Japan. Air-to-air, air-to-water and ground-source heat pumps commonly used in homes have undergone extensive development and testing, resulting in a high level of reliability and efficiency.

Larger heat pumps designed for commercial applications and larger residential buildings are equally mature technologies, but are less widespread than their smaller scale counterparts, as these systems often involve more complex designs and larger-scale installations. However, many commercial heat pumps, especially those integrated into Heating, Ventilation and Air Conditioning (HVAC) systems, have reached advanced stages of development, offering significant energy savings for larger buildings and facilities.

In the case of the **industry sector**, heat pumps are only beginning to be used in China and other countries, and today account for a negligible share of industrial heating equipment. Nevertheless, heat pumps for drying are a promising segment in China's light industries, with annual sales growth of over 25% in recent years. Similarly, in the case of **district heating networks**, which supply heat to both industry and buildings, the use of heat pumps is not widespread in China. Only a few countries worldwide, such as Sweden, have a significant share of heat pumps in their district heating mix. For some industrial processes and for district heating, commercial technologies are already available, albeit at low levels of deployment. Although technological improvement can help to overcome some barriers to deployment, no major technological revolution or breakthrough would be required for heat pumps to gain a foothold in these areas.

This chapter assesses the prospects for heat pumps in buildings and industry, focusing on the increased deployment levels expected by 2030 and 2050 following current policy trends and to achieve the carbon neutrality target. In addition, the chapter provides a special focus section on heat pumps for integrating waste heat in industry and district heating networks, as well as other possible applications of this technology within district heating networks.

[23] The IEA uses a TRL system with a scale going from an initial idea at level 1 to a proof of stability reached at level 11.

Heat pump taxonomy in this report

Heat pumps in buildings: This category includes heat pumps that deliver heat directly to households and residential or commercial buildings for space heating and/or domestic hot water provision. It includes natural source heat pumps, including reversible air conditioners used as primary heating equipment. It excludes reversible air conditioners used only for cooling, or used as a complement to other heating equipment, such as a boiler.

Typical size	Equipment (electric-based heat pumps based on vapour compression)	Applicability
< 10 kW	- Air-to-water heat pumps, including heat pump water heaters. - Air-to-air heat pumps, including reversible air conditioners used as a primary heating source. - Ground-source and water-source heat pumps.	Individual households, small residential and commercial buildings, individual rooms.
10-50 kW	- Air-to-water heat pumps, including heat pump water heaters. - Air-to-air heat pumps. - Ground-source and water-source heat pumps.	Individual households, multi-family buildings and services buildings.
> 50 kW	- Large-scale air-to-water heat pumps, including heat pump water heaters. - Large-scale air-to-air heat pumps. - Ground-source and water-source heat pumps.	Multi-family buildings and services buildings.

Heat pumps in district heating networks: This category includes heat pumps connected to district heat networks, including those in heat substations.

Typical size	Temperature range	Equipment	Applicability
> 100 kW	70 - 120 °C (primary) 40 - 60 °C (secondary)	- Large-scale heat pumps, particularly to integrate waste heat. - Absorption heat pumps.	Temperature lift in the primary and secondary network. Reduction of return temperature in the primary network.

Heat pumps in industry: This category includes heat pumps that deliver heat directly to an industrial process. It includes heat pumps with a temperature range of up to 200 °C, and excludes mechanical vapour recompression.

Temperature range	Equipment	Applicability
< 100 °C	Large-scale heat pumps, particularly to integrate waste heat.	Industrial processes such as pasteurisation, boiling or bio-reactions.
100 - 200 °C	Large-scale heat pumps, particularly to integrate waste heat.	Industrial processes such as drying, distillation or steam production.

Box 2.1 Considerations for heat pump choice

Considerations for choosing the correct type of heat pump based on the application include the surrounding climate and built environment, as well as the output temperature required and distribution systems within the building. For instance, very cold environments are more challenging for **air-source heat pumps**, for which the coefficient of performance (COP) decreases under low temperatures (see Figure 2.4) and extreme drops in temperature can trigger automatic compressor shutdown or cause frosting issues. Nevertheless, innovation has led to heat pumps that operate in cold climates, with continuously improving performances. In addition, large air-source heat pumps located in dense urban areas can contribute to an air-cooled island effect during winter that can impact the efficiency of close-by units, so attention to the placement of the outdoor units is important (see Box 3.3).

In the case of **air-to-air reversible units** (to provide both heating and cooling), consideration needs to be given to whether to optimise the system performance for the heating or for the cooling mode. Specific components, such as the compressor, can be designed and sized to optimise efficiency during summer conditions in areas where the cooling load is expected to be higher. In split systems of this kind, the location of the indoor unit is an important criterion to determine the comfort level in different seasons: if the indoor unit is optimally placed for cooling, it may distribute hot air less effectively during the heating season, and vice versa.

Ground source heat pumps generally have a higher seasonal performance factor than air-source heat pumps. Some ground source heat pumps require a significant amount of space underground, with pipes that can be buried at a depth of as much as 120 metres. An installation of this size will need to take into account the development of underground space for other uses in dense urban areas (see Box 2.4).

In the case of **industrial heat pumps**, in addition to requirements based on the output temperature needed in the industrial process or the availability of waste heat at sufficient temperature, installing a heat pump may require the upgrading or replacement of the transformers and the electrical connection of the facility, resulting in additional costs. The availability of space, which may be limited in small industries, and of waste heat at certain temperature levels could also compromise the installation of an industrial heat pump.

Outlook for heat pumps in buildings

Heat pumps connected directly to residential and commercial buildings consume three to five times less energy compared to fossil fuel boilers or electric heaters, and today, shifting from fossil fuel boilers to heat pumps would reduce CO_2 emissions virtually everywhere they are installed.

In rural areas of China, heat pumps are gaining momentum with policies to support a coal-to-electricity shift (see Chapter 1). In regions with hot summers and cold winters, heat pumps are already the norm in the majority of households, used as the main heating system in winter, but also for cooling in summer.

Heat pumps directly used in buildings are less prominent in urban areas of northern China, where most of the existing floor space is already connected to district heating systems. However, heat pumps may be an attractive option for new buildings not connected to district heating systems, or for providing domestic hot water to residential or commercial buildings.

Global market trends

Global sales of heat pumps for buildings[24] grew by 11% in 2022, marking a second year of double-digit growth. The increased uptake of heat pumps globally was mostly driven by Europe and the United States, where heating equipment running on fossil fuels is still dominant. Fuelled by Russia's war on Ukraine and soaring natural gas prices, sales in Europe have nearly doubled since 2020, with growth rates of over 35% in 2021 and 2022, to reach 3 million units sold in 2022. Heat pumps are also gaining traction in the United States, with sales growing more than 10% in both 2021 and 2022. In China, even though heat pump sales have increased steadily over the last decade, 2022 saw a marginal decrease, with sales in both air-to-air and air-to-water segments remaining almost equal to 2021 levels. Despite rising sales in recent years, heat pumps met only around 10% of global heating needs in buildings in 2022.

While 2022 saw positive momentum around heat pumps globally, data on 2023 indicates negative market trends, with global sales decreasing by 3%, driven by lower natural gas prices, a slowdown of the construction sector and uncertainties around heat pump policy and support schemes. In the European Union, sales fell by 5%, with considerable downturns in markets such as Italy, Finland and Poland. In the United States, even though sales of heat pumps were down around 15% by the end of 2023, they are still performing better than their fossil fuel counterparts, as gas furnace sales are down by over 20% compared to 2022 levels. In Canada,

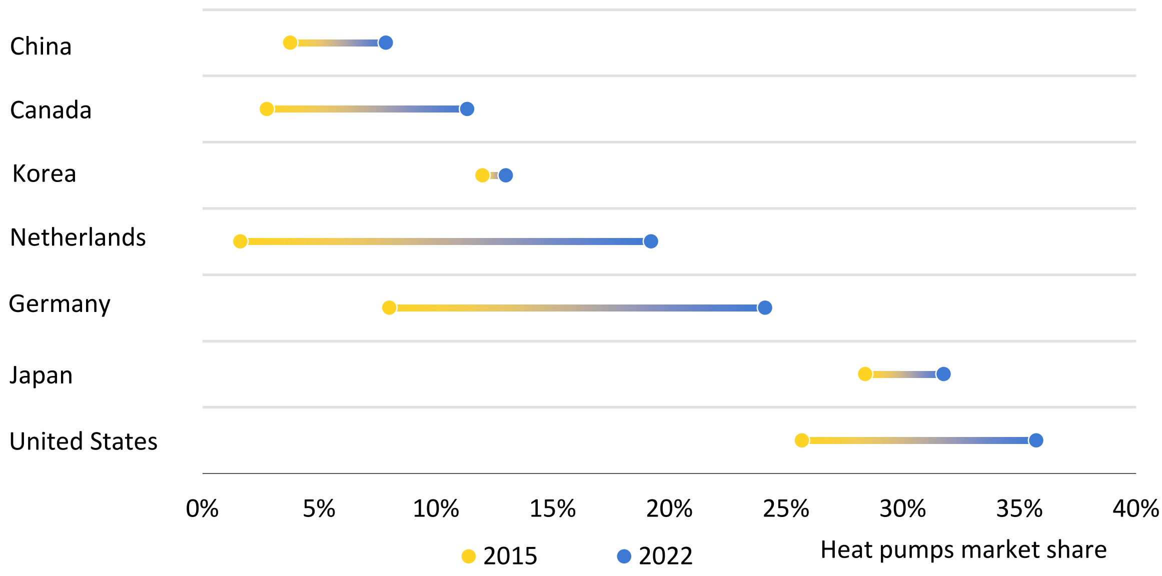
[24] "Heat pumps in buildings" refers to technologies used at building level, excluding heat pumps used in district heating networks to supply heat to buildings. For more information, see the section "Heat pump taxonomy in this report".

residential air conditioning units (including heat pumps up to 5 tonnes) were down by around 50%. In Japan, heat pump water heaters sales were 10% down by December 2023, after having experienced 7 consecutive years of positive market growth (8% year-on-year on average), which neared 20% in 2022.

In China, after the slowdown in 2022, sales of air-source heat pumps expanded again in 2023, primarily driven by air-source heat pumps used for space heating, which experienced growth of over 15% year-on-year. In contrast, domestic hot water heat pumps remained at the same level as 2022.

Even considering these recent global market trends, it is clear that the penetration of heat pumps has increased considerably during the last decade, displacing fossil fuel boilers in multiple markets (Figure 2.1). For example, in Canada the market share of heat pumps for residential space heating increased from 3% in 2015 to 11% in 2022. In the United States, the share increased from 26% to 36% over the same period. In Germany the increase was from 8% to 24% and in the Netherlands from 2% to 19%. In the case of China, the market more than doubled over the same period, rising from under 4% to over 8%.

Figure 2.1 Share of heat pumps in space heating equipment sales in selected heating markets, 2015-2022



Note: Heat pumps market share represents the share of heat pump sales over total sales of heating equipment.
Sources: IEA analysis based on ChinaIOL; EHPA (2023); AHRI (2023); Residential Energy Consumption Survey (2023); Canada National Statistical Office (2023); JRAIA; Bundesverband Wärmepumpe (2023).

The market share of heat pumps for space heating is increasing in all major heating markets, but maintaining these trends will require addressing barriers to scale-up.

Overview and outlook for China

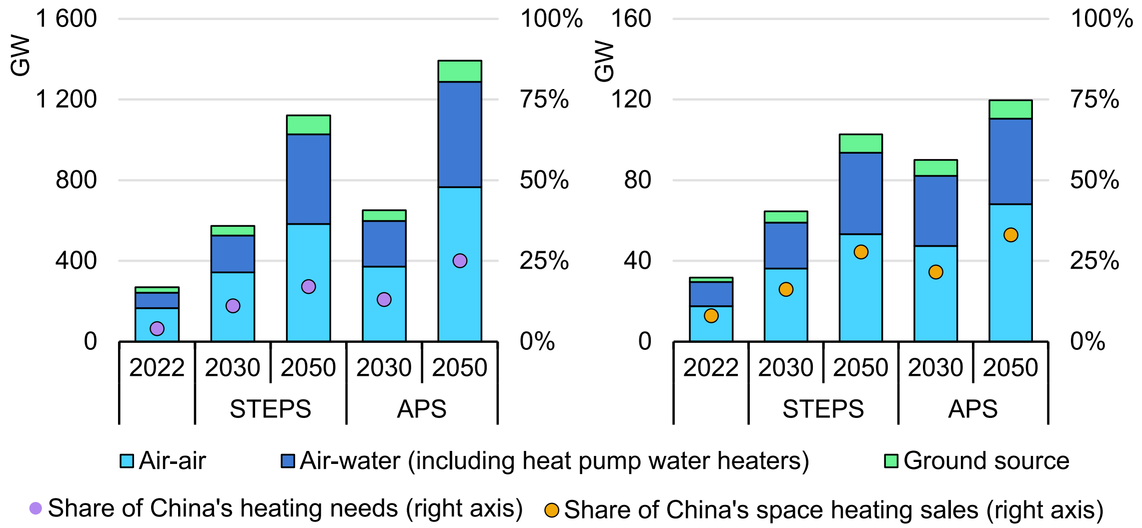
Globally, heat pumps in residential and non-residential buildings account for more than 1 000 GW of capacity[25] today – 10% of total heat capacity in buildings. China accounted for around 25% of total installed heat pump capacity and around 30% of total sales worldwide by the end of 2022, making the country the largest global market today. At present, nearly 30% of the installed capacity in China is in air-to-water units, which are most common in northern China and account for about 80 GW (Figure 2.2). Air-to-air units are predominantly installed in the HSCW zone (for heating and cooling purposes), where they are used on a part-time and part-space basis (see Chapter 1). The stock of air-to-air units in China reached around 165 GW by the end of 2022, representing more than 60% of the national installed capacity. Ground-source units are more widespread in urban areas and represent around 10% of the national heat pump stock.

Heat pumps are more widespread in residential buildings but are also gaining importance in commercial and public buildings, primarily driven by building codes and regional clean heat policies (see Chapter 1). For example, in Beijing, independent gas boilers for space heating are banned in new public buildings, and the installation of heat pumps or hybrid systems (with at least 60% of energy covered by renewable energy) is required to comply with current regulations.

Current policies favouring clean heat solutions are contributing to drive up demand for heat pumps in new buildings, as well as for heat pumps to replace existing distributed boilers. Equipment penetration is also growing fast in central and southern China, which has heating and cooling needs – both of which can be fulfilled by heat pumps. In the STEPS, which reflects the impact of current policies, such as coal-to-electricity policies in northern China, the stock of heat pumps in buildings in China doubles, reaching 575 GW by 2030, and surpasses 1 100 GW by 2050. Sales reach 100 GW annually by the same year, a 5% year-on-year increase on average since 2022. In the APS, the scenario compatible with the carbon neutrality target, additional policy support drives up the sales of heat pumps to around 120 GW per year by 2050, with a total installed capacity in buildings of almost 1 400 GW, up from 650 GW by 2030. In both scenarios, China consolidates its position as one of the leading heat pump markets, alongside the European Union and the United States, and accounts for more than 25% of global sales and installed capacity by 2050.

[25] Heat pumps are measured by their wattage of output capacity to facilitate cross-comparison across regions. The average capacity of the heat pump stock varies greatly across regions. Regions such as North America and Europe have larger heat pumps (5 kW to 10 kW) on average, while heat pumps in Asia are often smaller (3 kW to 5 kW). Based on this, a global average equivalent for heat pump capacity for single dwellings or rooms could be considered around 5 kW. Sizing also depends on the building stock and the climate. Centralised units in multifamily buildings have capacities of more than 20 kW, and those in large commercial buildings can have capacities beyond 100 kW.

Figure 2.2 Heat pump stock (left) and sales (right) in buildings in China in the Stated Policies and Announced Pledges Scenarios, 2022-2050



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Heating needs refer to useful energy.

Heat pump sales increase considerably by 2030 and 2050 in the APS and the STEPS, consolidating China’s position as one of the three largest heat pump markets in terms of sales and stock.

Share of heating needs covered by heat pumps

The expansion in heat pump deployment makes them one of the key technologies for providing space and water heating in both the STEPS and APS, together with district heating and other renewables-based technologies. By 2050, the share of heating needs covered by heat pumps exceeds 15% in the STEPS, while reaching 25% in the APS – up from around 4% in 2022. The share of heating needs covered is slightly higher if we consider space heating alone, and reaches as much as 30% in the APS scenario.

In both scenarios, decentralised heat pumps and district heating are the solutions covering the largest share of heating needs. In the APS, heat pumps, district heat, geothermal, solar thermal and biomass cover more than 70% of total heating needs by 2050, contributing to a large reduction of direct emissions. In combination with the decarbonisation of the power grid and district heating networks, decentralised heat pumps pave the way for meeting the target of carbon neutrality before 2060.

Type of equipment by climate zone

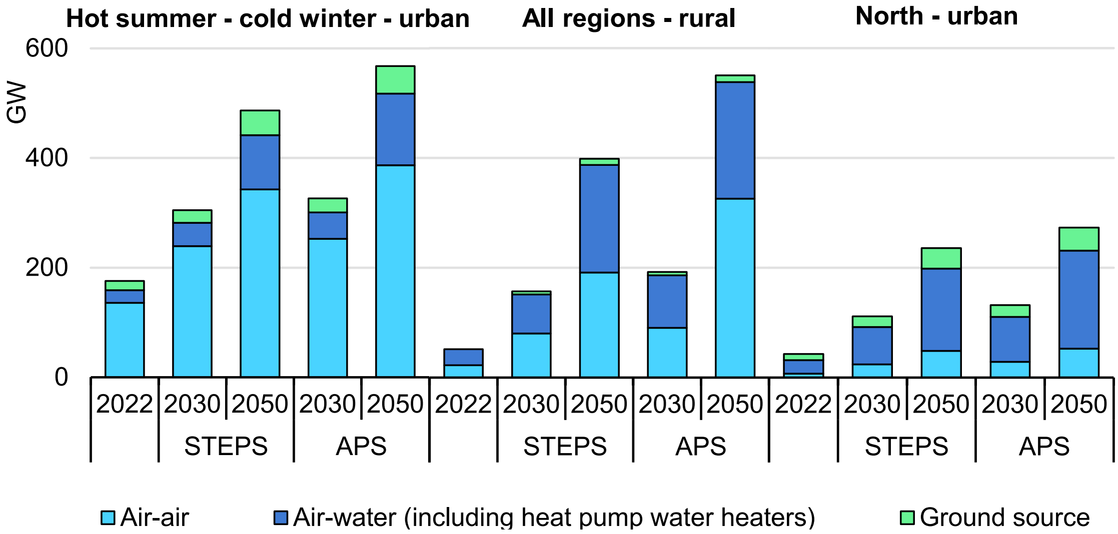
Air-to-air units are expected to remain the dominant heat pump segment through 2050, reaching around 600 GW in the STEPS and over 750 GW in the APS by 2050. The largest increase is expected in the HSCW climate zone, where air-to-air heat pumps typically provide heating in winter and cooling in summer (Figure 2.3), and in rural areas across all climate zones, driven by clean heat policies (see Chapter 1). Air-to-water heat pumps also witness an important ramp-up, primarily due to their growing penetration in rural areas of northern China, and due to the increasing uptake of heat pumps for domestic hot water across all regions. The penetration of air-to-water heat pumps also grows modestly in northern urban China, mainly in new buildings, as most of the existing floorspace remains connected to district heating networks by 2030 and 2050. In the STEPS, the stock of air-to-water heat pumps reaches 450 GW by 2050, almost 40% of the total installed capacity. The trend is similar in the APS, where air-to-water heat pumps surpass 500 GW by 2050.

Ground-source heat pumps, mainly deployed in urban areas, make up the remaining 10% of the stock in both the STEPS and in the APS by 2050. Overall, units relying on hydronic distribution systems, i.e. through water pipes within buildings, and connected to radiators, fan coils or underfloor heating, represent around 45% of installed heat pump stock by 2050 in both scenarios.

Even though most of the installed capacity of heat pumps in the STEPS and APS is primarily used to provide space heating, there is also a considerable deployment of decentralised units to exclusively cover water heating needs (see Box 2.2).

Heat pumps play an important role in both urban and rural areas in each scenario. In both the STEPS and the APS, around 35% of the installed heat pump capacity by 2050 is located in rural areas. The remaining units are installed in urban areas, with air-to-water units being particularly common in the north, and air-to-air units in the HSCW.

Figure 2.3 Heat pump stock in buildings in China in the Stated Policies Scenario and Announced Pledges Scenario by climate zone, 2022-2050



The installed capacity of heat pumps in China increases in all climate zones in the STEPS and APS.

Box 2.2 The role of heat pump water heaters

Most of the heat pumps installed today worldwide are primarily used for space heating, but heat pumps used for domestic water heating are gaining momentum, especially in Japan, the European Union and China. In Japan, close to 700 000 heat pump water heaters were sold during 2022 – **12% of total water heater sales** – and cumulative sales over the past two decades add up to almost 9 million units. In the European Union, sales of heat pump water heaters have expanded in the past few years, reaching more than 300 000 sales in 2022 – **10% of total heat pumps sold**. In China, the largest market for heat pump water heaters, sales more than doubled between 2014 and 2021, but have since remained largely stable at more than **1 000 000 units sold per year**.

In contrast to space heating, hot water is needed by households outside of major heating zones, and demand is not heavily affected by climate. However, the suitability of different water heating technologies depends on factors such as the availability of space for both the unit and the tank, dwelling type, existing infrastructure and energy prices. For example, in Japan, around one-quarter of detached houses use heat pump water heaters, whereas in apartments, where space is more limited, the share is **around 3%.**

Characteristics of different types of water heaters

	Heat pump water heater	Electric water heater	Gas water heater	Solar water heater
Upfront cost	USD 890-1150, (CNY 5990-7700)	USD 150-310, (CNY 1010-2080)	USD 260-500, (CNY 1720-3400)	USD 450-890, (CNY 3000-6000)
Operational cost	Low	High	Medium	Low
Seasonal performance	High (> 2)	Low (> 0.9)	Low (> 0.8)	Medium (1)
Indoor tank	✓	✓/✗	✓/✗	✓
Installation complexity	High	Low	Medium	High
Average lifetime	15 years	12 years	15 years	20 years

Notes: Most residential water heaters are sold online (through e-commerce platforms like Jingdong, Taobao, Pinduoduo, etc.), and offline sales (through physical appliance stores, department, direct-sale stores, etc.) are decreasing. The upfront cost of an electric water heater is for heaters with a water tank for storage type.

Compared to gas boilers and traditional electric water heaters, heat pump water heaters in China have advantages such as higher energy efficiency, lower operational cost and lower operational CO_2 emissions. However, there are barriers to adoption, such as the higher upfront cost and more complex installation process, not only with regards to the installation of pipes, which in multi-dwelling residences requires permission from the owner or management union, but also for charging the refrigerant, which requires qualified installers. Space requirements for the outdoor unit are an important constraint in dense urban areas with limited space.

Heat pump water heaters are gaining importance alongside PV systems in new buildings. For example, Zhejiang province has announced a policy to increase the promotion of renewable energy (including heat pumps), aiming for 100 million m^2 of building application area for solar and air-source heat pump water heaters during the 14th Five-Year Plan (FYP14) period, which could create a market for 500 000 heat pump water heaters.

A particularity of the Chinese market is that space heating and water heating have traditionally belonged to completely different market segments, with heat pump equipment typically supplying either space heating or water heating, but not both. In other regions, such as central Europe, heat pumps often meet both space and water heating needs. There is an opportunity to increase the penetration of heat pumps with this dual function in Chinese areas not connected to district heating, though not in areas with district heating, given the improbability of running networks for water heating during the summer.

In spite of their rapid development, heat pump water heaters cover a minor proportion of hot water needs in China today, with around 40 GW of installed capacity across different regions. In the STEPS, there is a modest expansion of capacity by 2050, reaching nearly 200 GW and covering 8% of domestic hot water needs. However, further deployment will be needed in order to meet milestones consistent with reaching the carbon neutrality target before 2060, as highlighted in the APS, where deployment surpasses 250 GW by 2050, meeting 12% of water heating needs.

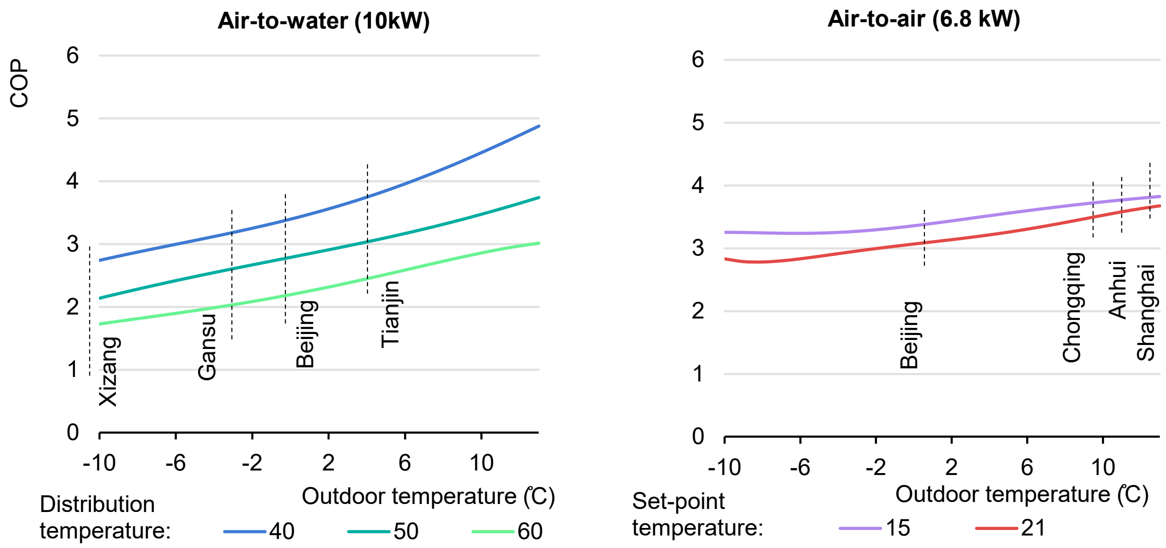
Higher efficiency enabled by improved buildings energy performance

In the APS, stringent buildings energy codes and ambitious retrofit rates, together with clean heat policies, result in a 35% drop in average space heating intensity by 2050 compared to 2022, 30% lower than in the STEPS (see Chapter 1). The improved building performance (including better insulation and air tightness) envisaged in the APS mean that the average heat pump capacity and utilisation rate required to cover the heating needs of a household are smaller than in the STEPS scenario. In addition to reducing energy bills, improved buildings performance also helps reduce the impact of increased electrification on the power grid (see Chapter 3).

Furthermore, increased building performance also enables lower heat distribution temperatures, thereby allowing heat pumps to operate with a higher COP. The COP of a heat pump is directly affected by the required temperature lift, i.e. the difference between the input and output temperatures. This is influenced by weather conditions, as with lower temperatures the temperature lift required increases, and by building performance, as poorly insulated buildings require a higher output temperature, and therefore a greater temperature lift.

Heat pumps that operate efficiently even in cold climates are already on the market in China. For instance, in Xizang province, with temperatures reaching an average of -10 °C during the heating season, the COP of air-to-water heat pumps ranges between 1.5 and 3, with higher values reached when the distribution temperature of water within the building is lower (Figure 2.4). This is considerably higher than the efficiency of a conventional gas boiler or an electric heater. In cities in cold climate zones in the north urban area, such as Beijing or Tianjin, with average temperatures of around 1-6 °C during winter, the COP of an air-to-water heat pump ranges between 2 and 4. In cities within the HSCW zone, where air-to-air systems are prevalent, and where temperatures during winter are milder, the COP of a heat pump is typically above 3.

Figure 2.4 Coefficient of performance of air-to-air and air-to-water heat pumps based on different outdoor and indoor temperatures, 2022



Notes: COP = Coefficient of performance. Average temperatures over the heating season are derived from the IEA Weather for Energy Tracker.

The COP of heat pumps may vary from less than 2 to more than 4 across China depending on factors including location and buildings performance, with implications for technology choice.

Outlook for heat pumps in industry

The use of electricity to provide heat in industry is already widespread worldwide (see Chapter 1), though heat pumps are only just starting to be used. Numerous electric heating technologies currently exist in addition to heat pumps, including resistances, dielectric and infrared electric heaters, induction and electric-arc furnaces. Each has its own range of operational temperatures and application. For example, induction and electric-arc furnaces can be used for melting metal, while dielectric and infrared can be used for high-temperature drying. Heat pumps are used in various industrial processes, such as the production of hot water for distillation or boiling, the production of steam for heating or sterilisation, or the production of hot air for drying. Industrial heat pumps can also work in synergy with district heating systems by raising the temperature when taking energy from the network, as well as when supplying networks with industrial waste heat.

Global market trends

Today, industrial heat pumps represent a small fraction of the global installed heating equipment stock in industry, which is dominated by fossil fuel boilers and other electric heating alternatives, primarily due to their ability to reach higher temperatures. Additionally, in multiple markets, the taxes and levies on electricity are considerably higher than those on natural gas, to the detriment of the competitiveness of electric heating options throughout their lifecycles (see Chapter 3). However, heat pumps are gaining momentum in specific markets, such as Europe, where industrial heat pump sales are growing rapidly, surpassing 2 500 units during 2022 (up from 600 in 2016), or Japan, where there were more than 6 000 systems installed by 2020. In China, even though industrial heat pumps are only just emerging, early examples exist, particularly in light industries. These include the Hongjitang brewery, which produces steam at 120 °C using a 216 kW heat pump (see Box 4.10), and the grain dryer built by the Chinese Academy of Science using a 650 kW heat pump to provide hot air at 70 °C.

