Prospects for Clean and Renewable Heating in China – Insights from Denmark

STRATEGIC SECTOR COOPERATION - CLEAN HEATING IN CHINA

CREEI DEA

SSC Clean Heating

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Preface

Today, Denmark's district heating system is recognized as one of the most efficient in the world, with two-thirds of all Danish households connected to the system. But it has not always been like that. Fifty years ago, most of homes were heated by individual heating systems burning fossil fuels. The switch from individual boilers to district heating systems has played an important role in reducing CO2 emissions by 53% since 1975, without compromising GDP growth, which has doubled over the same period.

The flexibility of district heating networks has also allowed Denmark to respond to different strategic challenges over the years. For example, responding to the security of supply disruptions in the 1970s, a global fuel crisis in the 1980s, and today in the form of rising gas prices. Moreover, it has been possible to integrate renewable wind sources better through decentralization and flexibility, also in the heating sector. This has been done through efficient and flexible dispatch of co-generation plants; direct electrification through large heat pumps, and intelligent storage systems in heating. This is one of the reasons why Denmark already can supply over 50% of its electricity through wind with minimal curtailing.

Since China began to open up and reform its economy in 1978, the country has experienced rapid GDP growth in part based on manufacturing and exports. This development has led China, the world's most populous country, to become the largest CO2-emitter. Ambitious targets to reduce CO2 emissions and air pollution are strong drivers for China in terms of switching to a greener energy system, and heating is an integral part of the energy consumption. Today, the vast majority of energy used in heating buildings in China still comes from coal. However, China has started its journey towards a clean and renewable heating sector, with clean heating policies having already significantly improved air quality in northern China compared to 2015, particularly in Beijing and surrounding cities.

Both China and Denmark are experienced in district heating and have cooperated in energy for almost 20 years both benefitting from a renewed cooperation. In China, the Danish Energy Agency (DEA) and the China Renewable Energy Engineering Institute (CREEI) are currently collaborating on a Strategic Sector Cooperation (SSC) for Clean Heating. The SSC project can open the door to Chinese authorities establishing an enabling regulatory framework for clean and renewable district heating development with positive socio-economic and environmental and climate impact. This forms part of a wider cooperation between the Danish Ministry of Climate, Energy and Utilities (MCEU) and the Chinese National Energy Administration (NEA).

With the great efforts of both sides, outcomes evolve even during the COVID-19 pandemic. A Sino-Danish Clean and Renewable Heating Cooperation Centre has been established to strengthen the knowledge transfer of two countries' district heating and energy efficiency sectors and share best practices to support clean and renewable heating practices in China. A Sino-Danish expert panel composed of Danish experts, Chinese experts and international academics has been set up to provide sound inputs and experienced technical support to ongoing developments in the cooperation project.

Even more important, a comparative analysis on" Prospects for Clean and Renewable Heating in China – Insights from Denmark" has been conducted and finalized. The analysis has its focus on the district heating sector, which has been and still constitute the cornerstone of the Danish green energy system. Danish experiences indicate that district heating could also be a key component of China's green transition. The report highlights several areas to analyze the differences and similarities of district heating systems in both countries, and presents the Danish lessons learned during the energy transition from black to green, thus inspiring China to build the path towards green, clean, and highly efficient district heating.

This report can serve as a solid foundation for continued knowledge sharing between regulatory bodies, research institutions and industries in both countries.

We want to thank the DEA team for their strong efforts, NEA, MCEU, CREEI, and the Sino-Danish expert panel on clean heating, which made it possible to prepare this report.

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Executive Summary

China and Denmark have both set a target to become carbon neutral by 2060 and 2045 respectively. To achieve these ambitions, they have a common responsibility to share and inspire each other with best practices.

As part of the Sino-Danish Strategic Sector Cooperation (SSC) on Clean Heating Programme, this Report performs a prospective analysis highlighting the main focus areas where Danish experiences can support the development of clean and renewable heating in China.

Though both countries have a long experience with centralized heating[1] , they have not developed similar policies. Hence today the regulatory framework and the profile of the DH systems in China and in Denmark differ. China's DH system is mainly based on coal-fired combined heat and power (CHP) and on a "push" system, i.e., sending large amount of heat from the heat source location to a block of buildings via large-scale substations at high temperature and pressure levels over large distances. In practical operation, the adjustment of the primary network (from the heat source to the substation) is normally managed by changing the water supply temperature and the volume of circulating water as response to changes in outdoor temperature. In addition, the limited application of control measures in the secondary network (from the substation to the building) could lead to uneven heat distribution between buildings and the deviation between heat supply and heat demand. Thus, the Chinese DH system is a production-driven system. Denmark's DH[2] system utilizes diverse renewable energy sources and operates at lower temperature as a "pull" system where the heat supply follows the end-users' consumptions. Thus, the Danish DH system is a demand-driven system.

Drawing upon feedback and insights from the Sino-Danish expert panel on clean heating, the analysis has pinpointed eleven focus areas. These areas suggest that adopting solutions inspired by Danish DH best practices could play a key role in promoting clean and renewable heating in China. These focus areas are categorized into four main groups covering the whole DH supply chain.

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[1] In China, the term "centralized heating" is commonly used. Centralized heating refers to a system in which heating is produced at central locations and distributed to end-users, e.g., buildings via heat carrier such as pressurized water in insulated pipes. Centralized heating is an essential infrastructure in densely populated urban areas; the end-users are typical high-rise buildings, making the heat density per km pipeline relatively high. Another concept commonly used in China's heating sector is "distributed heating." In distributed heating system, the served heating areas are medium or small scale compared to the centralized heating system.

[2] "District heating" refers to a similar concept in which heating is produced at central or decentralized locations and distributed to end-users via a medium (often pressurized hot water) in insulated pipes. The term is commonly used in Denmark and refers to a system in which local energy resources, including renewable and waste energy, are utilized to ensure sustainability, economic efficiency, and resilience of the system. In the English version of the Report, the term of district heating (DH) is used for both two countries.

Energy planning

1. **Heat planning**. To facilitate the transition to clean and renewable heat supply for DH, China can draw valuable insights from Denmark's experience in holistic strategic heat planning. This approach relies on tools that take into account both local conditions and the overall energy system and policy landscape.
2. **Heat demand forecasting**. Heat demand forecasting is a flexible tool useful for both heat planning and day-to-day operational optimization. In China, heat demand forecasting is not widely applied, whereas software applications are commonly used in Denmark. Implementing a heat forecasting scheme offers the advantage of optimizing the utilization of local clean energy sources and strategic planning for future heat demand in the supply system.
3. **Thermal storage**. Energy efficient technologies for developing seasonal thermal storage are increasingly utilized in Denmark, whereas the technologies are yet to be developed in China. These technologies are designed to store excess thermal heat, including that coming from renewable sources and surplus heat from CHP plants and industries. This storage facility is particularly valuable during periods when there is no immediate heat demand within the district heating network.

Renewable energy for heating

4. **Geothermal heating**. Data shows that China has abundant geothermal resources, including shallow geothermal, hydrothermal geothermal, and hot dry rock. Moreover, the Chinese government has also released relevant policies in recent years to actively promote utilization of geothermal energy, signaling enormous potential and promising prospects for its development in China. This lays an excellent foundation for China to foster international cooperation and thus break technical bottlenecks by drawing on the lessons and practical experiences from other countries, such as Denmark.
5