Technology considerations

Many heat pumps for the industry sector, including high-temperature heat pumps (HTHP),[26] have already reached the level of market uptake (Table 2.1). In particular, heat pumps with output temperatures up to 140 °C have already been implemented in multiple commercial applications. In contrast, heat pump applications beyond 140 °C are scarce, with only a small number of specific commercial applications being deployed in small-scale systems where high-temperature waste heat is available, and therefore the temperature lifts required

[26] High-temperature heat pumps are defined in this report as heat pumps able to provide heat at temperatures above 100° C.

are low. Only a few early-stage prototypes exist for temperatures beyond 200 °C, all of which are far from being ready for the mass market.

Compared with conventional electric heaters or fossil fuel boilers, heat pumps today operate in a much narrower temperature range, but where they do, they have a much greater efficiency. While conventional electric heater technologies achieve efficiencies typically between 80% and 98%, heat pumps have a COP usually between 2 and 5, but some can have a COP as high as 10.

Importantly, most industrial heat pumps, unlike those in the buildings sector, cannot use ambient air as their heat source but must instead rely on waste heat at a sufficient temperature. Current models are most efficient at temperature lifts of between 20 °C and 50 °C, even if some units are capable of temperature lifts of up to 200 °C, albeit at the cost of efficiency (see Box 2.3). As such, in order to achieve high output temperatures compatible with processes in the paper and food industries, for example, the source must have a sufficiently high temperature. Industrial waste heat is often a good source in such cases.

Heat pumps typically operate in a closed cycle, where a working fluid is compressed and expanded to change its temperature, but mechanical vapour recompression (MVR) devices, which operate in an open cycle, also exist. These are sometimes called open-cycle steam heat pumps. In an MVR, the waste steam itself is compressed to raise its temperature. Heat pumps and MVR devices have similarities but are sufficiently different to be considered as two distinct technologies. For temperatures above 160 °C, MVRs have higher TRLs compared to heat pumps.

Table 2.1 Technology readiness level of industrial heat pump per temperature level

	Temperature range	Technology readiness level (TRL)	Example process	Example model
State-of-the-art heat pump technologies	< 80 °C	● TRL 11: Proof of market stability	**Paper**: De-inking **Food**: Concentration **Chemical**: Bio-reactions	Carrier Siemens H. Stars
	80 °C to 100 °C	● TRL 10: Commercial and competitive, but large-scale deployment not yet achieved	**Paper**: Bleaching **Food**: Pasteurisation **Chemical**: Boiling	Siemens

	Temperature range	Technology readiness level (TRL)	Example process	Example model
	100 °C to 140 °C	● TRL 8-9: First-of-a-kind commercial applications in relevant environment	**Paper**: Drying **Food**: Evaporation **Chemical**: Concentration	Eco Sirocco Skala Fabrikk AGO Johnson Controls
	140 °C to 160 °C	● TRL 6-7: Pre-commercial demonstration	**Paper**: Pulp boiling **Food**: Drying **Chemical**: Distillation **Various industries**: Steam production	EPCON
	160 °C to 200 °C	● TRL 6: Full prototype for heat pumps	**Various industries**: High-temperature steam production	HoegTemp Kobelco
Early prototype and concept	200 °C to 400 °C	● TRL 4: Early prototype for heat pumps	**Various industries**: High-temperature processes	Spilling Technologies
	> 400 °C	●TRL 1-3: Concept needs validation	**Various industries**: Very high-temperature processes	Gupta et al. Pimm et al.

Readiness level: ● TRL 1 to 5 ● TRL 6 to 7 ● TRL 8 to 11

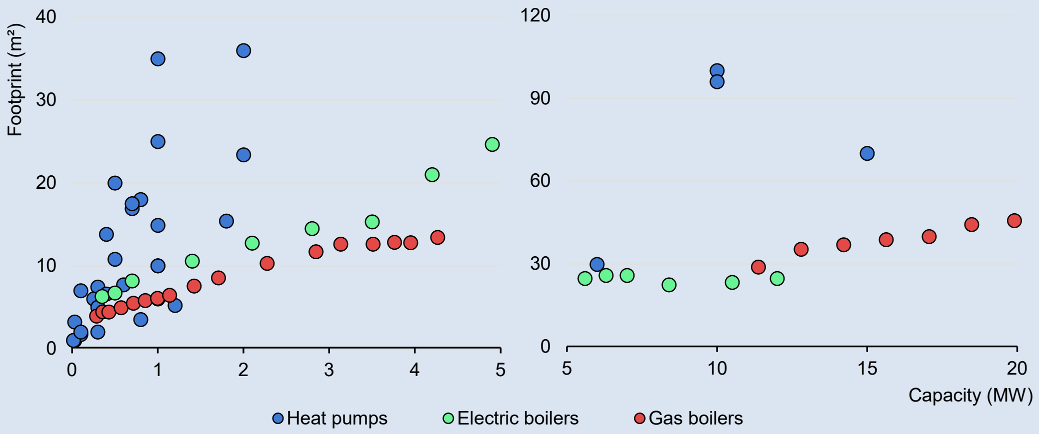
Note: TRL = Technology Readiness Level.

Sources : Maruf et al. (2021) Classification, potential role, and modeling of power-to-heat and thermal energy storage in energy systems: A review; IEA (2022) The Future of Heat Pumps.

Box 2.3 Technical specifications of industrial heat pumps

The size of the heat pump also determines the space needed to install the equipment, with more space required than for alternative heating technologies. Using already-existing units as a reference, a 1 MW heat pump requires on average 17 m² and weighs 10 tonnes, compared to just 6 m² and 5 t for a gas steam boiler with a similar capacity. This difference in size could be a challenge for the integration of heat pumps in industrial facilities where space is at a premium, or in retrofitting existing industrial facilities.

Size and capacity of various heat pumps, gas and electric boilers



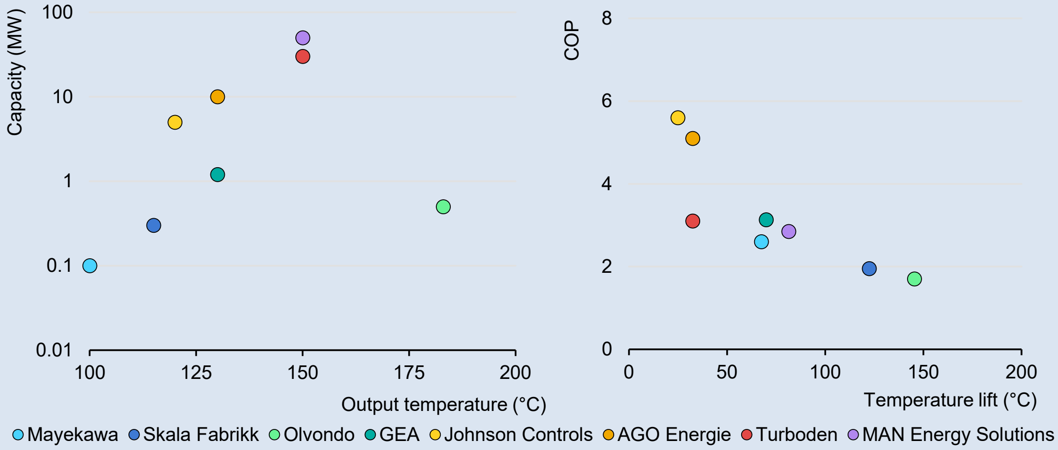
Notes: The footprint and capacity of 30 heat pumps listed by Annex 58 are used. For gas boilers, the Borderer and Thermax Twin Furnace steam boilers from Cochran are used as a reference. For electric boilers, e-Pack boilers from Babcock Wanson are used as reference.

Sources: IEA HPT TCP Annex 58 (2023) High -Temperature Heat Pumps; Cochran (2013) Industrial Specifications; Babcock Wanson (n.d.) e-Pack.

Existing high-temperature heat pumps can reach capacities of up to 70 MW (see figure below). However, a large part of today's heating need in industry is met by conventional boilers with higher capacity outputs. For example, in the United States, more than 70% of industrial boilers are in the 1 to 10 MW range, but they represent less than 25% of the installed capacity. On the other hand, those larger than 100 MW represent only 3% of units but almost 40% of the capacity. For example, in the paper sector about half of current heat demand could theoretically be supplied by heat pumps, but it is also the sector where the average boiler size is the largest, at 48 MW, compared to 13 MW for industry in general, and 70% of the boiler capacity is larger than 100 MW. In order for heat pumps to be deployed in more industrial sectors, large units able to compete in capacity with gas and electric boilers need to become widely available.

When switching to a heat pump, careful planning and design are required to take all these specificities into account. Today, limited awareness of the benefits of heat pumps and how to select the most efficient options is limiting their development in industry.

Capacity and Coefficient of Performance compared to temperature output and lift for various heat pumps



Notes: COP = Coefficient of Performance. The temperature lift is defined as the delta between the average temperature of the sink and of the source. Each colour represents one of eight selected high-temperature heat pump models from different manufacturers. For each heat pump, the working configuration providing the higher-temperature output and the maximum capacity are shown.

Source: Adapted from IEA HPT TCP (2023) Annex 58.

The potential for heat pumps in Chinese industries

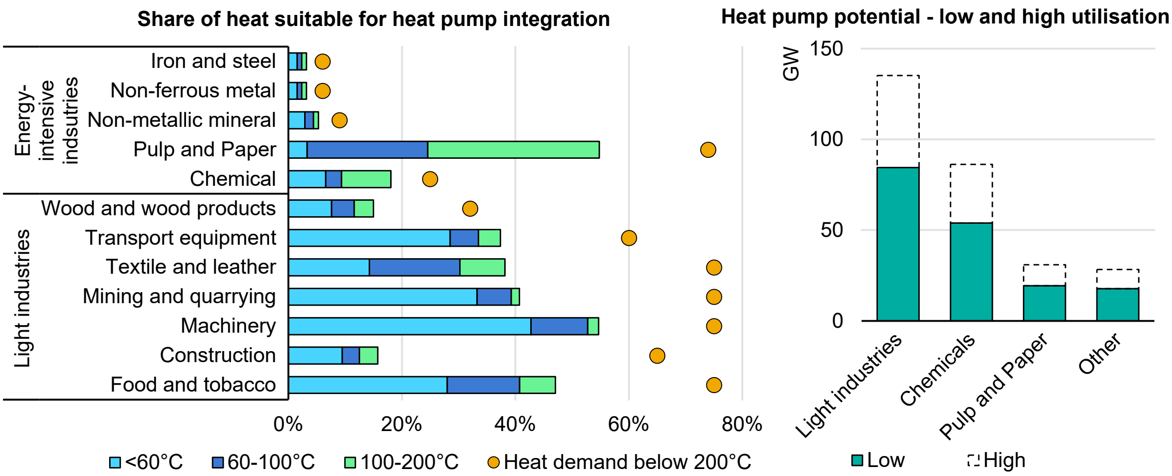
Given the significant demand for heat below 200 °C (see Chapter 1) and plentiful waste heat sources, about 15% of today's industrial heat demand could theoretically be met by heat pumps (Figure 2.5). This would entail having between 175 and 280 GW of heat pumps in operation, assuming a technology utilisation rate[27] of 50-80% at today's production levels. The theoretical share of heat demand is lower than that estimated for the European Union, where heat pumps could potentially reach 37% of the heating needs. This difference is mainly due to the larger share of high-temperature process industries in China today. However, as outlined in Chapter 1, the share of lower temperatures in process heat in China is expected to increase in the coming decades.

Light industries have the largest potential to integrate heat pumps, due to the lower average process temperatures compared to energy-intensive industries. On average, 45% of the heat demand of light industries would be suitable for heat pumps, with shares rising to around 50% in machinery, food and tobacco sub-sectors. Supplying all this heat demand with heat pumps would entail the deployment of 85-135 GW today.

[27] The utilisation rate is the percentage of total time the equipment is running.

Two energy-intensive sectors have a particularly high potential for heat pump deployment. The first is the pulp and paper sector, where around 55% of the heat demand today in China could technically be supplied by industrial heat pumps, which would equate to 20-30 GW of heat pump capacity being deployed based on 2022 energy demand. The second energy-intensive sector with considerable potential for heat pumps is the chemical sector, in which around 18% of current heating demand could be provided by heat pumps. This would entail an installed heat pump capacity of 55-85 GW, again assuming a utilisation rate of 50-80%.

Figure 2.5 Share of heat demand that could be covered by industrial heat pumps per temperature level and range of heat pump deployment potential in selected industrial sectors in China, 2022



Notes: Temperature ranges show the share of heat that could be delivered by heat pumps considering the constraints imposed by the need for suitable waste heat. For Food and tobacco, Chemical and Pulp and Paper, the same assumptions as in the article by Marina et al. are used. For other sectors, we assume a deployment potential of 95% of temperatures below 60 °C, 50% between 60 °C and 100 °C, 30% between 100 °C and 150 °C, 3% between 150 °C and 200 °C and no deployment potential above 200 °C. The low and high ranges of capacity use a utilisation rate of 80% and 50%, respectively. These deployment potentials are calculated for the current industrial landscape.

Sources: IEA analysis based on Marina et al. (2021) An estimation of the European industrial heat pump market potential; Taibi et al. (2010) Renewable Energy in Industrial Applications – An assessment of the 2050 potential; ITP Thermal (2019) Renewable energy options for industrial process heat; Madeddu et al. (2020) The CO_2 reduction potential for the European industry via direct electrification of heat supply (power-to-heat); CHPA (2023) 工业热泵发展白皮书 (2023) [Industrial heat pump development white paper 2023].

Heat pumps could theoretically supply up to 15% of today's industrial heat demand, with most of the potential in absolute value being in the chemical, food and machinery sectors.

Overview and outlook for heat pumps in Chinese light industries

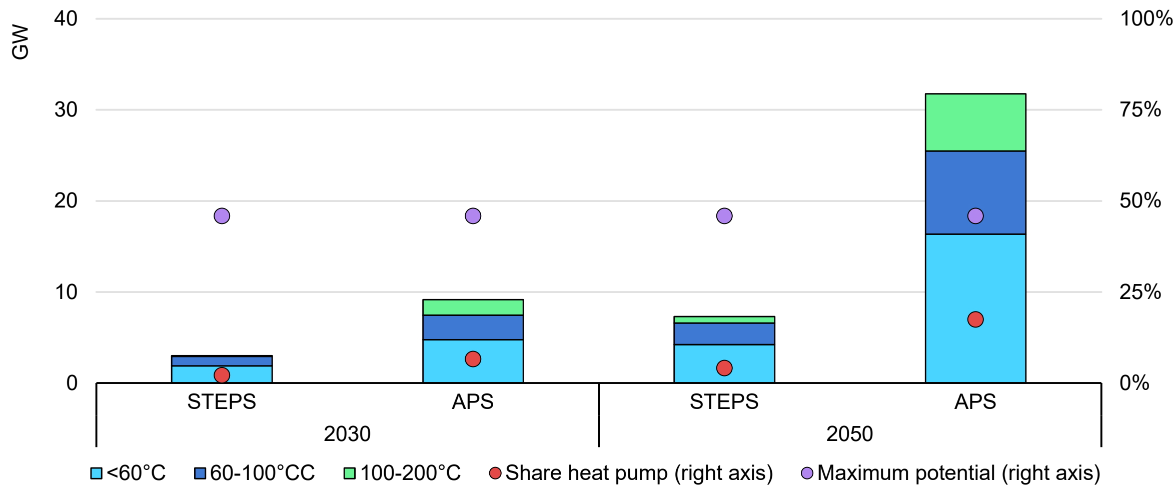
Even though the theoretical share of heat demand in light industries that can be covered by heat pumps is very high, it is unlikely that heat pumps will fully exploit all this potential. In certain processes alternative technologies might be less costly and more appropriate, and – depending on policy decisions – different levels of heat pump deployment may be stimulated.

In the STEPS, there is no drastic turnaround in the heating fuel mix in Chinese light industries (see Chapter 1), with electrification remaining around 35% until 2050. However, in the APS, electrification is one of the key levers for aligning with China's carbon neutrality pledge, with the share of electricity in final heating demand rising to over 75% in 2050. This increased support for electrification in the APS drives the uptake of heat pumps, particularly in light industries. In light industries alone, heat pumps provide almost 270 PJ of heat in 2030 (10% of total heat demand from those sectors) and 840 PJ of heat in 2050 (20%) in the APS. For comparison, in the STEPS, those numbers are only 85 PJ and 2% in 2030, and 200 PJ and 5% in 2050. These values are notably inferior to the theoretical potential: heat pumps face competition from other heating technologies, particularly solar thermal, geothermal and bioenergy, which – if the correct conditions are in place – can be extremely cost-competitive. Furthermore, space constraints, financing issues, lack of expertise or even incompatibility of specific processes may also limit the deployment of heat pumps. Nevertheless, outside of conventional electric heaters, heat pumps remain the most important innovative technology in 2050, with around four times more installed capacity than biomethane and nine times more than solar thermal in the APS.

The installed capacity of heat pumps required to meet heating demand in light industries will depend on multiple variables that can vary significantly, such as working shifts, utilisation rates or optimisation of different processes. Assuming a utilisation rate of 80%, the required installed heat pump capacity in the APS by 2050 is 30 GW (Figure 2.6). Most of this capacity is located in the food sector, which accounts for about 40% of the 2050 heat pump stock in the APS, followed by the machinery and textile and leather sectors, with 30% and 15% of stock, respectively. To build up this stock, about 1.5 GW of heat pumps would need to be installed every year between 2025 and 2050 in the APS.[28]

[28] This accounts for initial installation and the replacement of units reaching end-of-life.

Figure 2.6 Installed capacity of industrial heat pumps per temperature level in the Stated Policies and Announced Pledges Scenarios in Chinese light industries, 2030-2050



Notes: APS = Announced Pledges Scenario; STEPS = Stated Policies Scenario. A utilisation rate of 80% for heating equipment is assumed to calculate this capacity. Maximum potential represents the theoretical maximum deployment share for light industries (see Figure 2.5).

In the APS, heat pumps become one of the main sources of heat in Chinese light industries, supplying 20% of the demand, mainly at temperatures below 60 °C.

The large uptake of heat pumps in light industries in the APS brings considerable efficiency improvements. If the deployment of heat pumps were to be substituted by conventional electric boilers, the 2050 electricity demand would be almost 650 PJ higher in the APS – equivalent to the electricity needs of South Africa today.

Special focus: heat pumps connected to district heat networks

District heat networks are used as the main space heating method in northern Chinese cities and towns, and today they largely rely on fossil fuels, either via cogeneration or large heat-only boilers (see Box 1.2). Large-scale heat pumps connected to district heating networks provide an opportunity for system integration and can support the decarbonisation of district heating networks. They are key to enabling the recycling and reuse of waste heat from different activities.

Global market trends

Today, large-scale heat pumps represent a negligible amount of the global installed capacity in district heat networks. They are mostly deployed in Europe, where large heat pumps represent an installed capacity of around 2 500 MW, which is slightly less than 1% of the total installed capacity for district heating. Sweden accounts for almost half of European capacity, with over 1 000 MW of heat pumps operating within their district heat network. In China and Russia, the first- and second-largest district heating markets (see Chapter 1) the share of heat pumps is negligible.

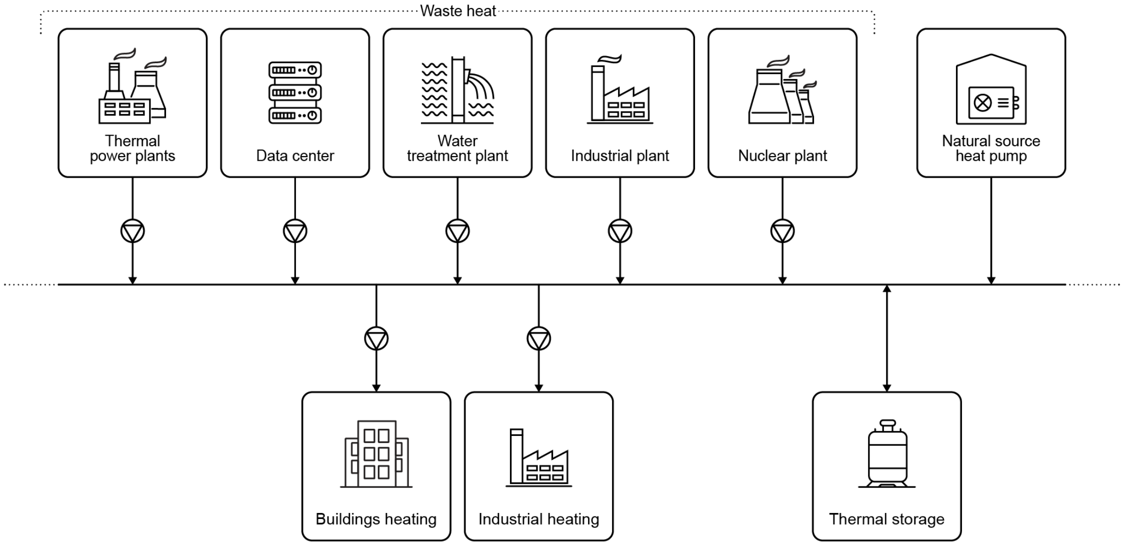
However, heat pumps are gaining momentum in district heat networks in northern China. Currently, most of the heat pumps connected to district heating networks in China are air-source units installed in small networks operating at low temperatures (< 65 °C), covering the heating needs of between 0.5 and 3 million m^2. There are also some examples of large-scale heat pumps recycling waste heat used in district heating networks in China (see Table 2.2), and the deployment of these configurations is expected to increase in the future.

Technology considerations

Heat pumps can play multiple roles in district heat networks, and can be connected in different ways (Figure 2.7):

- **Heat pumps connected to the primary network** allow for the integration of ambient or waste heat and can be used to lift the supply temperature of the primary network. Combined with thermal storage, they add flexibility to the electricity grid, enabling the integration of intermittent renewables and taking advantage of periods of low electricity prices (see Chapter 3). In Sweden, where 7% of the heat supply to district heat networks was provided by large-scale heat pumps in 2021, most of which use sewage water and ambient water as a source.
- **Heat pumps connected to the secondary network** are used to lift the temperature at the end-user level. They can be used in low-temperature networks to meet domestic hot water needs, which require a higher temperature than space heating, or in ultra-low-temperature networks, where they lift the temperature at the end-user level for space heating and/or water heating.
- **Heat pumps connected to heat substations** are useful for increasing the efficiency of the system, as they can integrate waste or ambient heat and optimise the performance of the network by reducing the return temperature of the primary network. Absorption heat exchangers based on absorption heat pumps are a widely researched alternative that is receiving increasing attention, especially in China (see Box 2.4).

Figure 2.7 The integration of heat pumps and waste heat in district heating networks

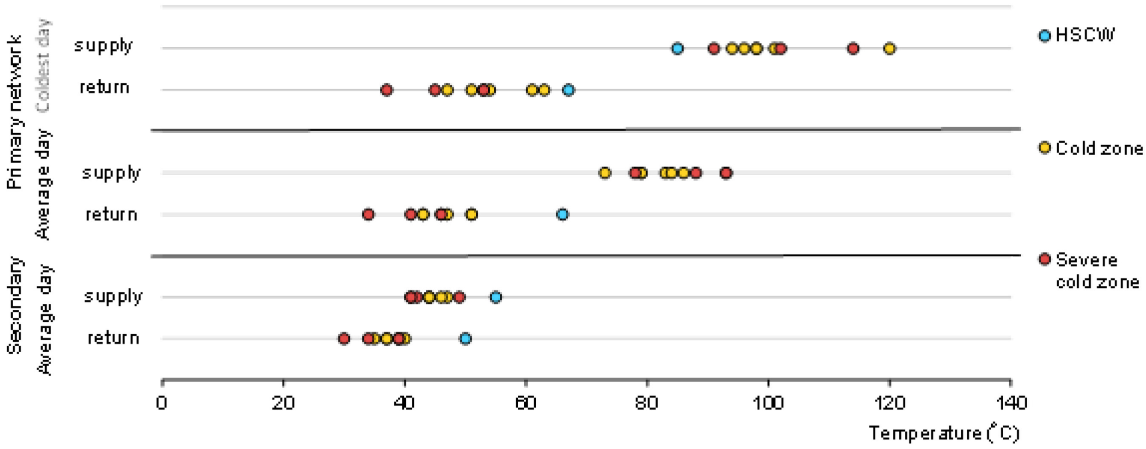


Heat pumps can play diverse roles in district heat networks through connections to primary networks, secondary networks and to substations.

District heating systems have evolved considerably over the past century, from systems using high-temperature steam as the heat carrier (first generation district heating systems), to systems using superheated water (second generation), to systems where the supply temperature has been reduced to levels below 100 °C (third generation), which are widely used today. Ongoing efforts are being made to reduce supply temperatures even further, to lower than 60-70 °C (fourth generation). Recently, temperate water loops have emerged as a new concept based on an even lower-temperature network, in which cooling and heating needs are met by heat pumps located at the end-user level.

Reducing the operating temperature of the network often brings significant system-wide benefits by reducing distribution losses and enabling the integration of further low-temperature waste heat and ambient heat. However, reducing the operating temperature of district heating networks is not easy. In most cities in China, the average water supply temperature in the primary network (i.e. the part of the network connected to the heating sources, such as combined heat and power plants, boilers or large heat pumps) is between 75 °C and 100 °C during the heating season, while the return water temperature is between 40 °C and 60 °C (Figure 2.8).

Figure 2.8 Supply and return temperatures of different networks in Chinese climate zones



Notes: HSCW = Hot summer-cold winter climate zone. The primary network is the part of the network connected to the central heating sources, while the secondary network is connected to the final consumers. Data collected by Tsinghua University Buildings Energy Research Centre in typical urban central heating system network across 12 cities in China.

The shift to lower-temperature district heating (<60 °C) could reduce energy losses and enable the integration of renewables, waste heat and large-scale heat pumps.

Table 2.2 Selected case studies integrating heat pumps in district heating systems in China

Case study	Location and climate	System description	Impact
Steel mill waste heat utilisation	Qianxi (Hebei, cold climate zone)	- 200 MW (absorption heat pumps) - 4.5 million m^2 heated (2020) - first energy-saving and emission reduction demonstration town in China that fully utilises low-grade industrial waste heat for heating.	- Reduction of 54 kt coal/year - Reduction of 145 kt CO_2/year - Reduction of 54 t NOx/year
Dalian Seventh People's Hospital primary sewage source heat pump project	Dalian, (Liaoning, severe cold zone)	- 2 heat pumps and 4 heat exchangers - 2191 kW of designed heating load in winter, and 1266.8 kW of designed cooling load in summer - Untreated sewage at 10-30 °C used as a heat source - COP of 4 during the heating season	- Reduction of coal use by 50% - Reduction of 1.5 kt CO_2/year - Reduction of 4.4 t nitrogen oxides (NO_x)/year - Reduction of 5.1 t sulphur dioxide (SO_2)/year

Case study	Location and climate	System description	Impact
Yongcheng Longyu Chemical Industrial waste heat utilisation	Yongcheng (Henan, cold climate zone)	- 1.3 million m² heated, 10% being commercial buildings and 90% being households - 53 MW - China's first case of recycling waste heat from coal gasification plant wastewater for district heating	- Reduction of 49 kt coal/year - Reduction of water consumption by 208 kt/year
Zhao County project: "coal-to-electricity" and "coal to gas" technology switch	Shijiazhuang (Hebei, cold climate zone)	- Air-source heat pumps and gas boilers - 46 heat supply stations - 180 MW (air-source heat pumps) - > 3 million m² heated	- Reduction of 18 kt coal/year - Reduction of 47 kt CO_2/year

Box 2.4 The role of absorption heat pumps and deep and medium-depth ground-source heat pumps in district heat networks.

District heating in China currently operates with relatively high supply and return temperatures in the primary network (Figure 2.8). Lowering the return temperatures in the primary network would bring significant benefits to the system. Lower return temperatures increase the temperature difference between supply and return, meaning that the same heat can be transferred with a lower water flow, thereby reducing the power consumption of the network's water pumps and increasing the efficiency of the whole system. Reducing return temperatures to around 20 °C and enabling supply-return temperature differences of around 100 °C could increase the transport capacity of networks by up to 70%.

Absorption heat exchange technologies, consisting of an absorption heat pump combined with a heat exchanger, have proven to be a viable alternative for reducing the return temperature and allowing larger temperature differences in the primary network. Absorption heat pumps are essentially heat pumps driven by thermal energy. If the flow temperatures of the primary network are high enough, they can drive absorption heat pumps, allowing for an effective exchange of heat between the primary and secondary network and return temperatures as low as 20 °C.

Ground-source heat pumps are also a key solution to decarbonise district heating, complementing shallow ground-source heat pumps. Deep and medium-depth heat pumps are already in use, for example in Xi'an, Shaanxi Province, and are around 40-60% more efficient with respect to shallow ground-source heat pumps, as they extract heat from rock layers around 2-3 kilometres below ground level.

At this depth, heat reservoirs reach temperatures of up to 80-90 °C, which is much warmer than in layers closer to ground level that are mainly heated by solar radiation. A typical deep and medium-depth geothermal well can extract at least 3 000 GJ of heat per year, enough to meet the winter heating demand of 160 households in northern China. However, under typical settings, efficiency could decrease over time, because the rock layers from which the heat is sourced get cooler as continuous heat extraction exceeds the amount of heat gradually released from the interior of the Earth.

Due to the lack of targeted design, the distance between two pipes used in such systems has previously often been just 20 metres or less. However, in this configuration the limited heat extraction radius implies that ground temperatures decrease by up to 13 °C over 10 years of operation. By increasing the distance between two pipes to 50 metres or more, temperatures decrease by just 2 °C over 10 years, guaranteeing the stable long-term operation of such heat pumps over many decades.

Consequently, the distance between pipes for deep and medium-depth ground-source heat pumps should be increased according to the site conditions, and dense layouts should be avoided. A range of recent building projects in Xi'an, Beijing and other cities in northern China already reflect this guidance in order to maximise ground-source heat pump efficiencies.

Special focus: heat pumps to recycle and reuse heat

The availability of waste heat is one of the preconditions for exploiting more of the potential of heat pumps in industry and district heating networks. Human activities consume large amounts of energy, very little of which is retained in the products they generate, and most of which ends up in the form of low-temperature **waste heat**. If the discharge of this waste heat is relatively concentrated, it can be recovered and reused as a low-temperature heat source for heat pumps. Most of the higher-temperature heat is currently recycled and utilised for power generation, but there is still a large amount of waste heat below 100 °C, particularly between 30-50 °C, which is discharged into the atmosphere (Figure 2.9). A large amount of low-grade waste heat is also generated and emitted from data centres, industrial cooling processes and large power substation cooling. In addition, nuclear and peaking thermal power in China also emits low-temperature waste heat equivalent to about 1.5 times its power output in energy terms.

Thermal power plants, including pure condensation power plants and cogeneration plants, exhaust large amounts of waste heat through steam and flue gas. There are currently nearly 1.3 TW of coal-fired and gas-fired thermal power plants in China, producing waste heat resources of about 30 EJ per year, most of it below 50 °C, and nuclear power plants with an installed capacity of 57 GW, and waste heat of about 2.5 EJ per year. The distribution of these power plants across China is typically closely correlated with human activities and economic development, and concentrated in the North China Plain, the Yangtze River Delta, and the Pearl River Delta region.[29]

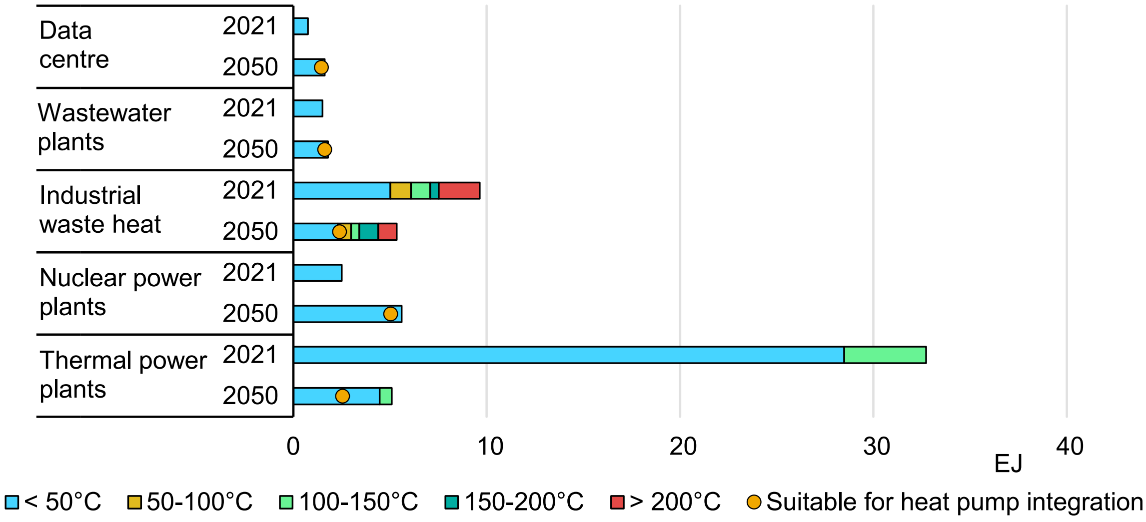
Under the carbon-neutral development goal, China's power system is expected to be gradually transformed into a zero-carbon power system, with a huge reduction in coal-fired and gas-fired power generation, but some coal-fired power plants will remain in order to meet the seasonal demand for power regulation (for a more detailed analysis, see Chapter 3). Tsinghua University estimates that by 2050 the total installed thermal power capacity will be 510 GW, with about 1 500 hr of power generation and waste heat resources estimated at about 5 EJ, most of it below 50 °C. By 2050, **nuclear power** will have reached an estimated installed capacity of 200 GW, with 7 500 hr of power generation and waste heat resources estimated at 5.6 EJ.

Industrial waste heat is another valuable source of heat. At present, there is still a large amount of unutilised low-temperature waste heat. Waste heat generated by the five major sub-sectors of energy-intensive industries, namely ferrous metal smelting, non-metallic mineral processing, non-ferrous metal smelting, chemical raw material manufacturing and petroleum processing, was estimated by Tsinghua University to have a theoretical potential of about 10 EJ of waste heat resources per year.[30] The geographic distribution of industrial waste heat is uneven across the country.[31]

Wastewater treatment plants also have the potential for waste heat recovery. In 2021, the national wastewater treatment volume was around 72 billion m³, and the waste heat of wastewater treatment plants was estimated to be about 1.5 EJ in the same year, if the heat extraction temperature difference is 5 °C. Notable projects in China include the planned district heating and cooling system in Qingdao, which will cover 180 km^2 and use air, ground and wastewater source heat pumps. In Shijiazhuang in Hebei province, 7 000 homes are heated using industrial wastewater heat pumps.

[29] Estimated by Tsinghua University through research on the geographic distribution of the waste heat of 2 186 coal-fired power plants, 171 gas-fired power plants, 820 waste power plants and 12 nuclear power plants.
[30] Estimated through production capacity, output and waste heat per unit of product.
[31] Assessed on the basis of 2 262 factories. Iron and steelmaking plants are mainly found in northern China and on the East Coast, and the cement industry is evenly dispersed across densely populated areas.

Figure 2.9 Waste heat availability per temperature level and per sector in China, 2021 and 2050

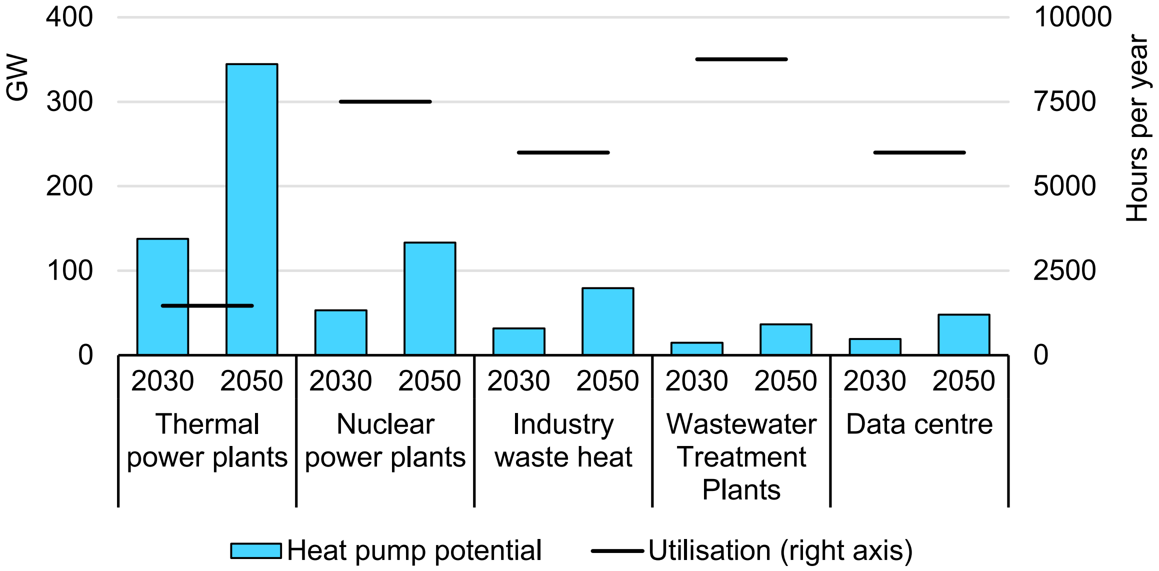


Note: Suitable waste heat for heat pump integration by 2050 is based on an assessment by Tsinghua University based on waste heat accessibility and economic assessment.

Almost 19 EJ of waste heat from power plants, industries, data centres and wastewater plants will be available by 2050, but only around 13 EJ would be suitable for heat pump integration.

The availability of large amounts of low-temperature waste heat from nuclear power plants, thermal power plants, industrial facilities and other processes provides an opportunity to integrate large-scale and absorption heat pumps. By 2030 and 2050, a potential of around 250 GW and 650 GW of heat pump capacity, respectively, could be deployed to harness waste heat resources (Figure 2.10). Most of the potential by 2050 – 350 GW – is in thermal power plants, which are used for peak generation for less than 1 500 hr per year, which therefore complicates their conversion to cogeneration plants. The remaining capacity, associated with industrial waste heat, data centres, wastewater treatment plants and nuclear power plants, has a higher annual utilisation, as these waste heat sources are expected to be available for more than 6 000 hr per year.

Figure 2.10 Potential heat pump deployment to recycle and reuse waste heat from Chinese power plants and industry, 2030 and 2050



Note: Heat pump capacity estimated based on waste heat availability and accessibility, and on a techno-economic assessment.

As much as 650 GW of heat pump capacity could be deployed by 2050 in China to harness waste heat potential.

Chapter 3. Implications of heat pump deployment

Highlights

- Investments in heat pumps in buildings are set to double by 2030 and more than triple by 2050 in the Stated Policies Scenario (STEPS). Investment levels are even higher in the Announced Pledges Scenario (APS), in which deployment is more rapid. The investment gap between the STEPS and the APS is more pronounced for industrial heat pumps, demonstrating the increase in policy support required to enable large-scale deployment.
- High upfront costs are the principal barrier to uptake, but heat pump investments typically pay off for households and businesses in the long run when compared with fossil fuel boilers or electric heaters. Financial incentives to reduce purchase costs will nonetheless be essential for scaling up deployment. Reducing the price gap between electricity and natural gas can also make heat pumps more cost competitive over their lifetime.
- Heat pumps are a critical decarbonisation lever in buildings, accounting for around 30% of direct emissions reductions for heating in China in the APS to 2050. Large units account for one-fifth of emission reductions for light industries in the APS. Emissions of air pollutants fall drastically as coal heating is phased out. Improvements in air quality associated with higher heat pump deployment in the APS contribute to avoiding some 6 000 more premature deaths in 2030 than would be avoided under the STEPS.
- The growth in peak electricity demand in winter associated with heat pump deployment is not without challenges, though these are far smaller than in the case of a larger shift from fossil fuel-based heating systems to less efficient resistance heaters. An expansion in time-of-use pricing could enable demand response to ease pressure on grids, while enabling heat pump users to reduce their energy bills by 10% by 2030.
- China is the largest manufacturer of heat pumps for buildings, producing around 35% of all units sold worldwide. Air-to-water units represent the fastest growing export segment, in response to rising demand in Europe. Manufacturing capacity could be quickly ramped up to meet increasing domestic demand, thanks to short lead times for expansions and large existing production lines for air conditioners.
- China has become a global hub for heat pump innovation, with a substantial workforce throughout the heat pump supply chain. By 2030, the number of people employed in the heat pump sector in China doubles in the APS. However, a revalorisation of vocational education is needed to address emerging challenges for recruitment in manufacturing, which could otherwise hinder the acceleration of heat pump manufacturing and deployment.

Introduction

Scaling up the deployment of heat pumps in buildings, industry and district heating in China will bring about far-reaching changes for the country's energy sector, with significant implications for economic activity, the environment and public health. This chapter explores these implications in turn, as well as any barriers to speeding up deployment. The opportunities for policy makers to address some of the challenges associated with accelerated heat pump deployment are highlighted throughout, and further discussed in Chapter 4.

The reduction in fossil fuel use for heating resulting from a switch to heat pumps would help to bring down GHG emissions, though emissions from refrigerants used in heat pumps need to be kept in check in order to maximise emissions reductions. Phasing out coal for heating would also bring major improvements in air quality, particularly for ambient air in rural areas, where coal use is more prevalent. However, tackling barriers such as the high upfront cost of heat pumps will be essential to facilitate the investments by a wide range of households and businesses needed to ramp up deployment. At the same time, an increase in the number of heat pumps would also increase demand for electricity, strengthening the need for solutions such as demand side management. China is already a major manufacturer of heat pumps, and the largest market in terms of sales, with great potential for domestic market expansion (see Chapter 2). Further increasing production would also create new opportunities for exports, innovation and employment, though staffing issues need to be addressed, in particular in manufacturing.

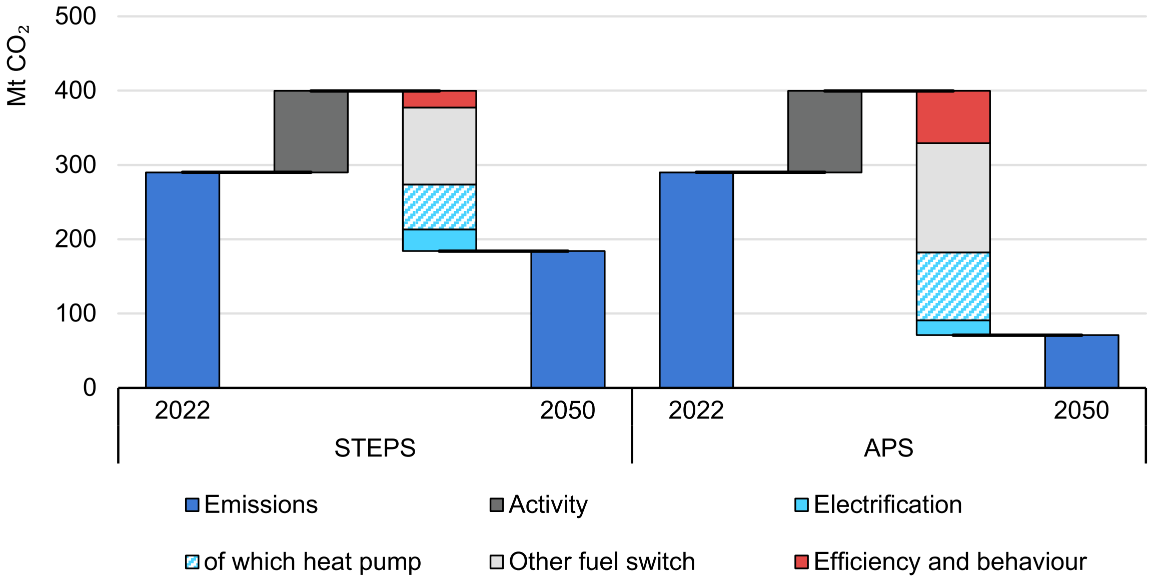
Environment and public health

Greenhouse gas emissions

Buildings

In 2022, emissions from fuel combustion for space and water heating accounted for the vast majority of direct emissions from buildings in China, or around 290 Mt CO_2. In the STEPS, buildings emissions are cut by more than a fourth by 2050, despite increases in floorspace and ownership of appliances. Heat pumps are responsible for more than a quarter of the reductions, with most of the remainder coming from other fuel-switching options such as coal to gas. In the APS, emissions are reduced to just 80 Mt CO_2 in 2050 thanks to greater efforts on electrification, energy efficiency measures and behaviour change. Heat pumps account for about 30% of reductions in this scenario and contribute to balancing out the increase in emissions associated with increased activity (Figure 3.1). The impact of indirect emissions associated with the electricity used by heat pumps is limited by the progressive decarbonisation of power generation in both the STEPS and the APS (see Box 3.2).

Figure 3.1 Direct CO_2 emissions reduction in space and water heating in China in the Stated Policies Scenario and Announced Pledges Scenario, 2022-2050

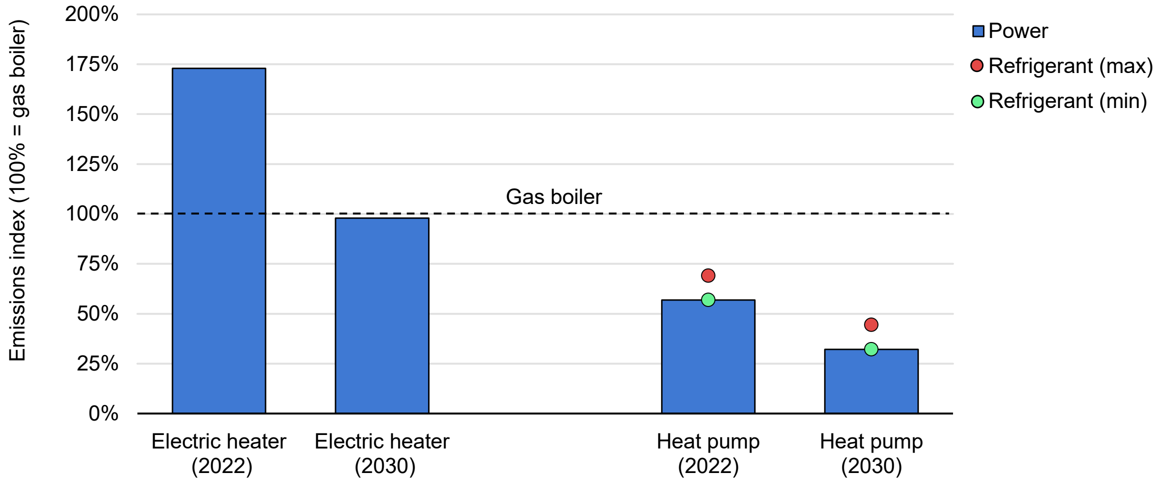


Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. The calculation of direct emissions assumes the fuel mix in buildings final energy consumption is as in Figure 1.1 of Chapter 1, and the considerations explained in Box 1.1.

Electrification is a critical decarbonisation lever for heating in buildings, and heat pumps account for around 30% of overall direct emissions reductions to 2050 in the APS.

Existing heat pumps installed in China are already providing substantial reductions in GHG emissions compared with fossil fuel-based heating systems: for example, annual emissions from heat pumps are today more than 30% lower than those of gas boilers (Figure 3.2). A switch to using alternative refrigerants that have lower global warming potentials (GWP), and action to prevent leaks, can further increase these benefits (Box 3.1).

Figure 3.2 Annual GHG emissions of electric heaters and heat pumps compared with gas boilers in the Announced Pledges Scenario, 2022 and 2030



Notes: Power = Annual emissions associated with electricity generation to power heat pumps; Refrigerant (max) = Annual emissions of a conventional hydrofluorocarbon refrigerant under full leakage; Refrigerant (min) = Annual emissions of a natural refrigerant under good practice leakage prevention.

Annual emissions from heat pumps are already over 30% lower than from gas boilers, and nearly 60% lower by 2030 in the APS. Alternative refrigerants and leakage prevention can further improve these benefits.

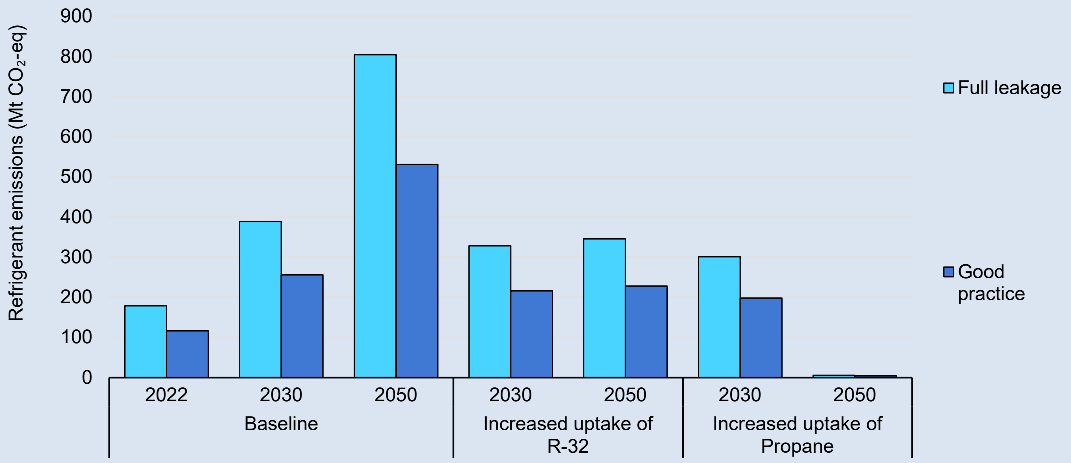
Box 3.1 Limiting refrigerant emissions can further increase heat pump benefits

Heat pumps rely on refrigerants to move heat. Although these substances operate in a confined refrigeration cycle, partial or full leakages frequently occur during manufacturing, operation and decommissioning. This poses climate risks as many refrigerants have a high GWP. Some of the most harmful refrigerants, such as R-22 and other hydrochlorofluorocarbons (HCFCs), are already being phased out in China in line with the Montreal Protocol.

However, hydrofluorocarbons (HFCs), which are fluorinated gases (F-gases) with high GWP, remain widely used. Without changes to the use of high-GWP HFCs, refrigerant emissions would more than double by 2030 and increase more than fourfold by 2050 under heat pump deployment levels in the APS. Good practice and well-designed refrigerant reclamation and recovery schemes can limit leakage of refrigerants. In addition, emissions can be reduced by switching to less harmful refrigerants, which are already available and increasingly deployed. Scaling up the use of less harmful refrigerants, along with good practice in equipment handling, will be crucial to maximising the benefits of heat pumps.

R-32 is a common F-gas refrigerant with a GWP two to three times lower than most refrigerants used today. However, when emitted, the climate impact of R-32 is still more than 200 times greater than that of non-HFC alternatives. This implies that even with a wide-ranging switch to this refrigerant, refrigerant emissions would almost double from today's levels by 2030 in the APS. Good practice for refrigerant safety could reduce those emissions by about one-third.

Refrigerant emissions from heat pumps in China under different refrigerant mixes, 2022-2050



Notes: Mt CO_2-eq = million tonnes CO_2 equivalent. Refrigerant emissions are based on heat pump deployment levels in the APS. The baseline includes the refrigerant mix as of 2022 and reflects the phase-down pathway of R-22 hydrochlorofluorocarbon according to the Montreal Protocol, to which China is a signatory. To be compliant with the Kigali Amendment to the Montreal Protocol (ratified by China in 2021), different HFC phase-down pathways are feasible, including the two alternatives in this figure. Good practice includes actions to limit leaks during installation and maintenance as well as refrigerant recycling.

Source: IEA based on Purohit & Höglund-Isaksson (2017), Global emissions of fluorinated greenhouse gases 2005–2050 with abatement potentials and costs.

China is already working to phase down high-GWP F-gas refrigerants. In 2019, China submitted its Green and High-Efficiency Cooling Action Plan and in 2021, the country became an official signatory to the Kigali Amendment of the Montreal Protocol, which aims to limit HFC use globally.

Natural refrigerants such as propane (R-290) and other hydrocarbons are another common alternative with GWPs so small as to be insignificant. A large-scale shift to such gases could therefore virtually eliminate F-gas emissions in China by 2050, though practical limitations remain, mainly related to higher flammability. Split units, in which the refrigerant circulates inside buildings, notably require more stringent safety measures than monobloc models where refrigerants remain outdoors. Innovation has the potential to further reduce the refrigerant loads needed to efficiently run heat pumps, as recent R&D advancements have demonstrated, which would reduce risks related to refrigerants.

In the European Union, the leading market for alternative refrigerants, a new regulation passed in January 2024 foresees reducing the overall amount of F-gases by nearly 80% from 2025 to 2030. Monobloc systems and air-to-water split heat pumps using HFCs with a GWP above 150 will be prohibited by 2027 and by 2029 for air-air split systems. The rule therefore virtually eliminates F-gases, including R-32, from most heat pumps and air conditioners sold in the EU in the coming years, with major implications for heat pump and air conditioner markets and supply chains in Europe and beyond.

Finally, hydrofluoro-olefins (HFOs), synthetic refrigerants with zero ozone depletion potential and low GWP, can provide a balance of thermodynamic performance, environmental performance and safety. However, recent research has revealed that many of these alternatives can be classified as Per- and Polyfluorinated Substances (PFAS) that can decompose in the atmosphere into trifluoroacetic acid, which is harmful to human and environmental health. Both the European Union and US Environmental Protection Agency have initiated evaluation programmes to assess the applicability and possible restriction of HFOs.

CO_2 can be used as a refrigerant, especially in heat pump water heaters. It is most efficient for higher temperatures, and requires higher pressures and stronger materials, but is non-flammable and has limited climate impacts if released, when compared with other refrigerants. Water steam also offers the same benefits in industrial applications with waste heat usage and high output temperatures.

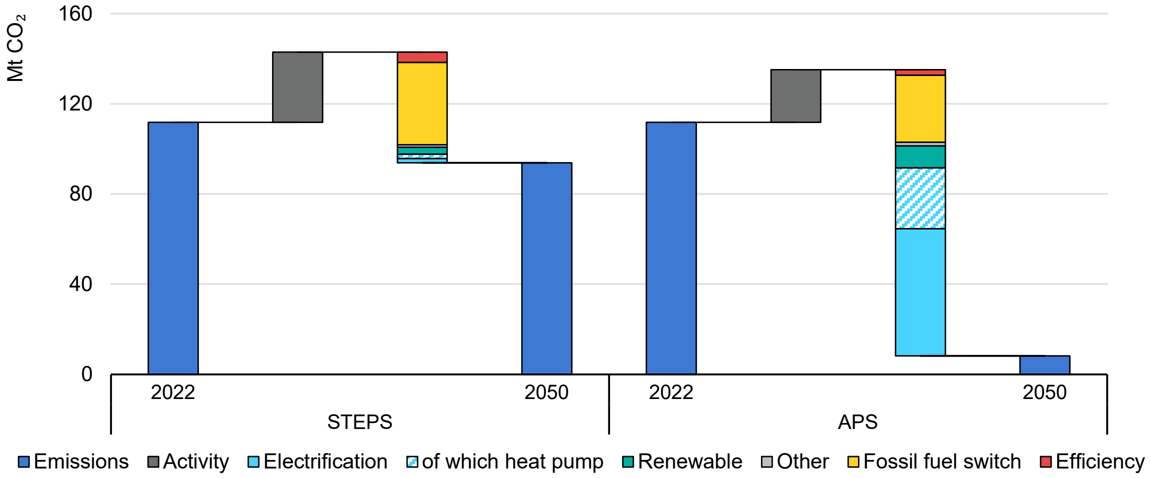
In addition, Chinese universities are researching advanced heating/cooling technologies which do not require refrigerants. These non-traditional solid-state solutions exploit properties of materials to move heat when under pressure or exposed to a magnetic field. Such technologies currently have low technology readiness levels but promise very high energy efficiency, potentially even higher than best-in-class air conditioners today, in addition to avoiding emissions resulting from refrigerants.

Industry

CO_2 emissions reductions provided by heat pumps in light industries remain limited in the STEPS through 2050, as heat pumps are deployed slowly on the basis of current policy settings. The increase in emissions resulting from increased industrial activity is largely balanced out by the fuel switch from coal to natural gas and growing uptake of blended biomethane, but electrification remains almost stagnant (Figure 3.3). As a result, emissions drop by only 15% in 2050 compared to their current level.

In contrast, in the APS, direct emissions from heating in light industries are drastically reduced from over 110 Mt CO_2 today to just 10 Mt CO_2 in 2050, a 95% drop. Increased industrial activity is offset by emission reductions resulting from fuel switching and efficiency measures. Electrification accounts for 70% of emissions reductions for heating by 2050. A third of this reduction is due to heat pump deployment, while a range of other electric heaters are used to decarbonise high-temperature processes. Other fuel shifting to more efficient and less emission-intensive solutions, such as natural gas, bioenergy, solar thermal, geothermal and hydrogen, is responsible for most of the remaining emissions reductions.

Figure 3.3 Direct CO_2 emissions change for heating in Chinese light industries in the Stated Policies Scenario and Announced Pledges Scenario, 2022 to 2050



Notes: APS = Announced Pledges Scenario; STEPS = Stated Policies Scenario. Industrial sectors included are construction, food and tobacco, textile and leather, machinery, transport equipment, wood and wood products, and mining and quarrying. "Renewable" includes solar thermal, geothermal, bioenergy and blended biomethane. "Other" includes district heat and hydrogen.

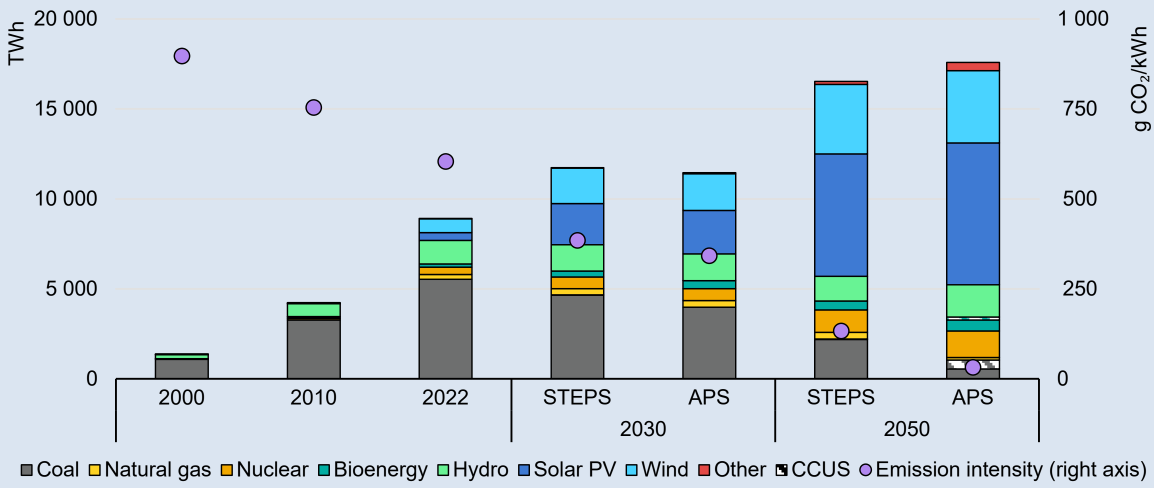
Heat pumps are a key tool for the decarbonisation of light industries and are responsible for around 20% of emission reductions by 2050 in the APS.

Box 3.2 Grid decarbonisation amplifies emission reductions from heat pumps

The majority of GHG emissions related to heat pump use in China are indirect emissions associated with producing the electricity used to power the devices. Grid decarbonisation therefore leads to reduced emissions from the use of heat pumps.

In 2000, more than three-quarters of electricity produced in China was from coal-fired power plants. Since then, power demand has grown nearly sixfold, and while coal-fired electricity production has expanded more slowly, it still accounts for more than 60% of power generation. Hydropower and other renewables account for most of the remainder. The emissions intensity of power generation decreased by one-third to 600 g CO_2 per kWh in 2022. By 2050, emissions intensity is set to fall to 130 g CO_2 per kWh in the STEPS and as little as 30 g CO_2 per kWh in the APS, thanks to the fast ramp-up of solar PV and wind, which account for around two-thirds of electricity generation in both scenarios. Lower emissions in the APS are mainly due to the share of unabated fossil fuels in the power mix being limited to just below 5% in 2050, compared with 15% in the STEPS.

Electricity generation by source and emissions intensity of the Chinese grid in the Stated Policies Scenario and Announced Pledges Scenario, 2000-2050



Notes: APS = Announced Pledges Scenario; STEPS = Stated Pledges Scenario; CCUS = Carbon capture, utilisation and storage. Energy values represent electricity production from a specific source rather than the energy used to produce this electricity. "Other" includes oil, geothermal, concentrated solar power, marine power, hydrogen, and ammonia.

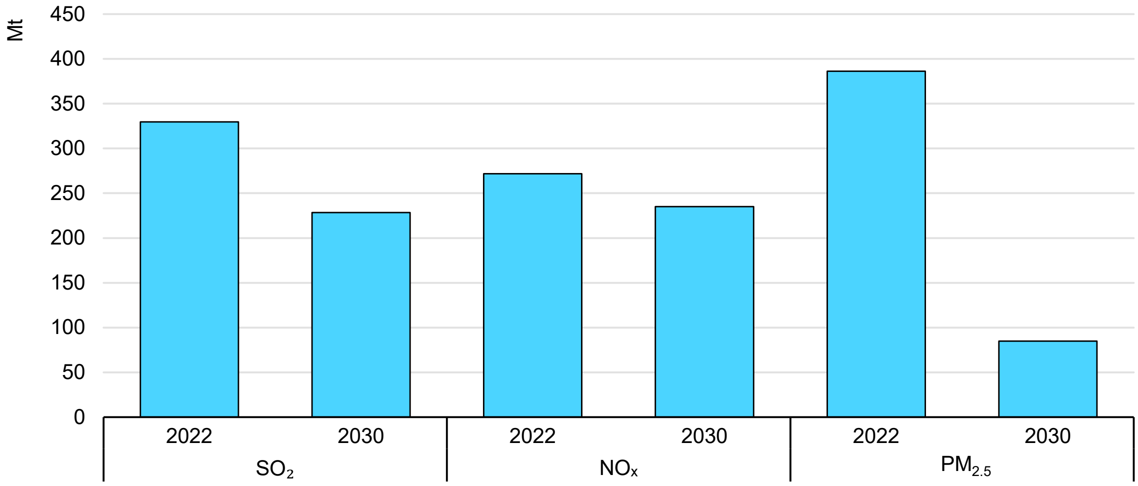
Air pollution

Air pollution from fossil fuel-based heating, transport, power generation and other activities was responsible for more than 12 million premature deaths in China between 2015 and 2022. Burning coal and traditional biomass for heating are major causes of both household and ambient (outdoor) air pollution. For example, residential coal burning was responsible for nearly half of the concentration of harmful fine particulate matter ($PM_{2.5}$) in the Beijing-Tianjin-Hebei region during winter haze periods in 2015.

A range of policies have been introduced since 2013 in Beijing and other cities in northern China to tackle the issue of air pollution and accelerate the switch to heat pumps and other alternative heating solutions (see Chapter 1). As a result, $PM_{2.5}$

concentrations fell by over 40% between 2015 and 2021 alongside substantial reductions of emissions from other pollutants such as sulphur dioxide. Nearly 24 000 premature deaths linked to air pollution were avoided in 2021 as a result of such measures.

Figure 3.4 Emissions of major air pollutants from direct fuel combustion for space and water heating in buildings in China in the Announced Pledges Scenario, 2022-2030



Notes: SO_2 = sulphur dioxide; NO_x = nitrogen oxides; $PM_{2.5}$ = fine particulate matter.
Source: IEA analysis based on International Institute for Applied Systems Analysis (IIASA) modelling.

Scaling up heat pump deployment can play a crucial role in substantially reducing emissions of major air pollutants from buildings by 2030.

The shift to heat pumps and other heating sources could reduce $PM_{2.5}$ emissions from heating buildings with coal and other fuels by nearly 80% by 2030 in the APS (Figure 3.4). Heat pump deployment is 13% higher in this scenario than in the STEPS in 2030, which helps avoid more than 6 000 premature deaths in that year alone.

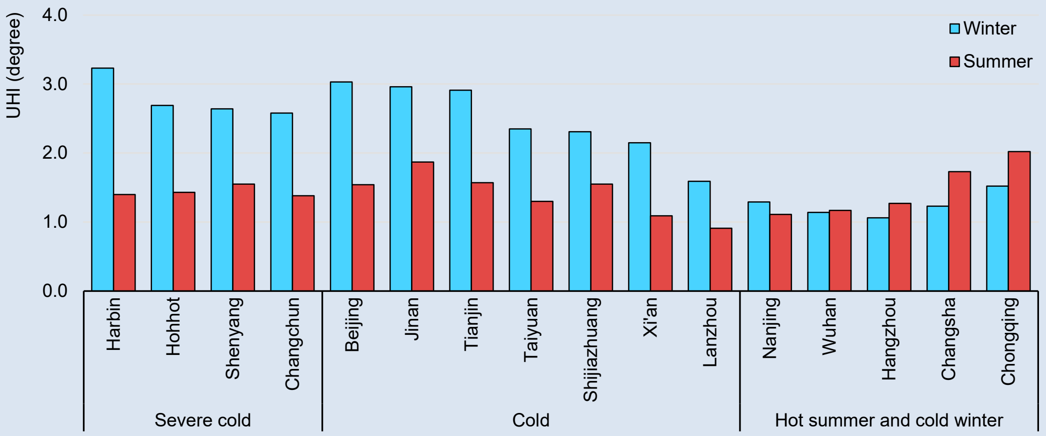
A large-scale switch to heat pumps could also prevent other risks associated with fossil fuel combustion. For example, poorly serviced heating stoves and gas boilers can emit carbon monoxide, which is estimated to kill around 40 000 people each year worldwide, with parts of northern China among the world's most affected regions. Clean heating solutions also avoid hazards associated with combustion heating, such as explosions and fires.

Box 3.3 The location of air-source heat pumps affects urban heat islands and operational efficiency during both summer and winter

Air conditioners (AC) expel heat from the indoor to the outdoor environment. In cities with high AC use, this heat can increase outdoor night-time temperatures in summer by more than 1 °C, exacerbating the heat island effect and increasing the risks of heat-related illness and death. In some dense metropolitan areas such as Chongqing or Changsha, widespread AC use, combined with factors such as a lack of vegetation and geographical features, increase temperatures by up to 2 °C. In cities with substantial heating requirements, the increase in outdoor temperature associated with fuel combustion in winter may be even higher than the increase driven by AC in summer. In cities in cold parts of China, temperatures can be up to 3 °C higher than in sparsely populated rural areas with similar climatic conditions.

In contrast, air-source heat pumps cause local air-cooling islands as they extract heat from the surrounding environment. As a result, increased heat pump uptake in cities such as Beijing could counteract the urban heat island effect in winters by around 0.5 °C. These localised cooling effects pose no risks to health, but can affect the efficiency of heat pumps. Outdoor units need to be sufficiently spaced out and well-ventilated in order to limit the urban heat island effect during summer (in the case of units used for cooling) and to maximise the efficiency of air-source heat pumps during summer and winter. This has implications for the space required in urban areas. For example, in Beijing, heating a 10 000 m^2 building with large, decentralised air-source heat pumps would require around 600-800 m^2 for the outdoor units. Surface areas of this size are often not available, favouring the deployment of small individual heat pumps and large ground-source heat pumps.

Urban heat island effect in selected Chinese cities in summer and winter by climate zone, 2016-2020



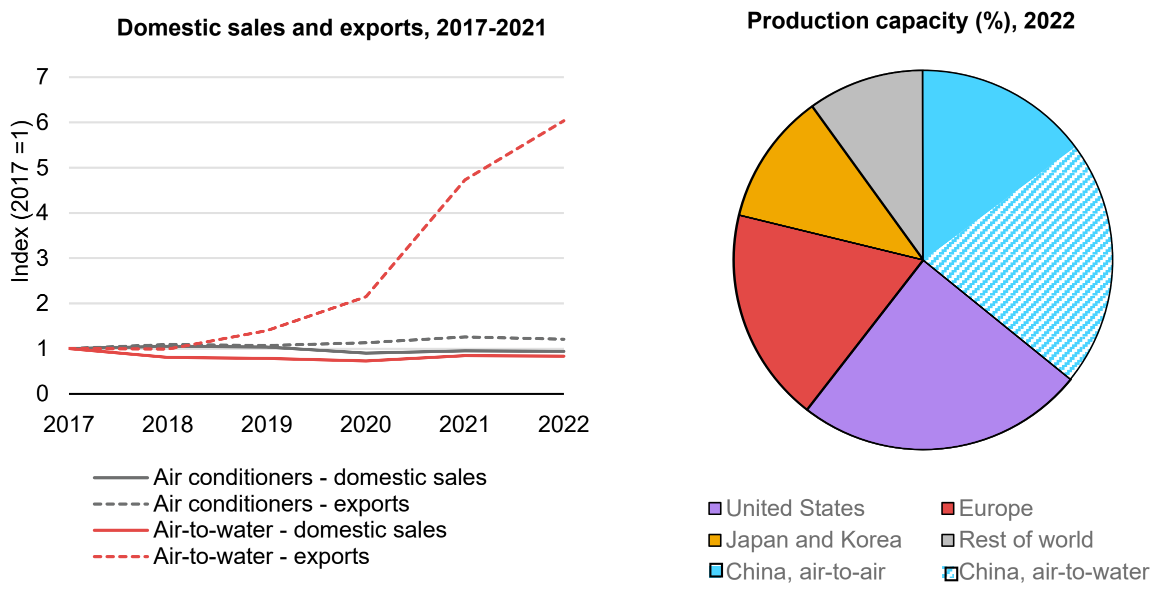
Note: UHI (degree) = Extent of the urban heat island effect in degrees Celsius.

Supply chains

Current status

China is the largest manufacturer of heat pumps deployed in the buildings sector, producing around 35% of all heat pumps sold for heating in buildings worldwide. Chinese heat pump manufacturing capacity[32] increased by nearly 8% in 2022 to cover growing demand, building on well-established existing manufacturing lines for air conditioners. Manufacturing capacity for air-to-air heat pumps is ten times larger than that of air-to-water devices, when units used for space cooling are included. However, exports of air-to-water heat pumps are growing rapidly, with a sixfold increase between 2017 and 2022 (Figure 3.5), in contrast to exports of air-to-air heat pumps, which have flatlined.

Figure 3.5 Domestic sales and exports of heat pumps for buildings in China, 2017-2020, and share of heat pump production capacity by world region, 2022



Note: Right-hand side graph refers only to units used as primary heating equipment.

Sources: ChinaIOL (left graph); IEA (2023), The State of Clean Technology Manufacturing – November 2023 Update (right graph).

About 35% of heat pumps for buildings sold worldwide are manufactured in China, with air-to-water units representing the fastest growing export segment in response to rising demand in Europe.

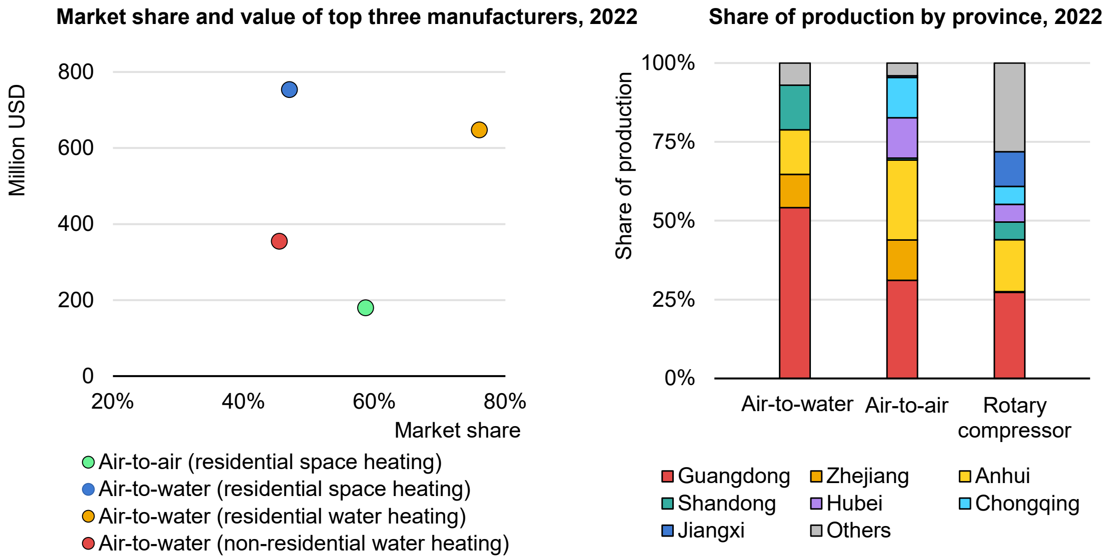
More than 10 large heat pump manufacturers operate in China today, across 15 provinces. However, the top three producers of the different heat pump types cover between 40-80% of the market – signalling the market dominance of a limited number of companies (Figure 3.6). Domestic companies produce 80% of

[32] Including capacity for air-to-air units deployed as primary heating equipment and air-to-water units.

heat pumps manufactured in China in terms of capacity,[33] some as original design manufacturers for exports to Europe or North America. In 2022, around one-quarter of domestic manufacturing output was exported.

The majority of heat pump factories are assemblers, but China is also a leader in manufacturing of key components. For example, over 99% of rotary compressors used in residential heat pumps and air conditioning units are manufactured in Asia, predominantly in China, where compressor manufacturing increased by 70% from 2013 to 2021 in terms of units produced.[34] The costs of materials and components such as compressors, heat exchangers or driver modules make up the majority of heat pump production costs, which implies a heavy reliance on commodity prices for steel, copper, aluminium and chips. Compressors are typically the single largest-cost item, accounting for around one-third of the manufacturing costs for air-to-air units. Most major Chinese manufacturers therefore have dedicated compressor manufacturing facilities, and the compressor market is equally concentrated, with the top three producers accounting for around two-thirds of the market.[35]

Figure 3.6 Market share and value of the top three manufacturers by heat pump segment in China and share of production by province, 2022



Notes: Air-to-air units in this figure exclude reversible air conditioners used as a primary heating source. Air-to-air units in the right-hand-side graph include only the residential market, for both cooling and heating. Air-source heat pumps from ChinaIOL are all assumed to be air-to-water heat pumps in this graph.

Sources: CHPA (2023), 2023 China heat pump industry annual conference; ChinaIOL (2022), 2022 China heat pump heating industry development yearbook, (left graph); ChinaIOL (right graph).

Heat pump manufacturing in China is concentrated in a few provinces, and the top three manufacturers together account for 40-80% of total production capacity.

[33] For further insights see IEA (2023), Energy Technology Perspectives 2023.
[34] Data from ChinaIOL.
[35] CHPA (2023), 2023 China heat pump industry annual conference.

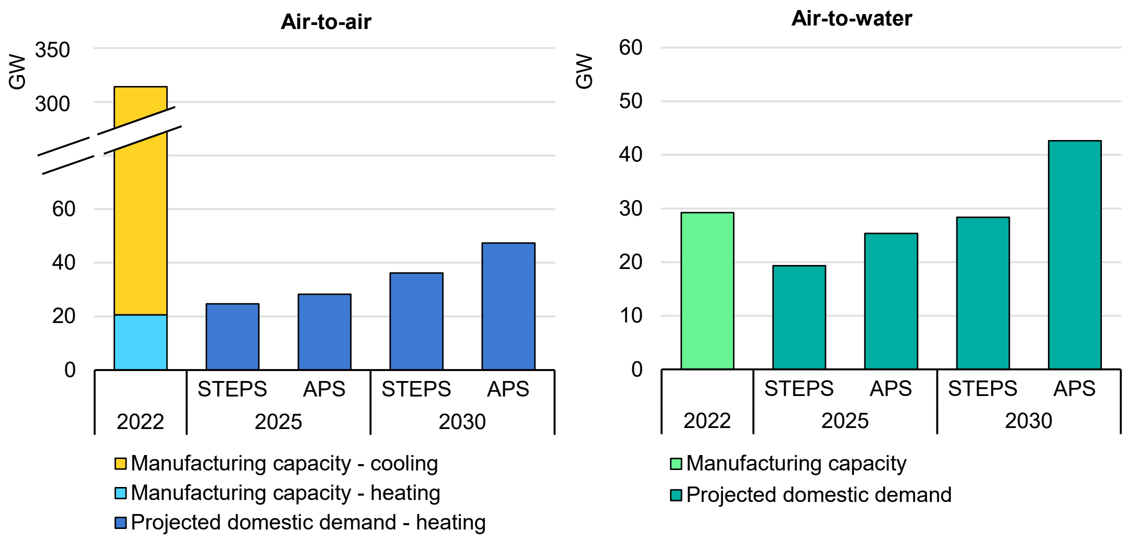
Production of heat pumps, air conditioners and compressors is largely concentrated in seven provinces, which account for around 70% of compressor manufacturing and over 90% of heat pump production. Today, every second air-to-water heat pump factory is located in Guangdong alone, as are more than a quarter of factories for air-to-air heat pumps (including air conditioners) and rotary compressors. Due to its hot and humid climate and large population, Guangdong continues to be the largest domestic market for air conditioners, while economic reforms have facilitated the emergence of private enterprises in the region since the late 1970s. The province is also China's largest exporter, accounting for nearly one-fifth of all exports from China in 2023. Given this favourable environment, the province has become a hot spot for R&D and manufacturing of air conditioners and compressors, and more recently of heat pumps. This concentration attracted a skilled workforce and allowed companies to reduce production costs in the early 2000s.

Future perspectives

Thanks to its strong manufacturing base, China is well positioned to meet growing domestic demand for heat pumps, which doubles by 2030 compared to today in the STEPS, and nearly triples in the APS (see Chapter 2). Expansions of production capacity for air-to-air units for space heating can rely on significant existing capacity for air conditioners (Figure 3.7). Further expansions of production capacity are likely, though plans are typically not announced publicly.

Production capacity for air-to-water units is sufficient to cover the growth in domestic demand by 2030 in the STEPS, but not in the APS. Further capacity would be needed to maintain China's position as a leading exporter for heat pumps, representing an opportunity for Chinese manufactures as demand grows abroad. The short lead times of just 1-3 years associated with expanding heat pump manufacturing capacity mean that manufacturers can adjust their expansion plans according to domestic and global trends. Expansion plans can also give greater confidence to heat pump installers over the coming years. The short lead times of just 1-3 years associated with expanding manufacturing capacity allow manufacturers to adjust expansion plans according to domestic and global demand trends.

Figure 3.7 Manufacturing capacity and projected domestic demand for heat pumps in buildings in China in the Stated Policies Scenario and Announced Pledges Scenario, 2022-2030



Notes: APS = Announced Pledges Scenario, STEPS = Stated Policies Scenario.

Existing manufacturing capacity for heat pumps exceeds domestic demand in the short term, especially for air-to-air units primarily used for cooling.

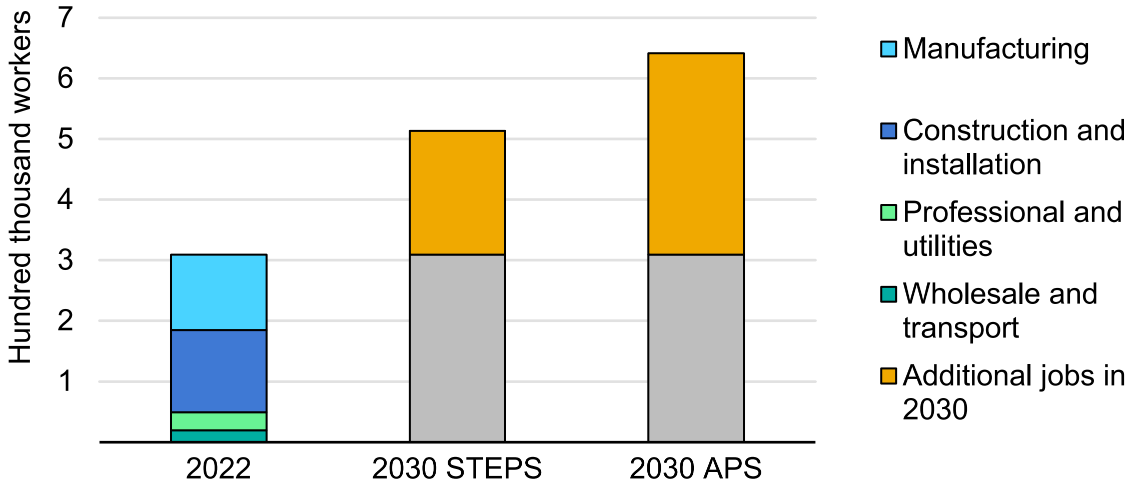
Job creation

Around 810 000 people worked directly in the heat pump supply chain worldwide in 2022, across manufacturing, planning and installation, wholesale, servicing and maintenance. The largest share of this workforce is in China, which is home to more than 300 000 workers, consistent with the country's 35% share in global heat pump manufacturing. Scaling up manufacturing in line with increased adoption of heat pumps in China would entail massive growth in the number of people working in the sector. Building up and training a workforce of this size will require the industry to work together with education institutions and government.

The largest subset of the Chinese heat pump workforce is engaged in planning and installation activities, which is a labour-intensive process for any heating, ventilation or air conditioning (HVAC) appliance but especially for heat pumps. Designing and installing a heat pump system requires many of the competencies needed in broader construction or HVAC occupations, as well as additional specialisations. These include evaluating properties, calculating heat loss and heating load and assessing thermal conductivity in order to design the installation, and updating existing heating systems and electrical wiring. Installations of ground-source heat pumps, which account for a small but growing share of the market, are especially complex, requiring thorough analysis of outdoor areas and the subterrain in advance of digging trenches or laying underground piping.

Manufacturing is the second-largest employment segment, reflecting the country's large manufacturing base.

Figure 3.8 Employment in the heat pump sector in China in the Stated Policies Scenario and Announced Pledges Scenario, 2022-2030



Note: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario. Grey bar: represents total employment in the heat pump sector in 2022.

The number of people employed in the heat pump industry in China doubles by 2030 in the APS.

Under current policies, China's heat pump workforce is set to grow by two-thirds to reach more than 500 000 workers by 2030 (Figure 3.8). In the APS, the workforce more than doubles over the same period, reaching approximately 640 000 workers by the end of the decade. The installation segment is responsible for most of this growth, followed by manufacturing. Although job creation in the latter sector will be moderated by labour productivity gains associated with modular design, standardisation and greater automation, certain heat pump manufacturing tasks, such as welding, will remain relatively labour-intensive.

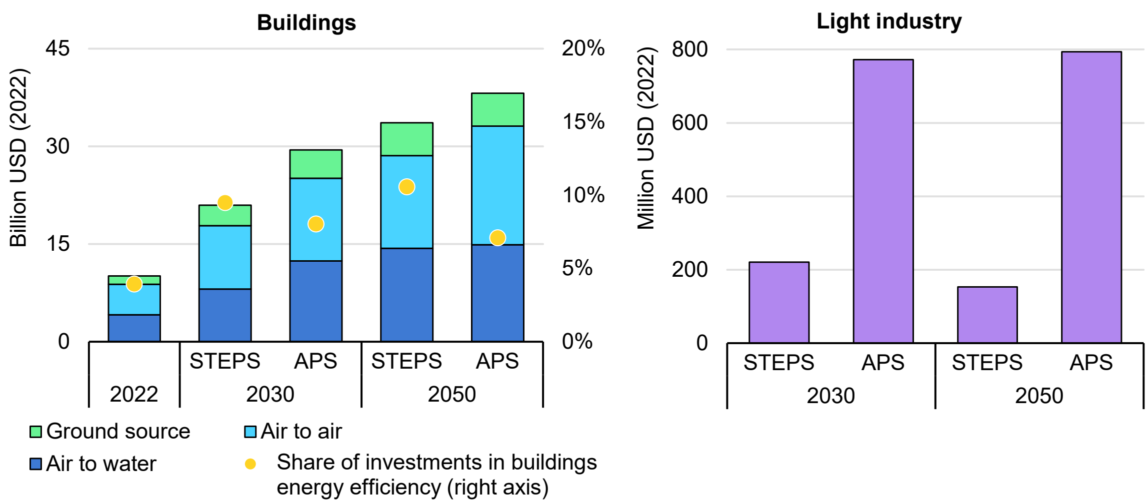
Despite high unemployment rates, the manufacturing sector in China is now encountering difficulties filling new positions as the working population declines and new workforce entrants increasingly seek white-collar jobs over factory work. However, shortages of installers for heat pumps and other appliances are a less pertinent issue than in foreign markets such as Europe. China has a particularly high number of installers, as many air-to-air heat pumps are used year-round for both cooling and heating, especially in southern provinces.

The vocational education system is essential for training energy workers, but enrolment has been falling in China in the face of institutional barriers such as a poor image and lack of understanding of the careers and salary options available following a vocational programme. In response, the Chinese government recently laid out skilling requirements for all regions to implement in order to revitalise vocational education.

Investment needs and affordability

Scaling up heat pump deployment in buildings, industry and district heating networks will require substantial investment. Upfront costs for heat pumps remain high when compared with less efficient electric heaters or fossil fuel-based solutions, but – in most circumstances – investments pay off quickly thanks to lower operating costs.

Figure 3.9 Market size of heat pumps in buildings and light industries in China in the Stated Policies Scenario and Announced Pledges Scenario, 2022-2050



Notes: STEPS = Stated Policies Scenario; APS = Announced Pledges Scenario.

Investments in heat pumps in buildings outweigh investments in heat pumps in light industries in 2030 and 2050 in both the APS and STEPS, due to their greater potential.

Buildings

An acceleration of heat pump deployment in China would entail a huge increase in spending on equipment and installation by the owners of residential and commercial buildings. Annual investments in heat pumps in China have already increased by 50% since 2015 to reach USD 10 billion (CNY 70 billion) in 2022, equivalent to around 5% of all energy efficiency investments in buildings (Figure 3.9).

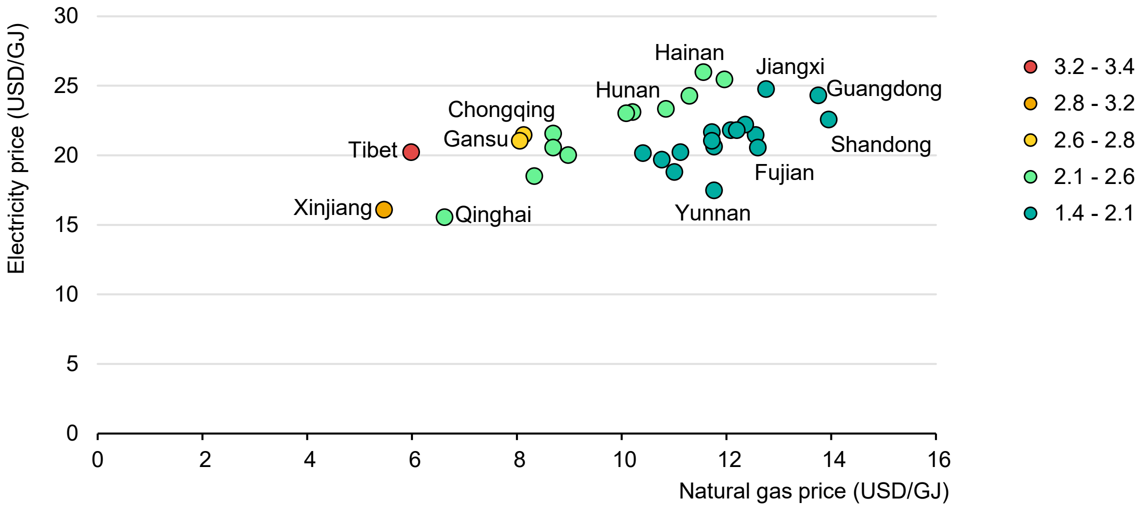
In the STEPS, investments in heat pumps in buildings are set to double by the end of the decade and to more than triple by 2050. In the APS, investment levels are even higher, reflecting more rapid heat pump deployment (see Chapter 2). By 2050, annual investments reach nearly USD 40 billion (CNY 250 billion), exceeding investment requirements in power transmission infrastructure in that year. However, total investments in heat pumps represent less than 10% of all energy efficiency investments needed over the same period in buildings, such as for increasing insulation and shifting to more efficient appliances.

Consumer uptake of residential heat pumps heavily depends on their upfront and operating costs compared with incumbent and alternative heating options. The upfront costs for air-to-air heat pumps are typically only around 20% more than for gas boilers. However, upfront costs are particularly high for air-to-water heat pumps, which are three to four times more expensive than electric heaters and more than twice as expensive as gas boilers.[36] Additional expenses associated with drilling or trenching also pose a major upfront cost burden for ground-source heat pumps, with total costs up to eight times higher than for air-to-water heat pumps. Cost barriers are similarly high for heat pump water heaters, which today are around four to six times more expensive than electric water heaters (Box 2.2). District heating systems that will increasingly rely on large heat pumps involve substantial complementary investments in network and heat storage infrastructure, but these costs are typically not directly borne by the end consumer.

The other main factor affecting the lifetime costs and savings potential of different heating equipment is the energy price, which varies significantly depending on the fuel and across and within provinces. District heating is typically the cheapest heating option per unit of energy where networks are available in northern urban areas. However, district heating costs are comparable to those of gas per unit of energy in north-western provinces, where gas prices are low due to the region's proximity to gas-exporting neighbours in Central Asia. Natural gas is around three times cheaper than electricity per unit of energy in these provinces. In a range of north-eastern and central provinces, natural gas costs half as much as electricity, with the price gap being smallest in coastal provinces (Figure 3.10). Some provinces have also introduced additional electricity price subsidies to improve the cost competitiveness of clean heating options. In Shanxi, for example, electricity prices in some cities have been reduced by up to 40% during the winter heating period.

[36] Based on a representative household.

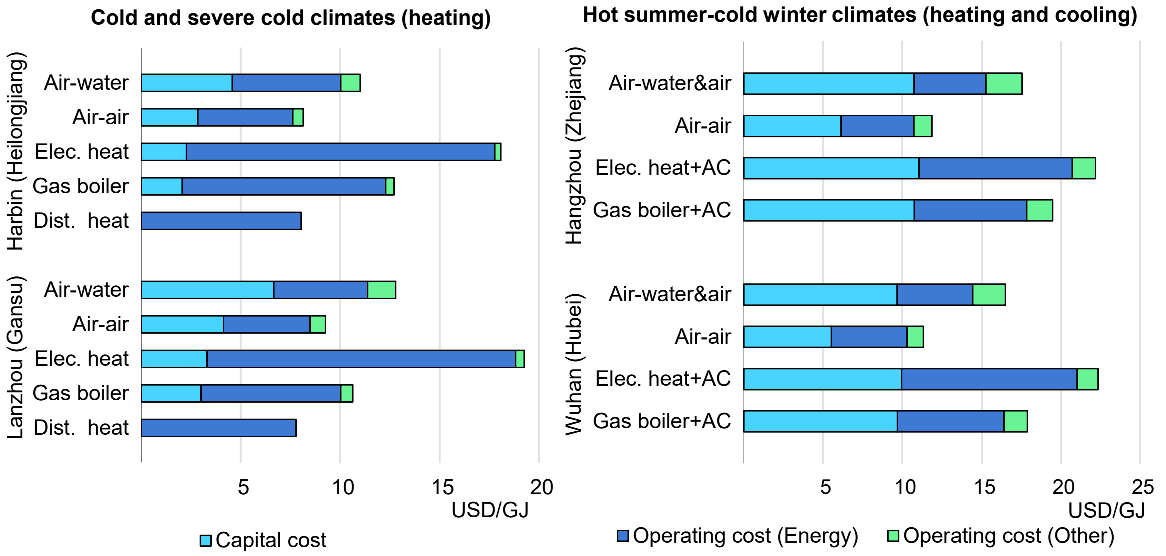
Figure 3.10 Ratio between residential electricity and natural gas prices, 2023



Electricity is up to three times more expensive than natural gas in the west of China, and costs around twice as much in central provinces.

Over their lifetimes, air-to-air heat pumps are often the cheapest option to heat a home. In Harbin, one of China's northernmost and coldest cities, for example, air-to-air heat pumps are cost competitive with district heating, as their energy costs are 40% lower, which compensates for equipment and installation costs (Figure 3.11). These benefits are even larger when compared with electric heaters and gas boilers. Air-to-water heat pumps are also cheaper than electric heaters and gas boilers over their lifetime in Harbin. In Lanzhou, where heating needs are also considerable, air-to-air heat pumps cost less than half as much as electric heaters over their lifetime, and also offer savings when compared with gas boilers. Air-to-water heat pumps, however, are only cost competitive in Lanzhou when compared with electric heaters. Where available, district heating remains the city's most affordable heating solution. Ground-source heat pumps are the most energy-efficient heating option, with energy costs that are up to four times lower than for electric heaters, but they also involve the highest upfront expenses. They are therefore a more suitable option for large building complexes.

Figure 3.11 Levelised cost of heating and cooling of residential heat pumps and alternatives by climate zone in Chinese urban areas, 2023



Notes: Air-air = air-to-air heat pump; Air-water = air-to-water heat pump; Elec. heat = electric resistance heater; Dist. heat = District heating; Air-water&air = air-to-water heat pump with blowers. The levelised cost of heating estimates the average cost of providing 1 GJ of heating over the lifetime of the equipment, considering the capital cost of the equipment and installation; operating expenditures include the cost of fuel and regular maintenance. A lifetime of 17 years is assumed for gas boilers, 15 years for air-to-air and 18 years for air-to-water heat pumps. Electric resistance heaters and air conditioners are assumed to have a lifetime of 10 years. District heating is assumed to have a lifetime of 25 years, with no upfront cost nor maintenance cost.

Source: IEA analysis based on data from Energy Foundation, Tsinghua University (2022), Rural Clean Energy System Helps Reduce Pollution, Reduce Carbon and Revitalize Rural Areas, accessed 13 March 2024.

Air-to-air heat pumps are already the most cost-competitive heating option over their lifetime in some cold climates, as well as in regions with hot summers and cold winters.

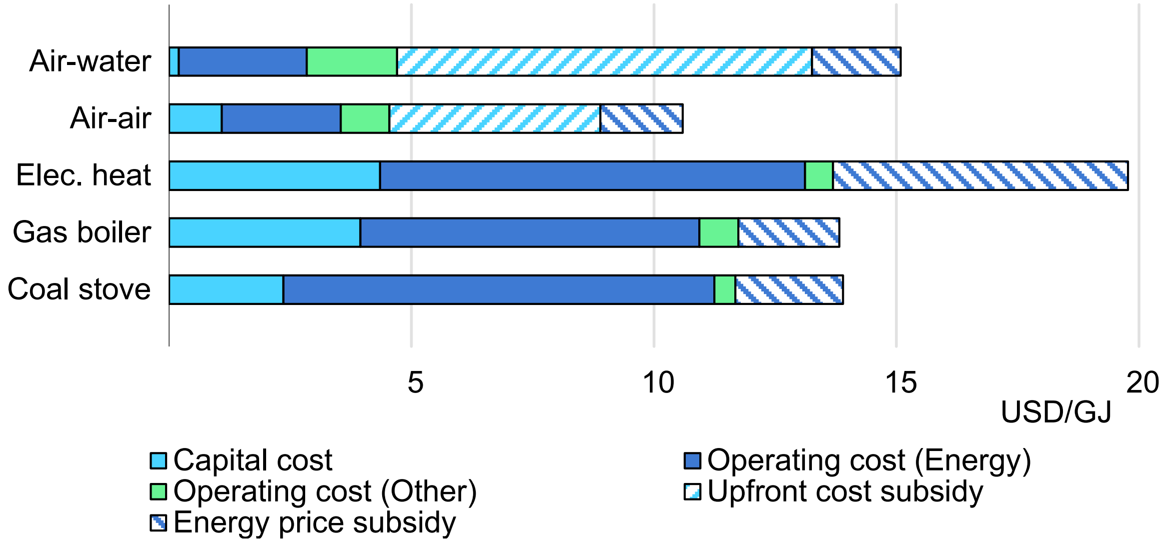
In cities in the hot summer-cold winter (HSCW) climate zone, air-to-air heat pumps are the most affordable solution to meet both heating and cooling needs.[37] In Wuhan, for example, lifetime costs are half as much as for a combination of electric heaters and air conditioners. Some air-to-water heat pumps can also provide cooling through blowers that are connected to the same outdoor units as the hydronic system. They are more expensive than air-to-air heat pumps, but provide savings compared with combinations of gas boilers or electric heaters and air conditioners.

In rural areas, coal is still used by many households for heating purposes, as costs for stoves and coal are low, but the energy efficiency of old stoves is often below 50%. In some regions, natural gas is offered at lower rates for households in rural areas than for those in cities, in order to encourage fuel switching and reduce local air pollution. Electricity prices tend to be the same across rural and urban areas, though prices in some rural areas are also held below urban levels in some provinces to support clean heating options. In rural Beijing, for example, heat

[37] Air conditioners have comparable lifetime costs.

pumps are now the cheapest heating solution thanks to a combination of energy price and upfront cost subsidies (Figure 3.12). Combining heat pumps with solar PV or thermal solutions can further reduce operating costs, which is crucial, as thermal insulation is typically poor in rural areas and households aim to keep their energy bills low. Improving building envelopes could further help households reduce energy costs and achieve higher levels of thermal comfort, as indoor temperatures often range between 12-15 °C in rural homes. In addition, heat pumps provide a more cost-effective solution for heat provision in rural areas that have limited access to gas networks, where provision of gas would require extensive investments in pipeline network expansion.

Figure 3.12 Levelised cost of heating of residential heat pumps and alternatives in rural Beijing, 2023



Notes: Air-air = air-to-air heat pump; Air-water = air-to-water heat pump; Elec. heat = Electric heating. The levelised cost of heating estimates the average cost of providing 1 GJ of heating over the lifetime of the equipment, considering the capital cost of the equipment and installation; operating expenditures include the cost of fuel and regular maintenance. A lifetime of 17 years is assumed for gas boilers, 15 years for air-to-air heat pumps,18 years for air-to-water heat pumps, 10 years for electric resistance heaters and 15 years for coal stoves.

Source: IEA analysis based on data from Energy Foundation, Tsinghua University (2022), Rural Clean Energy System Helps Reduce Pollution, Reduce Carbon and Revitalize Rural Areas, and subsidy policies from Huairou District People's Government of Beijing Municipality (2022), accessed 13 March 2024.

Heat pumps are already the most cost-competitive heating solution over their lifetime in rural Beijing.

Financial incentives for heat pumps are less common in urban areas, as fewer households rely on coal. However, some cities in the north have used subsidies to phase out coal use for space heating with the aim of improving air quality. In Tianjin, for example, households received support of up to USD 3 700 (CNY 25 000) when purchasing an air-source heat pump in 2017-18.

Reducing price gaps between electricity and natural gas through energy price and tax reforms could further increase the competitiveness of heat pumps in regions where electricity currently costs significantly more than gas. In addition, heat pump operating costs can be further reduced through the introduction of responsive devices and dedicated electricity tariffs to adjust heat supplies to power generation and demand peaks. Average heating bills of households in well-insulated homes with heat pumps in China could be reduced by around 10% by 2030 thanks to demand side response. Switching to heat pumps could also deliver additional benefits for individual households, including reducing the need to purchase fossil-based fuels, saving time and alleviating the need for storage space.

Industry

Technology and fuel costs are among the main factors influencing the fuel mix for heat production in light industries. Heat pumps account for only a small share of industrial heat supply today, because cost barriers remain high, as units generally need to be tailored to specific applications.

In light industries, scaling up heat pump capacity to 7 GW by 2050 in the STEPS and to 30 GW in the APS[38] requires substantial investment by the operators of industrial facilities. In the STEPS, investment needs are around USD 240 million (CNY 1.6 billion) per year through 2030 and around USD 160 million (CNY 1.1 billion) per year through 2050, as deployment slows after 2030 and is focused on replacements. In the APS, annual investment needs remain largely constant at around USD 760-800 million (CNY 5.2 billion). In total, this adds up to USD 5 billion (CNY 35 billion) by 2050 for light industries in the STEPS and about USD 20 billion (CNY 140 billion) in the APS. In comparison, Chinese light industries spent a roughly equivalent amount – around USD 23 billion (CNY 160 billion) – on natural gas in 2022.

Industrial heat pumps are about six times more expensive than gas boilers, but they are already nearly cost competitive with coal boilers over their lifetime, as greater efficiencies largely outweigh substantial upfront and fuel price gaps.

Today, coal remains the cheapest fuel for industrial use in China, at around USD 5 (CNY 32) per GJ compared to USD 18 (CNY 120) per GJ for natural gas and USD 23 (CNY 154) per GJ electricity. However, electricity has become more cost competitive since 2000, when coal was almost 20 times cheaper per unit of energy. Combined with a range of clean heating policies in industry (see Chapter 1), this has encouraged a gradual shift from coal to natural gas and electric boilers over the past decade, and increasingly also to heat pumps.

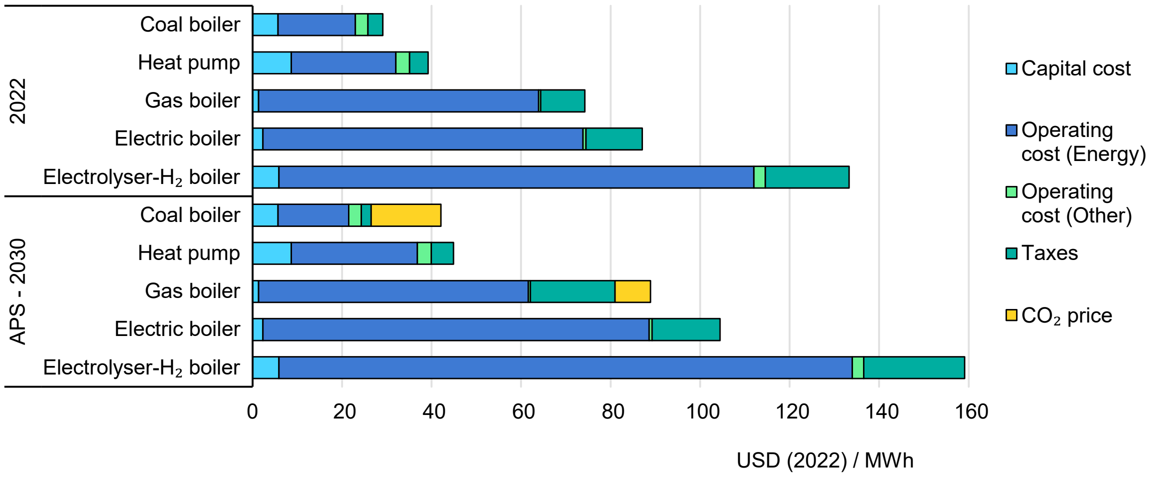
As in the residential sector, there are also regional variations in cost competitiveness for heat pumps. For example, in regions with low industrial gas prices such as Chongqing or Gansu, the levelised costs of heating are lower with gas boilers than with large heat pumps.

[38] Assuming an 80% utilisation rate.

Over the next decade, the lifecycle cost gap between heat pumps and alternative technologies could be further reduced (Figure 3.13). By 2030, lifetime costs will be half those of gas boilers or electric heaters, but coal boilers will remain cheaper by a thin margin. However, in the APS the price difference with coal is two times lower than it is in the STEPS. The sector could play an important role in reducing the reliance on coal. Where feasible, geothermal and solar thermal are also highly cost-effective solutions for clean heating in the industry sector. Electrolysers to produce hydrogen for high-temperature heat processes remain the most expensive option in both the APS and the STEPS, due to high operating costs. However, low-emissions hydrogen is a key solution to decarbonise heat in processes for which heat pumps are not suitable.

Despite the competitiveness of heat pumps over their lifecycle, they are set to remain the option with the highest upfront costs even in 2030, though a large-scale roll-out could result in further upfront cost reductions. Upfront costs present less of a barrier in industry than in the buildings sector, as planning horizons are longer and affordability considerations are different, but financial incentives are still key to accelerating heat pump uptake in industry. In Germany, for example, subsidies can cover up to 55% of the initial cost of the heat pump up to a ceiling of EUR 15 million per project.

Figure 3.13 Levelised cost of heat in light industries by technology in China in the Announced Pledges Scenario, 2022 and 2030



Notes: APS = Announced Pledges Scenario. A utilisation rate of 80% is used for every technology, the output temperature is 100 °C, the coefficient of performance of heat pumps is set at 3, and the discount rate is 5%. The H_2 boiler includes the cost of the dedicated electrolysers used to generate hydrogen. Taxes cover excise tax, VAT and subsidies.

Sources: IEA analysis based on IEA HPT TCP Annex 58 (2023), High-Temperature Heat Pumps; JRC (2017) Techno-economics for larger heating and cooling technologies, accessed 13 March 2024.

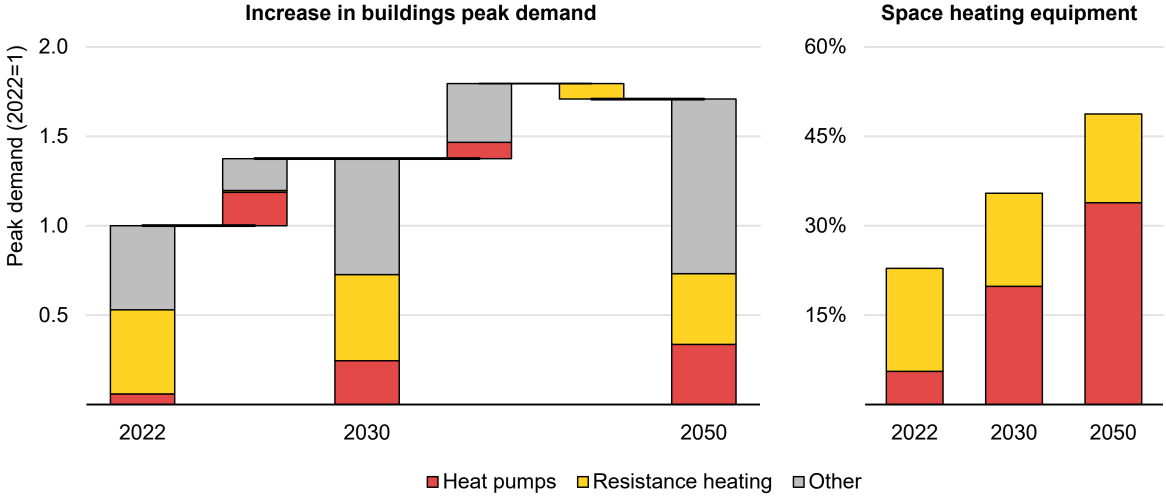
The gap between the lifetime cost of heat pumps and coal boilers could be divided by a factor of three by 2030 if all announced pledges are implemented, though high upfront costs could remain a barrier.

Electricity system and demand flexibility

Impacts of heat pumps in buildings on winter peaks

The growing peak electricity demand in winter associated with heat pump deployment poses challenges, though these are far smaller than if there were a larger shift from fossil fuel-based heating systems to less efficient resistance heaters. Thanks to their higher efficiency, a 1% increase in heat pump use corresponds to a modest 0.2-0.6% increase in electricity demand for heating – 2 to 5 times lower than with resistance heating. Demand side management, in addition to careful grid planning, can limit the need for distribution grid upgrades as heat supplies are increasingly electrified.

Figure 3.14 Contribution to winter peak electricity demand in buildings by technology, and heating equipment stock by technology in the Announced Pledges Scenario, 2022-2050

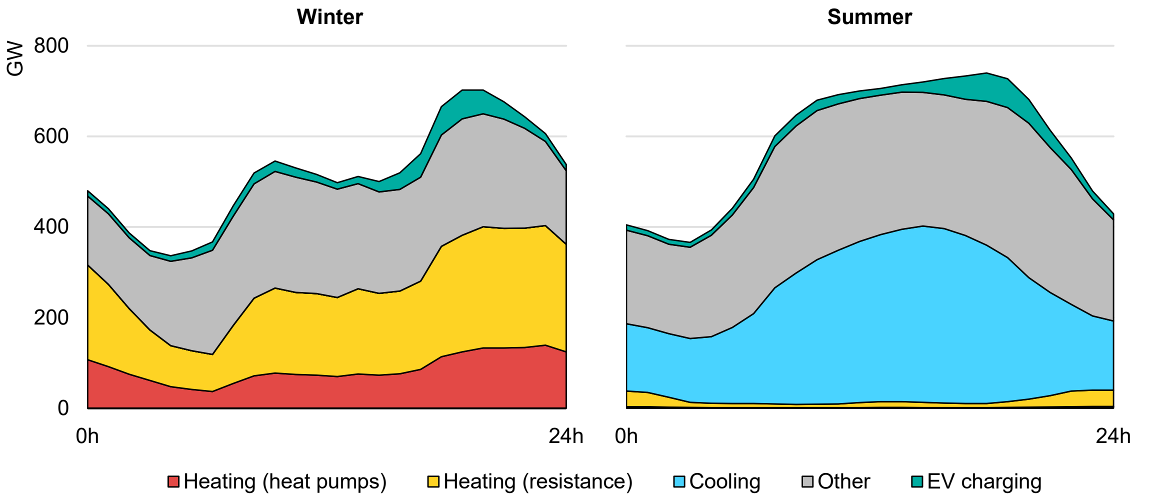


Notes: Peak electricity demand here is the average of demand for the 125 highest load hours in winter, before activation of demand response. Heat pumps and resistance heating cover space heating consumption. Charging electric passenger cars and two/three-wheelers is included in other end uses. Reduced heat pump efficiency at lower outdoor temperatures is captured.

High heat pump efficiency limits their contribution to peak demand to 20% in 2050, when their share of heating equipment stock reaches one-third.

In the APS, peak electricity demand in buildings increases by more than a third by 2030 compared with 2022 levels. The share of heat pumps in space heating equipment stock more than triples to 20% over the same period, overtaking resistance heaters, yet they contribute only half as much as resistance heaters to peak demand (Figure 3.14). By 2050, heat pumps account for just over a third of space heating equipment, but their share in peak demand remains at only 20%, which is low compared to the typical share attributed to resistance heaters or cooling equipment.

Figure 3.15 Average buildings daily load curve by end-use in winter and summer in the Announced Pledges Scenario, 2030



Notes: EV = electric vehicle. Heat pumps and resistance heating consumption includes both space and water heating. EV charging covers passenger cars and two/three-wheelers.

The contribution of heat pumps to the average daily load in buildings is limited, especially compared with typical loads from resistance heaters, appliances or cooling in summer.

In the APS, the peak load impact of heat pumps is two times smaller than that of other electric appliances in buildings, while the difference between off-peak and peak demand from heat pumps is lower than that of EV charging (Figure 3.15). Cooling demand peaks in summer are also significantly higher than peaks resulting from heat pump use in winter. This underlines the importance of ensuring high energy efficiencies of space cooling equipment, to keep peaks in check. Improved buildings energy performance can further reduce strains on power systems from heating and cooling needs.

Demand side flexibility of heat pumps in buildings

As the share of power generation from variable renewable energy sources such as solar PV increases further, it will be necessary to adjust demand profiles to fluctuating electricity output. The demand side flexibility potential of district heating networks is reliant on the heating technology used.

Electricity generated from fossil fuel-based combined heat and power plants is dependent on heat, and therefore extremely inflexible, unlike heat pumps. Smart-enabled heat pumps can be thermostatically controlled without significantly affecting occupant comfort, provided that the building is sufficiently insulated, or thermal storage solutions are in place. Curtailing or adjusting their load to lower or higher temperatures (from several minutes to a few hours) can provide several benefits to the grid, such as peak load reduction, reserve provision, fast frequency response and congestion management.

Flexible heat pump operation in China can reduce curtailment of renewables by 60 TWh, equivalent to over 20% of electricity consumption by heat pumps for space and water heating in 2050 in the APS. This flexible operation can be managed statically under pre-set operational patterns, for instance with a simple signal under a time-of-use (ToU) tariff (Box 3.4), or more dynamically through connected devices within a building's energy management system.

Numerous pilot projects using connected devices are already being deployed in different countries. In Germany, the ViFlex project demonstrates how the flexibility of heat pumps can be aggregated within a virtual power plant to manage grid congestion. Recent and planned demand response trials in the United Kingdom and in Australia aim to demonstrate how households can be remunerated for flexibility services from heat pumps and air conditioners. In China, a pilot is ongoing for demand response associated with cooling equipment in Huzhou, in the HSCW zone.

The expansion of ancillary services markets in China represents a big opportunity for the operators of district heating networks and aggregators of distributed energy resources like heat pumps to provide demand side flexibility and gain revenue from it. Ancillary markets exist at the regional and provincial levels (7 regional and 30 provincial markets) and were historically only created for peak adjustment. However, with the development of spot market pilots in several provinces, these markets have evolved to cover reserve and frequency control, as peak adjustment services are no longer necessary once the spot market steers dispatch. A national policy released at the end of 2021 expanded ancillary products and eligible market participants, promoting the inclusion of new actors such as battery storage, load aggregators and virtual power plants. Those entities will also be allowed to fully participate in spot market transactions by 2030, as announced by the Chinese government in October 2023. Implementation of these reforms in the different local markets will be key to harnessing the benefits associated with using heat pumps for load management.

Box 3.4 Time-of-use electricity tariffs for residential heating in China

Time-of-use (ToU) tariffs, which vary throughout the day, have been playing a increasing role at the provincial and local level in China over the past few years. In 2017, the National Development and Reform Commission released pricing policy options for clean heating in northern China, as part of broader policies to promote a switch from coal to gas and electric heating. This included the aim of improving ToU mechanisms during the heating season between 1 November and 31 March, in order to reduce the cost of moving from coal to electricity, and replacing ladder tariff policies with a ToU mechanism for promoting peak shifting, known as the "peak-valley" mechanism.

According to National-level guidance from 2021, in regions where the maximum difference between peak and valley (off-peak) load is above 40% in the current or previous year, the peak: valley end user price difference set for these two periods should be no less than 4:1. In other regions, the ratio should be no less than 3:1. ToU price mechanisms have now been adopted in multiple provinces and cities to manage electricity demand peaks during winter and summer, in line with broader plans to reform China's power markets.

Anhui province

Anhui province, in eastern China's HSCW zone, is primarily reliant on coal for power generation. However, renewables are expanding rapidly (dominated by solar PV) and accounted for nearly one-third of electricity generation capacity in 2020. In light of increasing demand for electricity and in order to avoid curtailment of renewables, the province is developing demand response, with the aim that by 2025, demand side capacity should account for 5% of annual maximum power load.

Anhui province provides a ToU pricing scheme for consumers that sets separate peak and off-peak price periods. To help consumers better understand ToU pricing and its benefits, the province's state grid operator launched a mobile phone application that allows customers to calculate the potential cost savings of using a tariff with peak and off-peak pricing via an 'Electricity Cost Calculator'. The application provides users with a breakdown of electricity use over the past 40 days, recording total consumption in peak and off-peak time periods.

According to Anhui's 2022 per capita electricity consumption, a household of three consumes around 3 000 kWh per year. By opting into use of ToU electricity pricing, it is estimated that a household of this size in Ahnui province could save CNY 500 in electricity bills each year, or more than CNY 40 each month (assuming that more than 70% of total electricity consumption takes place at night during the off-peak period of 22:00-08:00).

Time-of-use pricing policies in Anhui province

Monthly power usage (kWh per household)	Electricity price (CNY/kWh)		
	Standard price (no ToU tariff)	Peak period (08:00-22:00)	Off-peak period (22:00-08:00)
0-180	0.57	0.60	0.32
181-350	0.62	0.65	0.37
>350	0.87	0.90	0.62

Shanxi province

Shanxi province in northern China has a total power generation capacity of over 120 GW. Coal power generation still accounted for nearly 60% of the total at the end of 2022, though renewable capacity had expanded to 23 GW of wind and 17 GW of solar PV. Residents have typically been reliant on use of scattered coal for heating during the province's cold winters, but the government has introduced campaigns to promote a switch from coal to electric heating, including preferential electricity tariffs during the heating season. Residential users can choose from three options: 1) the peak-valley pricing approach; 2) an electricity consumption quota (CNY 0.29/kWh), with any excess charged at a higher rate (CNY 0.51/kWh); or 3) a flat price of CNY 0.48/kWh.

Thermal energy storage for district heating to facilitate the integration of variable renewable energy

Thermal energy storage is a key technology for limiting the impacts on electricity systems as district heat supply is increasingly electrified with large-scale heat pumps.

Using heat pumps in combination with thermal energy storage technologies can help to optimise heat supply by transforming surplus electricity from renewable sources produced in the summer into heat and storing it for use during the winter heating season. This avoids curtailment of renewables at the same time as reducing the need for additional power generation capacity for large-scale heat pumps during winter. Waste heat from industry and other sources such as data centres can also be recovered by large-scale heat pumps and stored during warmer months, further optimising the interaction between electricity and heat systems. In such a system, most heat could be stored in the form of large water pits, which are among the cheapest storage options and allow for heat to be stored over long periods of time (Box 3.5).

Storage systems combined with large-scale heat pumps therefore have a critical role to play in Chinese district heating systems. In northern Hebei, for example, heat recovered by heat pumps from renewable power and waste heat could account for 80% of the district heat supply during winter in 2050.

Box 3.5 Thermal energy storage in heat, power and industry sectors

Thermal energy storage technologies cover a wide range of applications, sizes and temperatures, though only few options are widely used today. Heat is commonly stored in hot water tanks at the household level, for example. Heat storage in large water pits for use in solar-based district heating is already common in Denmark. In China, there are two water pit demonstration projects to date, while several pits with volumes between 100 000 m^3 and 400 000 m^3 are in planning. These examples are intended for inter-seasonal storage, but the same technologies can be used for a wide array of timeframes, from a just few hours to months. For industrial applications with high-temperature heat requirements, heat can be stored at up to 1 800 °C, or at temperatures as low as -160 °C for other industrial applications. However, technological readiness levels for heat storage in industry remain relatively low.

Characteristics of key thermal energy storage technologies

	Sensible heat storage	Latent heat storage	Chemical reaction storage
Description	Energy is stored by changing the temperature of a solid (rock, metal, etc) or liquid without changing its phase.	Phase change of a material is used to store energy.	A reversible thermo-chemical reaction is used to store energy.
Storage options and main applications	Water tanks: buildings Water pit: district heating Molten salt: utilities and industry Solid: all applications	Ice: space cooling PCM: buildings High-temperature PCM: industry	Calcium looping: industry
Storage period	Water tank: Up to months Water pit: Up to months Molten salt: Up to days Solid: Up to months	Ice: Up to days PCM: Hours High-temperature PCM: Up to days	Calcium looping: Up to months
Temperature range	0 to 100 °C for water Up to 560 °C for molten salt Up to 1 400 °C for solids	-110 to 1 000 °C	50 to 1 800 °C depending on chemical
Density	<210 MJ/m^3 for water <110 MJ/m^3 for solid	<430 MJ/m^3	<26 000 MJ/m^3

	Sensible heat storage	Latent heat storage	Chemical reaction storage
Cost	USD 0.1-35/kWh	USD 60-230/kWh	USD 15-150/kWh
TRL	High	Medium to high	Low
Advantages	Inexpensive; Scalable to very large capacity	More compact than sensible	Higher energy density than sensible; Low heat losses
Limitations	Insulation is required; Lower energy density	Effective in a narrow temperature range	More expensive; Low maturity

Notes: PCM = Phase Change Material. TRL = Technology Readiness Level. Cost ranges based on 2018 data for district heating. Utilities cover power production and district heating.

Sources: EERA (2022) Industrial Thermal Energy Storage; IRENA (2020) Innovation Outlook: Thermal Energy Storage; Clifford at al. (2020) Thermal energy storage technologies; IEA (2023) ETP Clean Energy Technology Guide; IEA ES TCP (2024) Thermal Energy Storage.

Sensible, latent and chemical reaction storage are the most common heat storage types, but other technologies and combinations thereof also exist. For example, sorption relies on a reversible reaction between a gas and a solid or liquid absorbent, but it is not yet a mature technology. On the other hand, there are already technologies on the market that exploit synergies such as the improved energy density achieved by combining latent and sensible heat storage technologies. Thermal storage can also be coupled with mechanical storage. For instance, in an adiabatic compressed air energy storage facility, the compression of air generates heat which can be stored for later use to generate electricity when the gas expands.

Thermal energy storage can also help balance heat supply and demand, reducing the need for peak production capacity. For example, the Mustikkamaa storage facility in Helsinki, Finland, can store up to 12 GWh in a cavern. To optimise space cooling, ice can be produced at night, when prices are lower, rather than during the day, when buildings need to be cooled. This technology is used at JCPenney's headquarters in Texas, United States, for example. Further applications include configurations used in combination with concentrated solar plants or thermal batteries to store excess energy and optimise electricity generation.

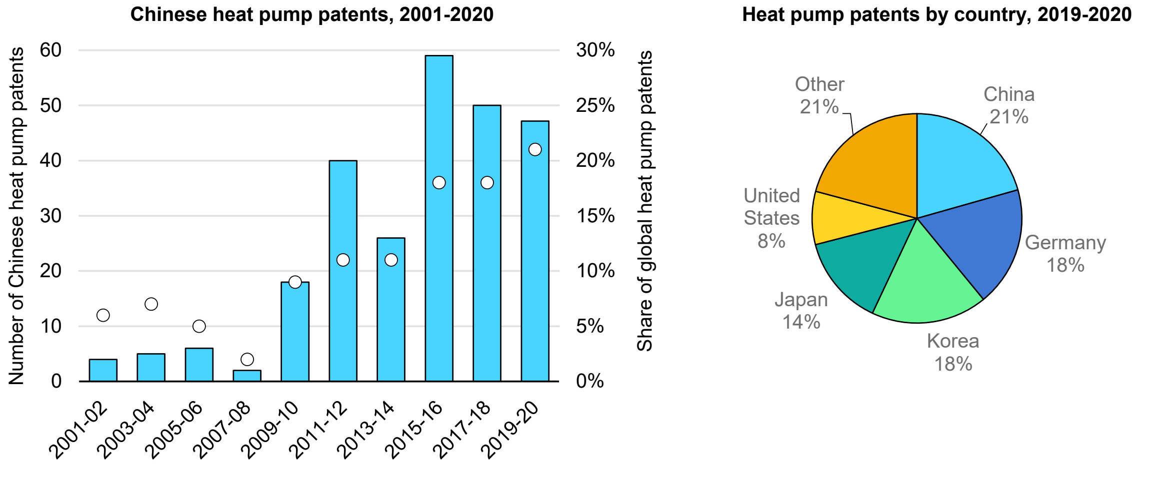
Space constraints are the key barrier to scaling up heat storage: for instance, a 2.6 GWh system operated by Vattenfall near Berlin, Germany, requires 56 million litres of water, equivalent to about 22 Olympic swimming pools. Common Li-ion batteries are about ten times more energy dense in comparison. The development of more energy-dense chemical solutions will help alleviate this burden, though at the cost of higher capital investment.

Innovation activity and needs

Heat pump performance has improved significantly over the last decades thanks to global R&D efforts, which have, for example, improved efficiency and reduced noise. Continued innovation is required, however, such as for heat pumps for use in very cold climates or in multi-family buildings. China's efforts on heat pump innovation are reflected in its membership in the IEA's Technology Collaboration Programme on Heat Pumping Technologies, through which China co-operates with international partners from academia and industry on topics such as high-temperature heat pumps and integrated solutions for heat pumps and storage.

In recent years, China has topped the list of countries registering patents for heat pump technologies, which reflects the country's position as a major heat pump manufacturer. China's share in global heat pump patent counts has more than tripled since 2000 to reach 21% in 2019-20, followed by Germany and Korea with 18% each (Figure 3.16). Innovation activity accelerated in the 2010s in China and peaked at nearly 60 patents in 2015-16, though patent counts for heat pumps designed for cold climate zones continue to rise. In 2019-20, patent counts relating to technologies for cold areas accounted for nearly 30% of all heat pump patents in China, more than double the share ten years earlier.

Figure 3.16 Chinese heat pump patents and their share in global heat pump patents, 2001-2020, and heat pump patent distribution by country, 2019-2020



Notes: Countries' data on heat pump innovation is based on the location of the patent applicants. Where multiple applicants are indicated for a distinct international patent family, each applicant and corresponding location was assigned a fractional share.

China's share in global heat pump patent counts has more than tripled since 2000 to reach more than 20% in 2019-20, making the country a hot spot for heat pump innovation.

Chinese heat pump technology inventors also increasingly seek protection abroad, both at the global level through the World Intellectual Property

Organization (WIPO) and at patent offices in the European Union and United States, reflecting export interests in these markets. Within China, most patents are registered by inventors in the R&D hubs of Shanghai, Beijing and Guangdong, which is also a focal point for heat pump manufacturing.

Chapter 4. Policy solutions for heat pump deployment

Developing a comprehensive policy framework for heat pump deployment in line with China's carbon neutrality goal

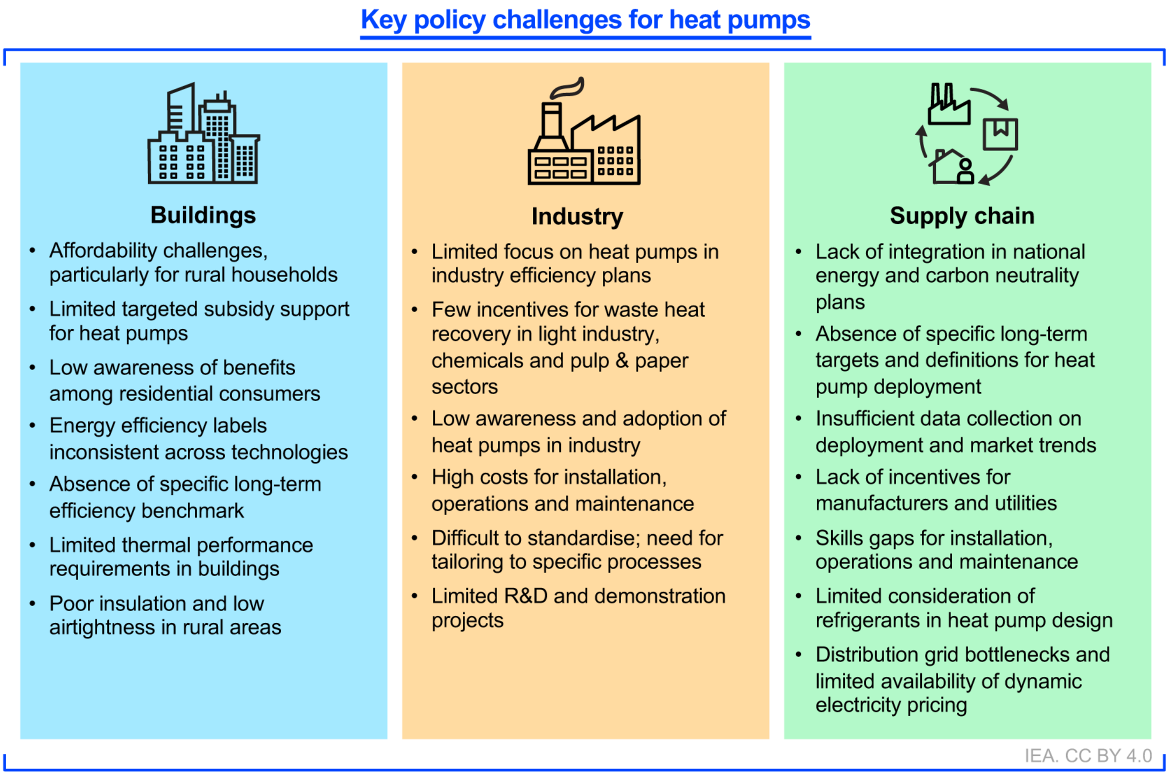
China has made significant progress on reducing energy usage, CO_2 emissions and other pollutants associated with heating by introducing a range of measures to encourage shifting towards cleaner heating alternatives, principally in north urban China. Achieving accelerated decarbonisation of heating will be key for meeting China's carbon peaking and neutrality targets. This will require closer co-ordination of national-level planning with local implementation to ensure adoption of the most efficient low-carbon heating technologies and solutions. An accelerated shift towards cleaner heating technologies could unlock significant benefits in terms of household, commercial and industrial energy savings, as well as air quality improvements and emissions reduction.

Heat pumps are a key clean heating technology in the transition to secure and sustainable heating and can deliver increasing advantages as electricity systems decarbonise in China. In addition, heat pumps can play an important role in supporting China's broader clean energy transition, such as through integration with distributed renewable energy technologies to support clean energy consumption and broader power system flexibility.

In recent years, heat pumps have increasingly featured in the latest Chinese national-level policies as part of plans towards carbon neutrality. The 14th Five Year Plan (FYP) for a Modern Energy System (2021-2025) highlights the expansion of clean heating as part of electrification for end users, in accordance with local conditions. Heat pumps are also included in the 2022 industry energy efficiency action plan, and actively promoted in the 14th FYP for buildings. However, there are no specific milestones for floorspace coverage or total installed capacity of heat pump technologies, limiting the overall signals for investment in the sector. In addition, there are multiple institutional, technology, policy, financing and behavioural challenges across buildings, industry and the broader supply chain in China that could limit wider adoption of heat pump technologies (Figure 4.1).

Key barriers to be addressed include the affordability of heat pumps, low awareness of their benefits among end consumers, the potential for future skills gaps as deployment accelerates, and insufficient overall data to track market and technology developments. This chapter sets out key policy recommendations for overcoming these barriers, and for ensuring that heat pumps are considered as a solution within China's broader policy framework for the decarbonisation of heating in the buildings and industry sectors.

Figure 4.1 Policy challenges for heat pump deployment in China



There are multiple technology, policy, financing and behavioural challenges that could limit adoption of heat pump technologies at a broader scale.

Policy measures to encourage sustainable growth of the heat pumps market in China should encompass targets for the near, medium and long term. Action to support the adoption of heat pumps must be complemented by measures to improve their efficiency and to encourage overall reduction of heating demand in buildings and industry. More widely, there is also a need for measures to promote flexible control of heat pumps and an increased proportion of renewable electricity in the system. Given that China's power system is currently moving into a phase of rapid transformation towards more granular electricity pricing and increased integration of renewables, it is important that the deployment of heat pumps is co-ordinated within this broader transition.

The definition of near-, medium- and long-term actions requires setting out a **clear national action plan for heating decarbonisation.** This should cover various types of heating demand and heating sources, alignment with broader clean energy and power system plans, R&D for key technologies and promotion of their uptake, as well as addressing existing institutional and policy frameworks that provide incentives for continued adoption of fossil fuel-based solutions. Such a plan could introduce specific targets for heat pump deployment and promote greater co-operation between policy makers, manufacturers and end users. This could also support the establishment of more specific milestones for heat pump installation in the 15th FYP (2026-2030) and other upcoming strategies to realise China's carbon peaking and neutrality targets, thereby sending a clear signal to manufacturers, stakeholders in the power sector, industry end users and individual consumers.

In combination with clear measures to reduce support to fossil fuel-based heating, which currently dominates China's heating sector, this could create a level playing-field for heat pumps and other clean heating solutions that can promote energy efficiency improvements in support of China's broader targets for improving energy and carbon intensity of its economy. Integrating measures into relevant sector plans under China's 1+N policy framework for carbon neutrality would help to ensure alignment, addressing potential issues with lock-in and emissions increases. This chapter aims to provide policy recommendations to support sustainable growth of China's heat pump sector, in line with short, medium and long-term energy transition and emissions reduction plans.

Figure 4.2 Policy recommendations to drive up heat pump deployment in China

Set a national action plan for heating decarbonisation, including detailed actions for heat pump deployment

BUILDINGS

SHORT-TERM

- Strengthen energy efficiency standards
- Revise and unify labels across heating devices and launch awareness campaigns
- Strengthen upfront cost support for heat pumps

LONG-TERM

- Integrate more stringent performance requirements in regulations for new buildings to prepare for heat pump adoption
- Support large-scale retrofit packages for existing buildings as part of a co-ordinated heat pump rollout
- Phase out subsidies for fossil fuel-based heating to free up financing for cleaner, more efficient heating solutions

INDUSTRY

SHORT-TERM

- Increase awareness and support selection of heat pump solutions
- Promote heat pump research and demonstration projects
- Provide support to overcome installation, operations and maintenance costs

LONG-TERM

- Expand actions to drive waste energy recovery through heat pumps in light industries and district heating
- Introduce heat pumps as a recommended technology choice for decarbonising heating in selected industries

SUPPLY CHAINS

SHORT-TERM

- Establish clear criteria for the classification of clean heating
- Set targets to increase sales and deployment of heat pumps
- Promote heat pump rollout in line with expansion of renewable energy

LONG-TERM

- Promote job opportunities and skills in manufacturing, installation, operations and maintenance
- Enhance data oversight to better understand opportunities for heat decarbonisation
- Consider strengthening standards for lifecycle emissions to inform energy efficiency improvements, including considerations around HFCs and the use of alternative refrigerants
- Consider electricity system and demand flexibility implications in future electrification of heating and heat pump deployment

Measures to promote heat pumps in China's buildings sector

Heat pump deployment can expand rapidly in China's buildings sector, particularly in rural areas and in specific climate zones, such as in the Yangtze River Basin and hot summer-cold winter (HSCW) zone, where centralised district heating is unavailable or difficult to implement. Air-source and ground-source heat pump stocks, in particular, could grow significantly in these regions as their costs come down. With incomes continuing to increase, especially among China's middle class, demand for climate-controlled living and working spaces will also increase, creating new opportunities for heat pumps.

Heat pump rollout must be aligned with broader actions to balance electrification with provision of clean electricity. The policy recommendations in this section specifically refer to decentralised buildings, including buildings in urban areas that are not part of a centralised district heating system, and rural areas, where opportunities for heat pump adoption have the greatest potential (Figure 4.3).

Figure 4.3 Actions to drive heat pump deployment in the Chinese buildings sector

Driving heat pump deployment in buildings

Heat pump deployment in China's buildings sector can be optimised through adoption and co-ordination of immediate, medium-term and long-term actions.

Immediate actions

- Improve the focus of existing subsidy schemes to promote heat pumps
- Encourage new business models for clean heating services
- Promote awareness campaigns on the benefits of heat pumps for carbon neutrality
- Review installer, operations and maintenance capacity and training schemes
- Work towards revision and unification of standards and labels for household heating equipment

Medium-term actions (2026-2030)

- Set targets for heat pump deployment in line with China's 30-60 targets
- Phase down subsidies for fossil fuel heating technologies, freeing up resources for promoting clean heating solutions
- Promote market-based incentives for coal-to-electricity switching
- Introduce certification requirements for heat pump installers
- Introduce zero-emission building standards for all new buildings
- Promote large-scale thermal retrofits in rural areas

Supply chain long-term actions (2030 onwards)

- Introduce mandatory energy performance requirements for major renovations
- Ensure all buildings are grid-interactive enabled
- Promote heat pump flexibility and power system integration
- Expand access to dynamic electricity pricing for end consumers
- Fully establish a market-based model for clean heating

Immediate priorities for promoting awareness and increasing support for heat pump uptake should be combined with medium-term action to accelerate adoption, increase provision of clean electricity and integrate heat pumps into broader buildings policies.

Promote comprehensive large-scale retrofits that combine envelope improvements with heat pump rollout

Under the 14th FYP, China aims to complete energy-saving renovations of over 350 million m^2 of existing buildings. The scale of this expansion presents a significant opportunity for measures that can pave the way for accelerated decarbonisation of heating in the buildings sector, including through the application of efficient heat pump technologies. When considering future heat pump adoption, it is important that the thermal envelope of existing buildings can be upgraded to ensure that heat pump adoption results in the most efficient outcome while avoiding significant heat losses.

The Chinese government could expand its ambitious objectives by targeting comprehensive renovations that combine improvements to the thermal envelope with a switch to clean heating in existing buildings. All policies related to retrofit incentives, regulation and information should then be adapted to promote more comprehensive renovation projects in line with such a target. Subsidy schemes can be adapted to provide additional incentives for more comprehensive renovation projects. Through Czechia's New Green Savings Programme, for example, a deep retrofit 'bonus' subsidy is awarded for simultaneous renovations to several elements, such as the installation of a heat pump coupled with wall insulation or window replacement.

Village, county or district-scale programmes can help reduce the complexity of comprehensive retrofit projects for citizens, as many of the project management functions and administrative burdens are taken on by professionals co-ordinating the work. Such schemes would also create the economies of scale needed to lower the upfront and installation costs of heat pumps. China's Whole County Solar PV scheme, which aims for a minimum percentage of rooftops to be equipped with solar PV, could provide inspiration for a retrofit scheme, and China's expansive energy services (ESCO) industry could co-ordinate large-scale insulation and heat pump installation programmes.

Advisory services should be set up to engage with citizens involved in large-scale renovation projects, and with owners of single-family homes carrying out comprehensive renovation projects on their own. In Ireland, a One Stop Shop Service provides the complete design and management of energy upgrades for homes, limiting the administrative burden of renovations for consumers.

Chinese authorities could strengthen the energy performance benchmarks provided to guide such comprehensive, large-scale renovation projects. Since 2013, all EU member countries have established building codes for existing buildings undergoing major renovation.[39] While the EU Energy Performance of Buildings Directive (EPBD) only sets requirements to at least cost-optimal levels, some countries – including Germany, Sweden and Denmark – have established more stringent requirements that are more closely aligned with standards for new buildings. Stronger building codes for retrofits can ensure that more buildings undergoing renovation are well suited to heat pump installation, either as part of the retrofit or at a later date. In contrast, the Netherlands has comparatively less stringent requirements for major renovations, but has developed a voluntary insulation standard which encourages building owners to go beyond legal requirements and ensure that the renovated building is well suited to any clean heating solution (Box 4.1).

Box 4.1 Dutch government scheme to encourage 'gas-free ready' retrofits

The Dutch government plans to ban new fossil fuel heating installations as of 2026. This builds on an existing home 'insulation standard', in place since 2021, which encourages building owners to renovate their buildings to be 'gas-free ready' – i.e. suitable for either the efficient use of a heat pump, or a connection to low-temperature district heating. The voluntary standard is displayed on Energy Performance Certificates and helps building owners future-proof their renovation works.

A single standard that takes into account both heat pump deployment and the evolution of district heating can remove some of the uncertainty associated with technology-specific policy decisions and differing approaches in different municipalities. The Dutch standard recommends varying levels of overall compactness and net heat demand, as well as target performance levels for key building elements across four broad categories of building type. The recommendations for overall heat demand are more ambitious than Dutch requirements for major renovations, while remaining substantially weaker than the Dutch nearly-Zero Energy Building (nZEB) standard.

[39] EU EPBD defines 'major renovation' as the renovation of a building where more than 25% of the surface of the building envelope undergoes renovation, or the total cost of the renovation relating to the building envelope or the technical building systems is higher than 25% of the value of the building, excluding the value of the land on which the building is situated.

Integrate more stringent performance requirements in regulations for new buildings to expand heat pump adoption

Reducing the overall future heating load in buildings through energy and thermal performance improvements will be key for maximising efficiency gains from heat pump adoption and limiting the impact on the power grids. Building energy codes currently provide the most effective way to improve energy performance, and are particularly important given that most buildings typically remain in use for many decades. At the Conference of the Parties (COP) 28, China pledged to commit to the Buildings Breakthrough, which calls for near-zero-emission and resilient buildings to be the norm by 2030. This builds on targets set out in the building sector 14th FYP to construct more than 50 million m^2 of ultra-low and near-zero-energy-consumption buildings by 2025.

China should aim to expand these requirements to all new buildings, both urban and rural, in the near future. The introduction of clear minimum requirements for clean heating and thermal performance in the national building code would provide a strong signal to manufacturers, developers and consumers on the future of heating in China's buildings. The European Union set targets under the EPBD, first introduced in 2010, requiring that member countries ensure that all new public buildings were nearly zero-energy after 31 December 2018, and that all new buildings were nearly zero-energy by the end of 2020. In its 2023 revision, the European Union proposed moving from current near zero-energy buildings to zero-emission buildings (ZEB) by 2030, with ZEB requirements to apply to all new buildings by 1 January 2030.

Furthermore, updates to the building code should include requirements relating to space for the installation of heat pumps and other clean technologies in new buildings, to avoid the installation challenges faced in many parts of the current building stock.

Box 4.2 California's updated building code and measures aim to promote affordable adoption of heat pumps in new buildings

There has been strong progress in rolling out heat pumps in California, United States, with more than 1.5 million units installed as of 2022. That year, the market share for new single-family homes was 55% for heat pump space heaters and 16% for heat pump water heaters. The California 2022 Building Energy Code aims to expand energy efficiency practices in buildings, and to establish heat pumps as the norm for new single-family homes. The code encourages installation of efficient electric heat pumps for space and water heating, establishing electric-ready requirements for new homes, expanding solar PV and battery storage standards, and improving ventilation standards. From the beginning of 2023, all new builds must comply with the code.

California's Electrification Strategy also includes measures to encourage adoption of highly efficient electric appliances, including heat pump space heaters and electric clothes dryers. Space must be reserved on the main electrical service panel in buildings to allow for the future installation of heat pumps and electric hobs. In order to help residents locate contractors, in 2023 the state launched Clean Energy Connection, a free online directory of vetted contacts that can provide heat pump upgrades. Utility companies also offer savings for customers upgrading to energy-efficient heat pumps, such as in the Sacramento Municipal Utility District, which offers up to USD 3 500 in rebates when the heat pump is installed by a qualified contractor.

Strengthen upfront cost support for heat pumps through provision of targeted incentives and development of market-based models

In order to make heat pumps more affordable, China could more effectively target tax credits and funding support already in place to promote coal-to-electricity switching for heating towards supporting switching to heat pumps as the most efficient available technology. Introducing more targeted support for heat pumps could benefit from the extensive administrative structures for heating subsidy provision already in place, in particular for district heating and in rural areas. In regions in the HSCW zone, where large-scale district heat is limited, expanding policies for supporting heat pump uptake will become increasingly important. This could be integrated with ongoing efforts to promote distributed renewable energy, such as those underway in rural areas. The operational costs of running a heat pump should also be considered. Giving households with a heat pump priority access to existing subsidised electricity tariffs would provide an additional incentive without requiring any additional government funding.

A range of subsidy types for heat pumps, including grants, rebates and tax deductions, have been introduced in countries around the world, which can provide experience for policy design in China (Box 4.3). Domestic examples of operational cost subsidies are also available, such as in Shanxi province, where households are provided with electricity subsidies under the coal-to-electricity switching programme. Combining such support with larger-scale programmes for heat pump rollout, similar to programmes focused on renewable energy, would further help to drive down costs, increasing access to clean heating technologies for more households and businesses. Given that provision of subsidies can be a burden for government budgets, China should look to explore market-based models that can continue to incentivise investment in and adoption of clean, efficient heating technologies without the need for long-term subsidy support.

Box 4.3 Consumer-targeted heat pump policy support schemes in selected countries

Despite a rapid increase in heat pump installations in key markets such as Europe, the investment costs for low-emissions heating systems such as heat pumps remain higher than for fossil fuel-based heating devices. Financial incentives, such as grants, rebates, and other subsidies, are currently available in over 30 countries around the world, covering 70% of today's heating demand.

Country	Programme description
Austria	Austria offers a grant for air- and ground-source heat pumps installed in new buildings of up to 50% of the costs to a limit of EUR 7 500 (USD 8 200/CNY 58 000), plus an additional EUR 2 000 (USD 2 200/CNY 15 500) if a gas boiler is replaced. For heat pumps with a Global Warming Potential (GWP) higher than 1 500 the total eligible amount is reduced by 20%, and GWP must not exceed 2 000. For retrofit installations, the grant covers up to 35% of the cost to a maximum of EUR 5 000 (USD 5 500/CNY 39 000). The subsidy is in place from 3 January 2023 to 31 December 2024, and is expected to be increased in 2024.
Canada	Under the Canada Green Homes initiative, grants of up to CAD 5 000 (USD 3 700/CNY 26 700) are offered for switching to energy-efficient space or water heating equipment. Replacement of an existing heat pump can give access to up to CAD 3 000 (USD 2 250/CNY 15 900). The heat pump must be installed by a licensed and trained professional to be eligible.
France	In France, existing properties can get a grant of up to EUR 10 000 (USD 10 900/CNY 77 800) for purchasing ground-source heat pumps and up to EUR 4 000 (USD 4 400/CNY 31 200) for air-water heat pumps. The scheme is in place from 2020 to 2024. A rebate of EUR 5 000 (USD 5 500/CNY 39 000) has also been available since 2023 for households that replace an old heating system with a new energy-efficient heat pump.
Germany	From 2024, all homeowners who install climate-friendly heating systems will be reimbursed for 30% of the investment costs. If the taxable household income is below EUR 40 000 (USD 44 000/CNY 312 600) (which applies to 45% of homeowners) a further 30% subsidy will be added. An additional 20% is available if the installation occurs before 2028, but total subsidies are capped at 70%.
Japan	In the residential sector, subsidies were introduced for heat pump water heaters (EcoCute) and hybrid heat pump water heaters up to JPY 50 000 (USD 344/CNY 2 460) in 2022. These have since increased to JPY 100 000 (USD 688/CNY 4 940) and JPY 130 000 (USD 895/CNY 6 420), respectively.
Poland	In April 2022 Poland introduced a new programme called "My Heat", aiming to promote increased acquisition of heat pumps, with an initial budget of USD 140 million (CNY 996 million). Participants can receive a subsidy of 30-45% of eligible costs, totalling between USD 1 600-USD 4 900 (CNY 11 400-CNY 34 800), depending on the equipment purchased.

Country	Programme description
United Kingdom	The United Kingdom has introduced the Boiler Upgrade Scheme. In October 2023 the government upgraded grant support towards the cost and installation of three low-carbon heating systems. For air- and ground-source heat pumps, a grant of up to GBP 7 500 (USD 9 500/CNY 67 800) is available, and GBP 5 000 (USD 6 400/CNY 45 200) for biomass boilers. Heat pump installations are also exempt from value-added tax, further reducing costs.
United States	Following the introduction of the Inflation Reduction Act in 2022, homeowners will be able to access support for household energy efficiency upgrades through 2032. Through provision of federal income tax credits, homeowners installing heat pumps will be eligible for tax credits covering 30% of heat pump cost and installation up to USD 2 000 (CNY 14 300). Tax credits are capped at USD 2 000 per year, and homeowners are encouraged to spread efficiency improvements over multiple years to maximise access to the credit. Rebates will also be made available in 2024 for low- and moderate-income households, covering up to 100% of point-of-sale purchases for low-income households and up to 50% of costs for moderate-income households.

Note: the examples above are for single-family residences unless otherwise stated.

Encourage new business models for clean heating services to help customers, facilitate adoption and reduce long-term need for subsidy support

New business models for household heating can help to expand the market for heat pumps, and new offers to consumers, such as property-linked financing, can help make installing and running a heat pump more affordable. Other innovative financing models include heat as a service, where consumers pay for heat rather than for both equipment and fuel, as well as subscriptions, rental and leasing models. The government could investigate the viability of such approaches with a view to supporting development of a new market structure for clean heating services. Schemes that aim to reduce upfront costs and provide an overall service package may be particularly useful in poorer rural areas, where initial costs could be a barrier even with targeted subsidy support. Such approaches could be particularly effective in addressing the affordability of higher cost technologies, including air-to-water, ground-source heat pumps and heat pump water heaters.

In the longer term, as incomes continue to increase, especially among China's middle class, the implementation of a market-based model for clean heating adoption can reduce the need for long-term subsidy support. Financial support for households could also encourage development of new business models, as has been seen in the United Kingdom, where Octopus Energy expanded into the heat pump market following the introduction of subsidies (Box 4.4). The Swedish company Aira has also introduced an end-to-end subscription service for heat pumps, involving monthly payments and no upfront charge. Introduction of market-based incentives that can encourage new business models will be key in the long-term in China to continue promoting affordability and sustainability of clean heating solutions without relying on public funding.

Box 4.4 Octopus Energy combines smart home control and affordable heat pumps to support heating decarbonisation

Heating buildings accounts for nearly a quarter of the United Kingdom's carbon emissions, and the country is targeting 600 000 heat pump installations a year by 2028 as part of wider efforts to reduce emissions and reach net zero. To support households with installation costs, the UK government recently increased grants for heat pumps from GBP 5 000 to GBP 7 500 (USD 6 300 to 9 500). Households are required to have an Energy Performance Certificate from within the past 10 years to be eligible.

Octopus Energy, a United Kingdom-based renewable energy company, has recently expanded to selling heat pumps as part of a package that includes a 6 kW heat pump designed to heat a typical three-bedroom UK home, home control system called 'Cosy Octopus', smart tariff and other features. The heat pump runs at temperatures of 78-80 °C and is designed to be compatible with most existing radiator and hot water systems. When combined with government grants, the system is free to small homes which have up-to-date hot water tanks and heating systems. For households that do not meet these criteria, the scheme starts at GBP 3 000 (USD 3 800) after grants under the government's Boiler Upgrade Scheme have been applied.

Phase out subsidies for fossil fuel-based heating to free up financing for cleaner, more efficient heating solutions

Over the past decade, the introduction of cleaner heating programmes promoting switching from coal-fired heating to either gas or electricity in China have contributed to reducing the use of coal-fired boilers and delivering significant improvements in air quality. Multiple provinces and municipalities in China continue to offer subsidies for both coal-to-gas and coal-to-electricity heat switching, such as Shandong, Shanxi and Henan. Subsidies are provided in the form of fuel subsidies per cubic metre, with an annual usage cap. Other support subsidises purchase and installation costs for gas equipment when switching from coal-fired boilers, such as in Hebei province. In some parts of Beijing, subsidies are available specifically for purchase costs of equipment including air-to-water and air-to-air heat pumps, but also gas heating.

Continued support for gas-based heating methods, which lock in CO_2 emissions, limits the support available for the cleanest and most efficient technologies. Reviewing existing support for gas-based heating will be important as China aims to promote electrification and accelerate emissions reductions. China could consider setting timelines for the exclusion of fossil fuel-based heaters, such as gas boilers, from existing subsidy programmes. Given that low-income households are more likely than others to be reliant on coal or gas-based heating, additional support may be required to ensure that they can transition to clean heating in line with such timelines. In the European Union, the EPBD sets a timeline to end subsidies for fossil fuel heating systems from 2025 and phase out gas boilers and other fossil fuel heaters by 2040. Adopting a similar approach in China would help to redirect funding that is currently allocated to supporting fossil fuel-based heating towards clean and efficient technologies, while supporting a broader decrease in fossil fuel subsidy provision.

A broader redefinition of what constitutes clean heating to only include globally recognised clean heating solutions could also help to clarify the technology, policy and financing options that policy makers can consider for longer-term decarbonisation. In addition, China could also consider introducing plans to phase out the use of fossil fuel-based heating in buildings in order to further strengthen signals around the shift to clean heating methods. This could accompany action to phase out subsidies for fossil fuel-based heating. To date in Europe, 13 countries have implemented or announced bans or other policies to limit the installation of oil-fired boilers, and 9 of them have done the same for gas-fired boilers.

Continue to strengthen energy efficiency standards for heat pumps and launch awareness campaigns

China's standards and labelling programme has led to significant energy savings, including delivering savings of over 90 TWh in 2022 alone – equivalent to the electricity consumption of Chile and Costa Rica today combined – across 16 product categories, including inverter and multi-unit (heat pump) air conditioners. Heat pumps are more efficient than other heating technologies, but rapid growth in deployment will nevertheless require attention to the energy efficiency of different models, in order to limit overall increases in electricity demand.

In China, energy efficiency standards are set for a range of appliances, including heat pump water heaters, and revised annually at three levels: a Minimum Energy Performance Standard (MEPS) (or 'Access' level), 'Energy Saving', and 'Advanced' levels. Policy makers could expand this structure by setting energy efficiency thresholds to enter into operation in future years, increasing the current MEPS level. This could follow an energy performance ladder model, and be aligned with key policies such as the 15th FYP (2026-2030), providing a clear signal to industry and consumers that policy makers are prioritising a medium- and long-term shift to more efficient models. Use of air conditioners and heat pumps with electric resistance auxiliary heating functions, which is widespread in China, can also affect the overall coefficient of performance (COP) of equipment used. China should undertake detailed analysis of the efficiency of models currently available in the domestic market and ensure that consideration of auxiliary heating functions is included in the standards-setting process. Similar approaches have been introduced in China for industry benchmarking, with recently set phase-out dates in 2025 and 2026 for least-efficient entities across major industry sectors.

Complementary measures can further support the uptake of best available technologies. For instance, China's building code requires a minimum COP of 3.5 for heat pumps in the HSCW and temperate climate zones. Shifting to best-in-class models should form part of medium and long-term rollout strategies in China. Current testing methods, which focus on cooling functions and heating at mild outdoor temperatures (around 7 °C), should also be revised to address underperformance of heat pumps installed in cold and severe cold climates, which can otherwise result in a negative consumer experience.

Low awareness of the benefits of heat pumps and limited access to information on operating costs can limit willingness to shift away from traditional heating methods and invest in heat pumps. Highlighting and strengthening awareness through provision of clearer information on lifetime costs, and comparison between technology options (see Chapter 3), is therefore key for supporting informed consumer choices that can promote long-term affordability. In particular, rural households may have lower awareness of the potential benefits of heat pumps. Education campaigns and targeted outreach programmes could play a pivotal role in highlighting the economic and environmental benefits of heat pump technology compared to gas-based and other heating methods.

Revise energy efficiency standards and labels across heating technologies and work towards their unification to promote competition and efficient purchasing behaviour

China is a member of the Super-Efficient Appliance Deployment Initiative (SEAD), a collaboration of more than 20 governments, the IEA and other partners to accelerate energy efficiency in appliances and equipment. SEAD launched a Product Efficiency Call to Action during COP 26 in 2021, pledging to double the efficiency of four commonly used appliances, including air conditioners. A key action towards meeting this commitment is the introduction of technology-neutral standards that treat all appliances fairly based on performance and features. This helps to prevent legacy technologies that are outdated or less efficient being unfairly protected by differing requirements that impair comparison with newer, more efficient technologies.

Labels for heat pump, electric, gas and solar water heaters in China currently have significant differences in terms of energy efficiency grades and indicators (Figure 4.4), which can be a barrier to comparison and understanding. For example, heat pump water heaters are graded 1-5 with an Energy Efficiency Rating (EER) provided as a Watt for Watt (W/W) measure, whereas electric water heaters have grades from 1-3 and EER presented as thermal load (kW). This makes it difficult for consumers to make informed choices based on energy efficiency, running costs and other key features.

Figure 4.4 Energy efficiency labels for different water heaters in use in China, 2023

Notes: Measures used on energy efficiency labels for water heaters differ across technologies, with heat pump water heaters using an energy efficiency rating as a Watt for Watt (W/W) measure, electric water heaters rated based on constant thermal load (kW), gas water heaters on 24-hour inherent energy consumption factor, and solar water heaters on Coefficient of Thermal Performance.

Source: reproduced from China National Institute of Standardization (2024).

There are significant differences in energy efficiency grades and indicators used across energy efficiency labels in China.

China should aim to work towards a unified standard for labels for heating appliances that can help guide consumers to the most energy-efficient appliances, and would provide clearer information on the potential economic payback of heat pumps compared to other technologies. Harmonisation would also help to steer the market towards development of more efficient technologies, by creating a more level playing-field for different technologies. Providing performance indicators for both heating and cooling modes for reversible units can also help consumers make informed choices. In addition, the introduction of climate-specific information can also better inform consumer choices depending on their region. China could draw on the experiences of introducing unified labels for heating in the European Union and Japan, for example, to inform design of their own labels (Box 4.5).

Box 4.5 Unification of labels for water heating technologies in Japan

In 2021 Japan revised its multiple-scale scoring system for electric, gas and oil water heaters. The revised system set a star rating based on energy efficiency regardless of energy type, as well as an annual energy cost. The rating and estimated charges are based on use by four-person households in Tokyo and Osaka. The labels also include QR codes to allow retailers and consumers to access further information, such as on differences in energy consumption of water heaters based on regional ambient temperatures and the number of people in a household.

Explore potential for heat pump rollout in buildings in line with expansion of distributed renewable energy technologies

Heat pumps have the potential to facilitate growth in the proportion of renewable energy in end-use consumption in line with national aims. Progressive increases in renewable electricity generation, combined with the electrification of end consumption, can increase the emissions savings from heat pumps over time. Heat pumps also enable greater use of renewable energy sources when deployed alongside distributed technologies and energy storage (Box 4.6). For example, heat pumps combined with a suitable storage buffer allow electricity generated with solar PV during the daytime to be stored for consumption during peak demand periods in the evening.

As distributed and off-grid solar solutions undergo rapid expansion in China, there are increasing opportunities for pairing with clean technologies, including heat pumps and EV charging. A heat pump combined with a solar PV system has the potential to optimise use of solar energy generated during the day and shift consumption to the evenings for hot water and other uses. The potential for solar PV and heat pumps to provide combined benefits is affected by multiple factors, including use of a buffer storage tank, weather conditions (sunshine and low temperatures), and consumer behaviour (use of appliances such as washing machines and showers). China should look to investigate this potential further, for example by exploring the potential of Efficient Grid-Interactive Buildings in urban and rural areas where rooftop solar PV is already in place or is planned. This could leverage existing policies such as China's Whole County Solar PV programme to promote wider scale application in the longer term.

China should look to align policies and programmes focused on clean heating and clean energy in order to facilitate a smoother transition towards integration of these technologies that can maximise utilisation of renewable electricity as its share in the power system increases. The February 2024 notice from the National Development and Reform Commission (NDRC) on strengthening the alignment of green electricity certificates and energy conservation and carbon reduction policies presents opportunities by promoting application of green certificates towards energy efficiency actions. Providing strengthened incentives for end consumers to use renewable electricity can also encourage adoption of the most energy-efficient technologies, including heat pumps. Ensuring that incentives are aligned with broader support for electrification of end uses would create potential for more systematic integration of heat pumps.

Box 4.6 Solar heat pumps promote optimisation of self-consumption of electricity for households with PV panels

Feed-in tariffs allow solar PV panel owners to sell electricity to the grid at an above-market price. These measures are designed to promote renewable energy sources such as solar PV in the early stages of their development, when they are not yet economically viable. In Europe, as prices for PV panels are falling and their efficiency is increasing, these incentives are no longer as necessary, and are therefore being phased out in countries such as Belgium, Germany and the Netherlands. This change in the electricity market reflects a shift in focus for households with PV installations, from selling excess production to the grid towards optimising self-consumption.

A case study made by Daikin in Belgium in June 2022 analysed the potential benefits of heat pump technology with PV optimisation as a replacement for existing gas boilers, exploring the impact of storing surplus electricity from solar PV as thermal energy instead of returning it to the grid. When surplus electricity is available, the heat pump increases the set heating temperature within the 250-litre water tank by 10 °C. This experiment showed positive economic returns, with the self-consumption ratio increasing from 33% to 40% and calculated that 35% to 50% of energy needs to produce domestic hot water could be covered by free PV energy over a year. This could deliver energy savings of EUR 90 (CNY 690) to 120 (CNY 925) over a year, more than the estimated EUR 23 (CNY 177) that would have been gained from exporting this additional energy to the grid.

Co-ordinate policy measures to unlock the full potential of heat pumps in China's buildings sector

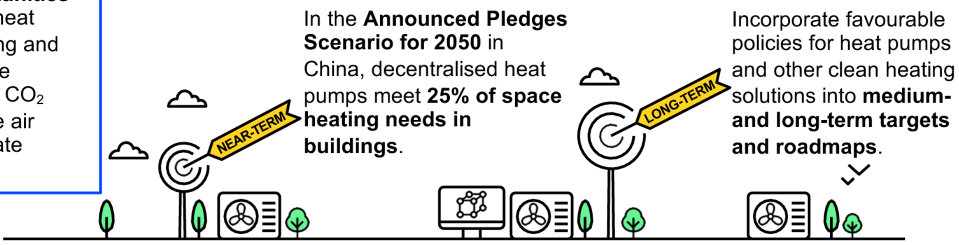
An effective combination of policy measures will be key to fully harnessing the opportunities offered by heat pumps for the decarbonisation of China's heating sector. Policies designed to support heat pumps should exploit synergies with – and be integrated into – China's carbon neutrality planning processes, and be more carefully considered in energy transition pathways.

A co-ordinated approach, based on the IEA's policy package toolkit, combines **regulation, information and incentives**. For example, a combination of strengthened energy efficiency requirements through more stringent standards (regulation), greater harmonisation of energy efficiency labels across heating technologies (information), and subsidies or rebates to address upfront costs (incentives), can lead to significant increases in adoption of heat pumps in the buildings sector (Figure 4.5). Integrating policy packages at the national, provincial and local levels can help to guide manufacturing, investment and uptake of cleaner and more efficient heating equipment.

Figure 4.5 Policy package approach to strengthening adoption of heat pumps in the buildings sector

Heat Pumps Policy Package for Buildings

Immediate opportunities
The expansion of heat pump manufacturing and installations has the potential to reduce CO_2 emissions, improve air quality, and generate employment.



Information

- Introduce stringent **Minimum Energy Performance Standards (MEPS)** to ensure that heating solutions including heat pumps adhere to high-efficiency requirements.
- Mandate that new heat pumps are equipped with **connected controls**, providing flexibility to end-users and the overall energy system, contributing to reducing peak demand.
- Establish **regulations, including building codes**, facilitating the integration of heat pumps. This includes adjustments related to thermal performance, and building permissions, as well as refining decision-making protocols in multi-owner buildings.
- Introduce **long-term policy support and regulatory certainty** with transparency on upcoming changes and providing opportunities for industry input.

Regulation

- Harmonise **labels** to inform consumers about the energy efficiency of heating solutions.
- Promote **consumer information campaigns**, informed by behavioural insights, to empower individuals to make informed decisions.
- Create **one-stop-shop platforms** for supporting consumers in the uptake of heating equipment.
- Promote upskilling through accreditation for heat pump specialists and integration of **heat pump content into educational curricula** at all levels.
- Provide **criteria to define clean heat** and improve heat pumps **market data collection** and data accessibility to inform policy decision-making.

Incentives

- Introduce **rebates, grants and other financial offers** to motivate consumers to buy highly efficient heat pumps.
- Introduce **finance or taxation benefits** to encourage manufacturers to scale up heat pump production.
- Establish **well-designed procurement processes** to increase market share of heat pumps and drive innovation.
- **Adjust the price of electricity** to make the operating costs of heat pumps more favourable.
- Offer **dynamic electricity pricing** to help incentivise flexible demand and new business models.

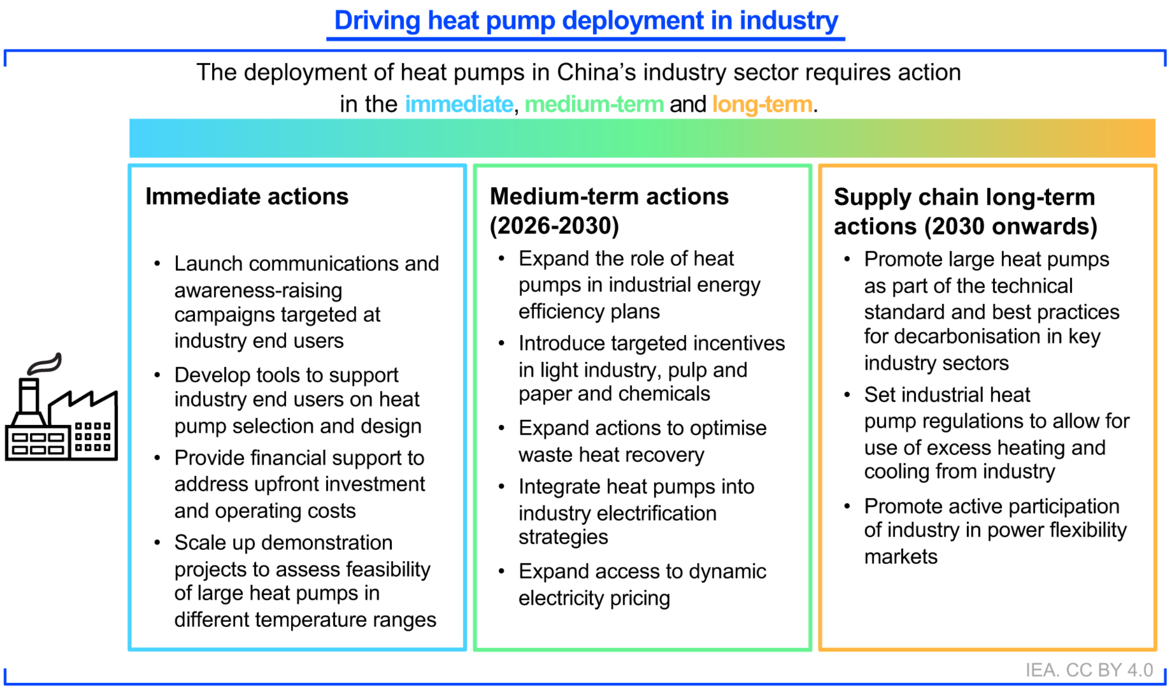
The integration of regulation, information and incentives can combine into an effective policy package to accelerate adoption of heat pumps.

Measures to promote heat pumps in China's industry sector

The greatest potential for heat pumps in Chinese industry lies in light industry, and in the chemicals and pulp & paper sectors, due to the lower average process temperatures required compared to other industrial sectors, and expected growth in heat demand. Capacity is expected to grow significantly in the coming decades, albeit from a very low level today.

Uptake is currently limited due to poor awareness of industrial heat pumps and their high investment costs compared to alternatives such as gas boilers, which can be up to six times less expensive. The high cost of electricity compared to gas and coal fuel further limits incentives to switch to heat pumps, despite their higher efficiency. In addition, the need for specific designs tailored to individual industrial processes makes standardisation and scaling up of the industrial heat pump market more challenging. Several specific policy and technology challenges need to be overcome in order to expand the use of heat pumps in Chinese industries (Figure 4.6).

Figure 4.6 Actions to drive heat pump deployment in China's industry sector



Immediate actions should focus on helping industry to address high upfront costs for heat pumps, while promoting awareness of their benefits.

Expand actions to drive waste energy recovery through heat pumps in light industries and district heating

The use of industrial waste heat for heating in China is currently primarily concentrated in energy-intensive industries including iron, steel and cement. Exploitation of waste heat is more limited in district heating networks and in light industries, due to challenges including unstable output of waste heat during winter (resulting from environmental policies), limited incentives for smaller industry players to participate in waste heat utilisation, and a lack of integrated planning of heat flows. There are opportunities for greater capture of waste heat through use of large-scale heat pumps, in combination with storage during warmer months for use during the winter heating period.

China should look to strengthen top-level design and planning to enhance waste heat utilisation, including highlighting key opportunities for application of heat pumps. To facilitate increased recycling of waste heat in Chinese light industries and district heating, the identification and mapping of potential waste heat recovery options could be strengthened, such as by implementing demonstrator projects and mapping available waste heat from industry, power plants, wastewater treatments, data centres and other applications. Identification of low-grade waste heat can also highlight opportunities for utilisation, such as through integration into district energy networks (Box 4.7). China could look to introduce mandatory heat planning at the local level in order to harness opportunities for waste heat recovery in the future, as well as prioritising waste heat in overall supply planning.

Alongside co-ordinated top-level planning and design, China should aim to set out clearer standards for planning, design and implementation of heat pump projects applied to waste heat. A review of current standards and practices, in combination with mapping key opportunities for heat pump application, would help to build a greater overall picture of heat pumps' potential. This could be supported through expanding financial support for waste heat recovery where heat pump technology is applied, and provision of incentives for the expansion of heat pump applications for waste heat recovery to further accelerate investment.

In 2020, the Korean government initiated a national heat map of all residual heat energy from power plants, incinerators, district heating, fuel cells and industrial sites, in order to facilitate utilisation of waste heat and accelerate energy efficiency improvements. China could look to design and implement incentive mechanisms, and prioritise waste heat in heat supply planning in order to further stimulate growth. Standardisation of the planning, design, construction and operation of waste heat systems will also be key, and would improve the ability to allocate financing to such projects in the future. Ratings measures could be formulated that reward projects for good design and energy efficiency improvements, highlighting best practices to wider industry end users.

Box 4.7 Industrial waste heat recovery provides heat for district heating networks in Hamburg

Recovery of waste heat, for example from wastewater treatment systems, presents an opportunity for decarbonising district heating. Heat pumps have a key role to play and have been applied in the city of Hamburg, Germany, as part of aims to develop a fossil-free wastewater treatment system by 2025.

The project, a collaboration between Johnson Controls, Hamburg Water and Hamburg Energie, aims to avoid around 66 000 tonnes of CO_2 per year through installation of four 15 MW heat pumps. The heat pumps will extract heat from treated wastewater from the city's Dradenau sewage treatment plant, which processes around 450 000 m^3 of wastewater every day, and feed this into the central district heating network. The project is estimated to be able to help supply around 39 000 homes with clean heat.

HafenCity, a new district to be built in Hamburg by 2030, is also aiming to supply its district heating system with 100% waste heat from the nearby Aurubis copper smelter. The project is expected to supply 20 000 households with hot water and could save over 20 000 tonnes of CO_2 emissions annually.

Introduce heat pumps as a recommended technology choice for decarbonising heating in selected industries

Many industrial production processes and methods require large quantities of process heat, which usually entails considerable energy costs for the businesses concerned. Comprehensive energy optimisation of a heating system can therefore significantly reduce energy consumption and costs. Optimisation of overall heating systems should look to package measures that minimise demand and losses, use heat recovery, adopt the most energy-efficient components and technologies, and optimise control systems.

China's action plan for energy efficiency in industry currently focuses on improving the energy efficiency of gas boilers as a key measure for reducing energy use, and includes recently introduced targets to improve average operating thermal efficiency by 5% by 2025 compared to 2021 levels. Heat pumps are mentioned in the plan as an option for diversifying industrial technologies and accelerating industry electrification.

In future action plans, China could look to introduce more specific requirements for heat pumps in targeted sectors, focusing on light industries and, where feasible, pulp and paper and chemicals. As an example, heat pumps could be included as a high-efficiency option in China's annual guidance catalogue for industrial restructuring, which encourages adoption of technologies that are in line with carbon neutrality objectives. Implementing measures aimed at optimising heat recovery from heating and cooling, such as by promoting process integration, can help to capture more waste heat via heat pumps. This could encourage industry end users to consider the efficiency of different heating technologies when upgrading their systems. Undertaking studies on the potential energy savings from heat pumps, as has been done in the European paper industry, could further help inform long-term strategies.

Box 4.8 IEA programmes advance research for the application of heat pumps in industry

IEA Technology Collaboration Programmes (TCPs) are part of the Agency's activities to promote and facilitate international co-operation to advance R&D for new and improved energy technologies. China joined the TCP in 2019. Projects on Application of Industrial Heat Pumps (2010-2016) and its second phase (2016-2019), jointly developed by the Heat Pumping Technologies TCP and the Industrial Energy-Related Technologies and Systems TCP, aimed to reduce the use of energy and GHG emissions by increasing the application of heat pumps in industry through the following activities:

- Generating information for policy makers and for key stakeholders in industry and its supply chain and consulting services.
- Gaining insight into business decision-making processes.
- Collating and increasing knowledge and information about industrial heat pumps through a database.
- Applying new technologies and identifying the needs for technological development.
- Creating a network of experts.
- Identifying synergies with renewable energy production to increase flexibility of the grid.

In total, 39 R&D projects and 115 applications of heat pumps in industry, particularly on the use of waste process heat as a heat source, have been presented and analysed by participating organisations based in Austria, Canada, Denmark, France, Germany, Japan, the Netherlands, Korea and Sweden. A complementary Annex focusing on high-temperature heat pumps was launched in 2020, and includes participation from China.

Increase awareness and support selection of tailored heat pump solutions among industry consumers

Although heat pumps with output temperatures below 200 °C have already been implemented or tested in multiple industrial applications globally, awareness and use of the technology in China remains low. Switching to a heat pump in an industrial process requires specialised planning, design, manufacturing and installation.

Limited awareness of the benefits of heat pumps and how to select the most efficient options could limit uptake in key industries. A short-term priority should therefore be improving the ability of industrial and commercial consumers to select and install heat pumps that suit the specific requirements of their projects.

Towards this aim, China could establish an information and knowledge base to support the integration of industrial heat pumps, engaging heat pump manufacturers and industry to develop tools that can help users to select the heat pump design that best fits their needs. Promoting investment in clean technologies by facilitating links between financial institutions and manufacturers can also help to increase awareness. For example, the Green Technology Selector, funded by the European Bank for Reconstruction and Development, provides a platform that connects retailers of technologies including heat pumps with financial institutions. Such platforms could also be linked with provision of financial support to incentivise industry stakeholders to select the most efficient technologies.

Provision of accessible educational materials, training courses, process integration and optimisation methods, standards and guidelines, technical support and technology demonstration will all be key to this process. Examples of such support include the PotencializEE programme in Brazil, which offers training for industrial energy efficiency experts to help facilities identify clean and efficient technologies. Elsewhere, the Australian Alliance for Energy Productivity (A2EP)'s online heat pump estimation tool allows industry end users to select potential heat pump options based on their specific needs.

Support industrial end users to overcome high upfront installation costs and manage longer-term operations and maintenance costs

Despite the large initial investments required to install an industrial heat pump, there is strong potential for longer-term savings on energy costs. As the market expands and innovation progresses, a reduction in the levelised cost of heat pumps, including through access to cheaper clean electricity, would make heat pumps more competitive compared to other industrial heating technologies. If future introduction of carbon prices in industry are taken into account, the savings offered by heat pumps compared to alternative equipment could increase further. However, in regions with low industrial gas prices, such as Gansu and Chongqing, large heat pumps are not currently an attractive investment. High electricity prices for industry reduce the incentives for industrial users, and risk slowing progress in the overall electrification of industry end uses.

In the short term, policy makers in China should consider measures to support industry end users with initial investments for heat pumps and related equipment, as upfront costs are projected to remain high even to 2030. This could take the form of loans towards initial costs, and/or tax reductions on electricity prices for adopters of heat pumps, which could reduce long-term operating costs. Increasing access to lower cost financing options for industrial adopters of clean heating technologies, such as by creating targeted funding instruments for heat pump integration in key sectors, or by leveraging the establishment of green finance pilot zones would further support uptake over the longer term. Policy makers could also drive deployment of industrial heat pumps by extending China's Emissions Trading Scheme (ETS) to the industry sector, which could be a means to deliver renewables targets cost-effectively. This would ultimately also improve the competitiveness of large-scale heat pumps compared to fossil fuel boilers. Revenues from ETS could be used to address the affordability or competitiveness concerns of heat pumps, in addition to other clean energy technologies and energy efficiency measures.

A number of countries have introduced policies to lower upfront cost barriers and reduce the payback period for industrial heat pumps. In Germany, subsidies can cover up to 55% of the initial cost of the heat pump, up to a ceiling of EUR 15 million per project. In Denmark, grants launched in 2022 cover up to 50% of the cost of an energy saving project, such as heat pump installation (Box 4.9).

Box 4.9 Energy Efficiency Obligation scheme delivers significant savings in Denmark

Denmark has proven that Energy Efficiency Obligation (EEO) schemes can be a tool for achieving energy savings in industry in a cost-efficient and market-based way. Since the mechanism came into force in 2006, 45% of energy savings at national level have been obtained from energy efficiency interventions in the industrial sector. Eligible energy efficiency measures include those relating to heating systems, building fabric, ventilation, lighting, process equipment, cooling, compressed air, pumps, motors, drives, appliances, distribution systems, and collective solar installations in connection with district heating supply.

The scheme especially promotes priority technologies that have a lifetime exceeding 15 years, and fosters the national objective of phasing out the use of fossil fuels in heating by promoting heat pumps, building insulation, heat recovery, district heating and solar thermal systems. A successful example of the Danish EEO scheme comes from the Arla Arinco dairy plant, where in 2012 a 1.2 MW hybrid heat pump was installed to recover waste heat from cooling water. The annual energy savings of 4.6 GWh covered almost half of the investment and allowed investments to be recouped in around 20 months.

Promote heat pump research and demonstration projects to foster innovation and highlight the benefits to broader industry consumers

Given the challenges of applying heat pumps for higher temperature industrial processes, further research, development and demonstration is required to both scale up application and showcase potential benefits to end users. Such projects require cross-industry collaborations that span R&D through to manufacturing and final application. Increased international collaboration on industrial heat pumps will also be vital for sharing best practices in policy and technology development. Collaborative forums such as Mission Innovation's Net Zero Industries Mission, the IEA TCP (Box 4.8) and the Energy Efficiency Hub, which all count China as a member, provide a platform for cross-border partnerships and learning.

China could look to expand pilots for heat pump applications in selected industrial sub-sectors based on the current technical feasibility of heat pumps at different temperature ranges, with an initial focus on sectors with greatest potential. Examples of heat pump demonstration projects in Chinese industry include a brewery in Shandong province, which is using heat pumps to supply steam for production (Box 4.10).

China could also boost investment in R&D through incentives such as tax credits or innovation grants for manufacturers that aim to develop more efficient and affordable heat pumps for targeted industry sectors, as well as heat pumps for higher temperature ranges. Through the 'Heat Pump Ready' programme, the UK government has invested GBP 60 million (USD 76 million, CNY 546 million) to accelerate uptake, and also provides R&D tax relief to support development and demonstration of heat pumps at large scale. Such a model could be adapted and applied to industry to promote development of more affordable and better-tailored heat pump options.

Box 4.10 Heat pumps already bring significant operations and energy savings to some Chinese light industries

The Hongjitang Brewery in China's eastern Shandong province introduced heat pumps to supply steam for the production process in 2020, replacing an electric boiler. The project team proposed a new way of supplying steam for industrial use, using air as the heat source and high-temperature steam as the output. When the ambient temperature is 18.9 °C, saturated steam is supplied at 120.2 °C. The COP of the heat pump is up to 1.85, and it can deliver energy savings of around 45% compared to an electric boiler. Use of the heat pump could save 777 600 kWh of electricity per year and CNY 467 000 (USD 65 000) in operations costs, with an investment recovery time of around 2.4 years.

The Wuxi Xia Lida printing and dyeing company installed 10 sets of waste heat source high-temperature heat pumps in November 2023. These produce high-temperature hot water up to 90 °C, achieving a COP of 4.6 and reducing the amount of steam that the company needs to purchase from the grid. The plant originally relied on the power plant pipeline network for steam supply at a price of CNY 330 per tonne, with an annual operating cost of over CNY 13.5 million. Following the heat pump installation, operating costs have dropped to CNY 3.9 million annually, a saving of over 70%. The payback period for the investment is estimated at less than one year.

Zhejiang Ningbo Yulin Metal Products introduced four high-temperature air-source heat pumps to replace natural gas boilers to supply steam at 120 °C. The price of natural gas in the area where the plant is located is USD 6/m³ (CNY 43/m³), and it costs CNY 1.73 million per annum to operate the gas boiler. The project entered operation in 2023, reaching a COP of 1.8 with temperatures above -20 °C. With an annual running cost for the four heat pumps of CNY 800 000, operating costs were reduced by nearly 60%, with a payback period of 1.7 years.

Measures to support development of a sustainable heat pump supply chain

Establish clear criteria for classification of clean heating used in buildings, industry and district heating

Even though heat pumps are now widespread in many markets across the world, significant differences remain with regards to how heat pumps are classified, how data is collected and how this is counted in renewable energy targets across key markets. This creates challenges for tracking overall trends in market growth and deployment at the global level. To help overcome this challenge, China should work towards setting clear criteria for how heat pumps are classified in the domestic market.

A clear definition of clean heating, and of what could be classified as heat generated from renewable energy, would help policy makers to allocate support and funding to the most efficient low-emissions technologies, and provide greater clarity to industry stakeholders and consumers to aid uptake. In addition, policy makers could further clarify how heat pumps contribute to renewable energy and electrification targets, including establishing guidelines on how heating using fossil fuel and renewable energy sources is accounted for against national energy and climate goals. The European Heat Pump Association (EHPA) also aims to have heat pumps recognised as 'sustainable' under the EU Taxonomy, which would provide a signal to investors.

China could work with stakeholders in other key markets, such as Europe, the United States and Japan, to promote exchange on such classifications and associated data collection in their respective markets. This would help to promote greater understanding of the world's largest heat pump markets, with the potential for a long-term ambition to work towards standardised classification and data collection. Differing approaches are likely to remain, due to the individual characteristics of certain markets, but increased dialogue can help support a more aligned overall understanding of the global heat pump market, future demand growth and potential challenges.

Enhance data oversight and use heating surveys to better understand opportunities for heat pumps and broader heating decarbonisation

Improved heat pump data collection and reporting at the provincial and local levels will allow for more efficient oversight of heat pump installation. Being able to produce more accurate estimates of installation rates across the country would also be beneficial in informing target-setting for future market share or installations. A more detailed understanding of heat pump rollout over time would also be useful for co-ordinating other aspects of the supply chain, as well as power system infrastructure planning. This could include collecting data on previous heat pump projects to identify lessons learned.

Heat pump installations could be reported via an appropriate certification scheme, in a similar way to the scheme to be used under the UK Clean Heat Market Mechanism (CHMM) for generating credits. The UK-based online Heat Pump Monitor also tracks data on installations, and has demonstrated that efficiency outcomes are improved when technicians have undertaken a detailed course.

Such mechanisms can be used to ensure that standards are met, and allow for information on the appliance make, model and capacity to be recorded.

City- or county-level consumer surveys can also provide information on local perceptions, behaviours and potential barriers towards heat pump adoption. Such studies can help to improve understanding of heating behaviours and changes over time, and heating technologies in use, as well as levels of awareness of energy-efficient heating practices. Surveys could also aim to assess the effectiveness of support schemes for heat pump adoption (where available), thereby supporting local governments with the design and rollout of subsidies, grants and other incentives. Heating surveys are widely employed by governments in Europe, including in the United Kingdom and Belgium, in order to inform wider policy-making on heating. In Germany, a survey commissioned by the German Energy Agency (DENA) found that more than half of the 1000+ people surveyed wanted to save energy on heating. The survey also collected information on heating behaviour.

Set targets to increase sales and deployment of heat pumps in national heating markets

Long-term policy consistency and regulatory certainty, together with targeted action to strengthen supply chains, will be key to meeting growing future demand and ensuring the sector is able to support progress towards China's carbon neutrality goal.

China could introduce quantitative targets for the deployment of heat pumps and other clean heating solutions, which would provide a clear signal to markets and promote wider investment in R&D, manufacturing and deployment. In Europe, for example, installation targets set by certain member countries have contributed to investments in heat pump manufacturing totalling more than EUR 3 billion (CNY 24 billion, USD 3.25 billion) over 2021, 2022 and 2023.

Obligation-based policies can also stimulate manufacturing and sales of clean heating technologies at the same time as bringing down costs. China could set a requirement for manufacturers and retailers of heating equipment to ensure that a minimum percentage of all sales is allocated to heat pumps. Such measures could be combined with incentives, such as allowing companies that sell more than their quota to trade credits or certificates with those that do not meet their quota. This could build on early experiences in China gained through the establishment of the Renewable Energy Certificate trading scheme, as well as drawing on recent developments in the United Kingdom (Box 4.11).

Box 4.11 UK Clean Heat Market Mechanism to boost sales of heat pumps

In April 2024 the United Kingdom government is planning to implement its Clean Heat Market Mechanism (CHMM) scheme to support development of the UK market for electric heat pumps by incentivising investments by the heating industry. The CHMM is also designed to support government ambitions of reaching 600 000 heat pump installations a year by 2028, and building a sustainable UK heat pump supply chain.

The policy would require oil and gas boiler manufacturers to sell heat pumps equivalent to 4% of their boiler sales, with a fine of GBP 3 000 (USD 3 800) levied for every gas boiler sold above the 4% heat pump target. A tradeable heat pump credit will be allocated to the manufacturer upon the installation of a qualifying heat pump device, after registration via a certified installer.

Harness rapid growth in heat pumps to promote jobs and skills in manufacturing, installation, operations, maintenance and recycling

China's strong manufacturing base is well positioned to meet growing domestic demand for heat pumps, though emerging concerns about the future manufacturing workforce could lead to vulnerabilities in the supply chain if not remedied. As a first step, policy makers could consider mapping out strengths and weaknesses across the existing workforce, as has been done in Europe, for example. Priorities could include identifying areas of the existing workforce with complementary skills, for example heating, ventilation and air conditioning (HVAC) and gas boiler technicians, as well as areas where more extensive retraining will be needed.

The installation and manufacturing segment is expected to be the most substantial source of new jobs through the end of the decade, with demand for operations and maintenance personnel also rising as heat pump adoption accelerates. Significant investments will be needed to build skills, such as familiarity with heat pump technologies, and to support certification and training (Box 4.12).

Improvements in heat pump installation and maintenance will be key for ensuring maximum operational efficiency, bringing down costs and reducing lifetime emissions. Poor installation, operations and maintenance can lead to low efficiency outcomes and missed opportunities for emissions savings that could potentially undermine perceptions of the technology, which risks slowing the transition. This challenge may be particularly large in rural China, where access to technicians is typically more limited than in urban areas. In addition, recycling will be of key importance, especially with regards to ensuring that all refrigerants are safely recovered and recycled.

China could consider introducing specific mandatory technical certifications for heat pump technicians and a minimum certification standard across the industry. While voluntary qualification certificates are available for companies servicing air conditioning and refrigeration equipment in China – including heat pumps – installation does not need to be conducted by a certified installer. In contrast, many other countries set requirements for heat pump installers, such as the United Kingdom, where only certified installers can guarantee eligibility for support under the Microgeneration Certification Scheme. Setting out clearer requirements for operations, maintenance and recycling can also signal to the industry a broader need to shift towards longer-term training and individual worker capacity building.

Such mandatory certifications could help improve the efficiency and safety of heat pump installation in China. However, such qualification schemes must not be too onerous for workers, who may be deterred from entering the industry by complex requirements or the need for costly training. Education and training will be key to ensuring that the transition to clean energy is fair and people-centred, especially for workers in traditional energy sectors that will see declining labour needs. Incorporating modules on heat pump technology in educational curricula and vocational training programmes would also contribute to building a future workforce that is knowledgeable and supportive of sustainable heating solutions.

Box 4.12 EUCERT programme provides training and education to heat pump installers

The EHPA is leading the EUCERT programme to ensure that growing heat pump demand in Europe can be met by a certified and well-trained installer workforce. Importantly, the programme provides identical training and examination material for all trainees across Europe to enable the development of a comparable qualification and easy mutual acceptance of certificates in different participating countries. Training courses cover a range of topics including marketing, costs of a heat pump system, energy-efficient buildings, and determining planning, installation and maintenance of a heat pump system. Each training course consists of up to 36 hours manufacturer-independent education, including 8 hours of hands-on, practical training.

Consider strengthening standards for direct and indirect lifecycle emissions of heat pumps to promote energy efficiency and refrigerant alternatives

As adoption of heat pumps accelerates, there will be an increased need to consider both direct and indirect emissions, looking at energy efficiency and refrigerant choice. China should consider these factors over the full lifecycle of a heat pumps when comparing different types of equipment and assessing the overall impact of heat pumps. Most emissions resulting from heat pumps are currently indirect, when the emissions factor of electricity generation and current COP of heat pumps are taken into account. As the electricity sector is decarbonised and energy efficiency in heat pumps improves, direct emissions from refrigerants will become more significant in overall heat pump sustainability considerations (see Chapter 3).

The ecological and environmental benefits of adopting heat pumps on a large scale should be studied across different heat pump types, allowing policy makers to address any concerns at an early stage. Future developments to MEPS should give stronger consideration to the refrigerants used in heat pumps, as has been initiated under China's latest round of energy efficiency standards. Both natural and synthetic low-GWP refrigerants should be considered, to reflect end users' needs and safety without impacting on heat pump efficiency. Further integration of refrigerants and energy efficiency considerations could be facilitated by promoting increased exchange between policy makers responsible for issues relating to the ozone and global warming and those working on energy efficiency.

In addition, policy support to deepen ongoing research on advanced heating/cooling technologies that do not require refrigerants (see Chapter 3) can ensure such technologies can be progressed to a higher level of readiness as the heat pump market grows. China can also draw on its recommended list of alternatives to ozone-depleting substances to further promote application in heat pumps to support overall progress under the Kigali Agreement. As a member of the heat pump TCP, China could consider joining the recently launched Annex 64 project, which will explore safety measures for flammable refrigerants across industry, district heating and household heat pumps.

Consider electricity system and demand flexibility implications in future electrification of heating and heat pump deployment

Increasing rates of end user electrification and progress on power market reforms will create new opportunities for the adoption of clean heating technologies such as heat pumps. There is a risk, however, that rapid electrification could outpace investments in distribution grids and other infrastructure needed to reliably deliver affordable electricity during the early stages of power market reforms. Ensuring that demand side response considerations are integrated into broader plans for electrification of heating, and that clean heating technologies including heat pumps are demand-response enabled, will allow for greater interaction with the power system to promote future system flexibility and stability. These measures would complement actions to promote grid decarbonisation, leading to reduced emissions from the use of heat pumps.

China has sharpened its focus on power market reforms, electrification and demand-side response capacity in recent years, including setting out aims for a unified national power market system by 2030 and an expansion of demand-side response capacity by 2025. Current adoption of tiered electricity pricing and time-of-use approaches at the provincial and local levels could provide opportunities for policy alignment in the shorter term. Over the longer term, the development of flexibility markets – including for ancillary services – would create opportunities and new incentives for expanding investment in demand side-enabled heating systems across buildings and industry. This could lead to district heating networks and aggregated heat pumps playing a growing role as both a heating provider and active power system participant.

China should look to further integrate demand-side readiness into heat pump design and rollout to ensure future power system interactivity (Box 4.13). As deployment scales up, millions of efficient heat pumps operating at the same time will affect power systems during peak winter demand and extreme cold events. Measures could be integrated with China's 14th FYP for Buildings, which emphasises the importance of buildings and power system interaction, such as developing energy management systems. This could include introducing requirements that specify demand-side flexibility in MEPS or building codes, sending a signal to industry players to shift towards manufacturing of smart products. The United Kingdom plans to implement a smart mandate proposal by 2027, mandating that all hydronic heat pumps, storage heaters and heat batteries can provide demand side response. Measures of this kind should consider potential cost increases related to adopting a combination of grid-interactive appliances, as well as the broader feasibility of power system integration.

Box 4.13 Mitsubishi explores demand-response readiness in heat pumps under EU "REACT" project

The REACT project aims to demonstrate the energy independence of remote islands through the deployment of heat pump systems in the Aran Islands, Ireland, and San Pietro Island, Italy. The programme involves 22 partners including companies and academic institutions from 11 EU member states, and aims to achieve energy savings of 10%, a 60% reduction in GHGs, and a 50% increase in use of renewable energy.

The projects use distributed renewable energy generation and storage technologies with demand response. Heat pumps installed at demonstration sites are from Mitsubishi Electric, which are linked with the REACT demand-response platform via a cloud service for HVAC systems. This allows heat pumps to share operating information, including temperature and energy consumption, and enables the REACT platform to adopt automatic demand-response control. The system also sends mobile phone notifications to users about home energy usage, electricity price and other factors, and provides tailored energy efficiency recommendations.

General annex

Abbreviations and acronyms

APS	Announced Pledges Scenario
CAD	Canadian dollar
CCUS	carbon capture, utilisation and storage
CHIC	Clean Heating Industry Committee
CHMM	Clean Heat Market Mechanism
CHP	combined heat and power
CNY	Chinese Yuan Renminbi
COP	coefficient of performance
COP28	Conference of the Parties 28
CO_2	carbon dioxide
EEO	Energy Efficiency Obligation
EER	Energy Efficiency Rating
EHPA	European Heat Pump Association
EMCA	China Energy Conservation Association
EPBD	Energy Performance of Buildings Directive
ESCO	Energy Services Company
EV	electric vehicle
EUR	euros
F-gas	fluorinated gas
FYP	Five-Year Plan
GBP	British Pound
GDP	gross domestic product
GEC	green electricity certificates
GHG	greenhouse gas
GWP	global warming potential
HCFC	hydrochlorofluorocarbon
HEERA	High-Efficiency Electric Home Rebate Act
HEPS	High Efficiency Performance Specifications
HFC	hydrofluorocarbon
HFO	hydrofluoro-olefin
HSCW	hot summer-cold winter
HTHP	high-temperature heat pump
HPT TCP	Heat Pumping Technologies Technology Collaboration Programme
HVAC	heating, ventilation and air conditioning
IRA	Inflation Reduction Act
MEPS	Minimum Energy Performance Standard
MVR	Mechanical Vapour Recompression
NDRC	National Development and Reform Commission
NOx	nitrogen oxides
PCM	phase change material
SEAD	Super-Efficient Appliance Deployment Initiative
SO_2	sulphur dioxide
STEPS	Stated Policies Scenario

TCP	Technology Collaboration Programme
TRL	Technology Readiness Level
USD	US dollar
ZEB	zero-emission building

Units

°C	Celsius
EJ	exajoule
Gt	gigatonne
Gt CO_2	gigatonne of carbon dioxide
GW	gigawatt
hr	hour
kg CO_2	kilogramme of carbon dioxide
km^2	kilometre
kt	kilotonne
kW	kilowatt
kWh	kilowatt hour
m^2	square metre
m^3	cubic metre
MJ	megajoule
mm Hg	millimetres of mercury
MW	megawatt
l	litre
PJ	petajoule
t	tonne
t CO_2	tonne of carbon dioxide
W/W	Watt for Watt
µg	microgram

Glossary

Absorption heat pumps	Heating devices that use heat from an outside source to heat water for radiators or underfloor heating or district heating networks. Unlike electricity-driven heat pumps, absorption heat pumps are driven by a heat source such as natural gas, propane, solar-heated water, geothermal-heated water, or waste heat. See Heat pumps.
Air-to-air heat pumps	Electricity-driven heating devices that use heat from the outside air to heat your home through in-room blowers or vents. Air-to-air heat pumps are ideal for homes without radiators or underfloor heating, and they can also provide space cooling. Some models can be combined with water tanks to provide domestic hot water. In other cases, separate water heating solutions such as an electric heater may be needed. Air-to-air heat pumps run on electricity, and when installed in well-insulated homes they can achieve significant energy bill savings – for example, up to 35% in Germany, or up to 50% in France, when compared to gas boilers. Their average lifespan before replacement is 12-15 years. See Heat pumps.

Air-to-water heat pumps	Electricity-driven heating devices that use heat from outside air to heat water for radiators or underfloor heating. Air-to-water heat pumps are usually connected to a tank that provides hot water for heat distribution systems, bathrooms, and kitchens. Some models also provide space cooling. They run on electricity, and when installed in well-insulated homes they can achieve significant energy bill savings – for example, up to 35% in Germany or up to 50% in France compared to gas boilers. Their average lifespan before replacement is 15-18 years. See Heat pumps.
Announced Pledges Scenario	An IEA scenario which assumes that all climate commitments made by governments and industries around the world as of the end of August 2023, including Nationally Determined Contributions (NDCs) and longer-term net zero targets, as well as targets for access to electricity and clean cooking, will be met in full and on time.
Buildings	The buildings sector includes energy used in residential, commercial and institutional buildings and other non-specified buildings. Building energy use includes space heating and cooling, water heating, lighting, appliances and cooking.
Carbon dioxide (CO_2)	A gas consisting of one part carbon and two parts oxygen. It is an important greenhouse (heat-trapping) gas.
Clean energy	In reference to power, clean energy includes generation from renewable sources, nuclear and fossil fuels fitted with carbon capture, utilisation and storage (CCUS); battery storage; and electricity grids. In reference to efficiency, clean energy includes energy efficiency in buildings, industry and transport, excluding aviation bunkers and domestic navigation. In end-use applications, clean energy includes direct use of renewables; electric vehicles; electrification in buildings, industry and international marine transport; CCUS in industry and direct air capture. In fuel supply, clean energy includes low-emissions fuels.
Clean heating (in Chinese policies)	Heating method that uses natural gas, electricity, geothermal, biomass, solar energy, industrial waste heat, clean coal (ultra-low emissions) or nuclear energy.
Coal	Includes both primary coal, i.e. lignite, coking and steam coal, and derived fuels, e.g. patent fuel, brown-coal briquettes, coke-oven coke, gas coke, gas works gas, coke-oven gas, blast furnace gas and oxygen steel furnace gas. Peat is also included.
Coefficient of Performance (COP)	COP is a ratio used to measure the amount of useful energy (i.e. heating or cooling output) delivered relative to the energy input. The higher the COP, the more efficient the device.
Demand-side flexibility resource	Describes resources which can influence the load profile, such as shifting the load curve in time without affecting total electricity demand,

or load shedding, such as interrupting demand for a short duration or adjusting the intensity of demand for a certain amount of time.

District heating Centralised systems, available in some areas, that distribute heat through underground pipes. District heating networks transfer heat to radiators or underfloor systems, and might also provide domestic hot water, and transfer heat to some industrial processes. Some systems can also cool connected buildings. They run on various energy sources, such as combined heat and power plants or large-scale heat pumps, depending on the network.

Electricity demand Defined as total gross electricity generation less own use generation, plus net trade (imports less exports), less transmission and distribution losses.

Electricity generation Defined as the total amount of electricity generated by power only or co-generation (combined heat and power) plants including generation required for own use. This is also referred to as gross generation.

Energy-intensive industries Comprises the five most energy-intensive industrial sectors: iron and steel, chemicals, non-metallic minerals, non-ferrous metals, and pulp and paper.

Energy sector greenhouse gas (GHG) emissions Energy-related and industrial process CO_2 emissions plus fugitive and vented methane and nitrous dioxide emissions from the energy and industry sectors.

F-gas Fluorinated gases that are used in different applications including refrigeration, air conditioning and heat pumps where they are the main component of the refrigerant cycle.

Fossil fuels Include coal, natural gas and oil.

Geothermal Geothermal energy is heat from the subsurface of the earth. Water and/or steam carry the geothermal energy to the surface. Depending on its characteristics, geothermal energy can be used for heating and cooling purposes, or be harnessed to generate clean electricity if the temperature is adequate.

Global warming potential (GWP) This metric allows for a comparison of different greenhouse gases in terms of their effect on climate change, and is used for the CO_2 equivalent calculations. The GWP of CO_2 is set to 1, so all other gases are classified relative to CO_2. To account for differing lifetimes of gases in the atmosphere, the most common metric is the 100-year GWP; the 20-year GWP is sometimes also used. A gas with a GWP100 of 27 has a 27-times-greater impact on global warming than CO_2 over a 100-year time frame.

Ground-source heat pumps Ground-source heat pumps use heat from the outside ground to heat water for radiators or underfloor heating. In North America, the heat is often distributed through forced-air systems. Ground-source heat pumps, as well as water-source heat pumps that absorb heat energy from a nearby river, lake or pond, or from groundwater, are also more

	energy-efficient than air-source heat pumps, as ground and water temperatures stay relatively stable compared with outdoor air temperatures. Ground-source heat pumps are usually connected to a tank for hot water for heat distribution systems, bathrooms and kitchens. Some models also provide space cooling.
Heat (end use)	Can be obtained from the combustion of fossil or renewable fuels, direct geothermal or solar heat systems, exothermic chemical processes, and electricity (through resistance heating or heat pumps, which can extract heat from ambient air and liquids). In this report, this category refers to the wide range of end uses, including space and water heating, and process applications in industry. It does not include cooling applications.
Heat (supply)	Obtained from the combustion of fuels, nuclear reactors, geothermal resources or the capture of sunlight. It may be used for heating or cooling, or converted into mechanical energy for transport or electricity generation. Commercial heat sold is reported under total final consumption with the fuel inputs allocated under power generation.
Heat sink	Target to which a heat pump provides heat.
Heat source	Source from which a heat pump extracts heat.
Heat pumps	A heat pump extracts heat from a source, such as the surrounding air, geothermal energy stored in the ground, or nearby sources of water or waste heat from a factory. It then transfers the heat to where it is needed. They are three to four times more energy-efficient than fuel-based or electric resistance systems. This is because they move heat in and out of buildings instead of generating it.
Hydronic heat pumps	Heat pumps used in a hydronic heating system that use water to move heat from a heat pump through piping to each room via radiators or underfloor heating. See heat pumps.
Hydrofluoro-carbons (HFCs)	Organic compounds composed of hydrogen, fluorine and carbon, widely used as refrigerants. See F-gases and see refrigerants.
Investment	Investment is the capital expenditure in energy supply, infrastructure, end use and efficiency. Fuel supply investment includes the production, transformation and transport of oil, gas, coal and low-emissions fuels. Power sector investment includes new construction and refurbishment of generation, electricity networks (transmission, distribution and public electric vehicle chargers), and battery storage. Energy efficiency investment includes efficiency improvements in buildings, industry and transport. Other end-use investment includes the purchase of equipment for the direct use of renewables; electric vehicles; electrification in buildings, industry and international marine transport; equipment for the use of low-emissions fuels; and CCUS in industry and direct air capture. Data and projections reflect spending over the lifetime of projects and are presented in real terms in year-2022 US dollars unless otherwise stated. Total investment reported for a year reflects the amount spent in that year.

Levelised cost of heating and cooling The levelised cost of heating and cooling estimates the average cost of providing 1 MWh of heating or cooling over the lifetime of the equipment, considering the capital cost of the equipment and installation; operating expenditures include the cost of fuel and regular maintenance.

Low-emissions hydrogen Hydrogen that is produced from water using electricity generated by renewables or nuclear, or from fossil fuels with minimal associated methane emissions and processed in facilities equipped to avoid CO_2 emissions, e.g. via CCUS with a high capture rate, or derived from bioenergy. In this report, total demand for low-emissions hydrogen is larger than total final consumption of hydrogen because it additionally includes hydrogen inputs to make low-emissions hydrogen-based fuels, biofuels production, power generation, oil refining, and hydrogen produced and consumed onsite in industry.

Light industries Describes a range of sectors with lower specific energy use than energy-intensive industries. Sectors comprise construction, mining and quarrying, transport equipment, machinery, food and tobacco, wood and wood products, and textile and leathers.

Mechanical Vapour Recompression (MVR) Also called open-cycle heat pumps, these devices compress waste steam to increase its temperature. This is distinct from regular heat pumps which operate in a closed cycle. MVR are therefore not classified as heat pumps.

Natural source heat pumps Heat pumps that use heat from the outside air, water or ground. See heat pumps.

Natural gas Includes gas occurring in deposits, whether liquefied or gaseous, consisting mainly of methane. It includes both non-associated gas originating from fields producing hydrocarbons only in gaseous form, and associated gas produced in association with crude oil production, as well as methane recovered from coal mines (colliery gas). Natural gas liquids, manufactured gas (produced from municipal or industrial waste, or sewage) and quantities vented or flared are not included. Gas data in cubic metres are expressed on a gross calorific value basis and are measured at 15 °C and at 760 mm Hg (standard conditions). Gas data expressed in tonnes of oil equivalent, mainly for comparison reasons with other fuels, are on a net calorific basis. The difference between the net and the gross calorific value is the latent heat of vapourisation of the water vapour produced during combustion of the fuel (for gas the net calorific value is 10% lower than the gross calorific value).

Near Zero Energy Building (NZEB) NZEB refers to buildings that significantly reduce the energy demand for heating, air conditioning and lighting through passive design, and greatly improve the efficiency of energy systems, together with further use of renewable energy to ensure a comfortable indoor environment. The energy efficiency level in an NZEB should be 60% to 75% lower than national and industrial standards for public building energy saving.

Oil	Includes both conventional and unconventional oil production. Petroleum products include refinery gas, ethane, liquid petroleum gas, aviation gasoline, motor gasoline, jet fuels, kerosene, gas/diesel oil, heavy fuel oil, naphtha, white spirits, lubricants, bitumen, paraffin, waxes and petroleum coke.
Power generation	Refers to fuel use in electricity generation plants, heat plants and co generation plants. Both main activity producer plants and small plants that produce fuel for their own use (auto-producers) are included.
Primary heating equipment	Heating equipment used as the primary source of heat in buildings during the heating season. This excludes reversible air conditioners installed in buildings where another heating device, such as a gas boiler, is already installed.
Primary network	Pipeline network that connects heating plants to heat substations.
Refrigerant	Substance that transfers heat through the refrigeration cycle in a refrigeration appliance (e.g. heat pump, air conditioner, refrigerator).
Renewables	Includes bioenergy, geothermal, hydropower, solar photovoltaics (PV), concentrating solar power, and wind and marine (tide and wave) energy for electricity and heat generation.
Residential buildings	A structure that is designed and constructed to serve as a place of residence for families or individuals. Energy used in residential buildings includes space heating and cooling, water heating, lighting, appliances, electronic devices and cooking.
Secondary network	Pipeline network that distributes heat from a heat substation to the delivery points (buildings or industrial sites).
Services buildings	Commercial facilities, e.g. offices, shops, hotels and restaurants; and institutional buildings, e.g. schools, hospitals and public offices. Energy use in services buildings includes space heating and cooling, water heating, lighting, appliances, cooking and desalination.
Solar photovoltaic (PV) electricity	Electricity produced from solar PV cells.
Stated Policies Scenario (STEPS)	An IEA scenario which reflects current policy settings based on a sector-by-sector and country-by-country assessment of the energy-related policies that are in place as of the end of August 2023, as well as those that are under development. The scenario also takes into account currently planned manufacturing capacities for clean energy technologies.
Temperature lift	Is the delta between the temperature of the heat sink and the temperature of the heat source of a given heat pump. Increasing the temperature lift usually decreases the COP of the heat pump.

Total final consumption (TFC)	Is the sum of consumption by the various end-use sectors. TFC is broken down into energy demand in the following sectors: industry (including manufacturing, mining, chemicals production, blast furnaces and coke ovens), transport, buildings (including residential and services) and other (including agriculture and other non-energy use). It excludes international marine and aviation bunkers, except at world level, where it is included in the transport sector.
Useful energy	Refers to the energy that is available to end users to satisfy their needs. This is also referred to as energy services demand. As a result of transformation losses at the point of use, the amount of useful energy is lower than the corresponding final energy demand for most technologies. Equipment using electricity often has higher conversion efficiency than equipment using other fuels, meaning that for a unit of energy consumed, electricity can provide more energy services.
Zero-carbon-ready buildings	A zero-carbon-ready building is highly energy efficient and uses either renewable energy directly or an energy supply that can be fully decarbonised, such as electricity or district heat.
Ultra-low energy buildings	Refers to buildings that are at the initial stage of Nearly Zero Energy Building (NZEB), with similar indoor environment parameters to an NZEB and a slightly lower energy efficiency level than an NZEB. Their energy efficiency index should be more than 50% lower than national and industry standards for public building energy saving.
Utilisation factor	Ratio of the time a piece of equipment is in use to the total time it could be in use.

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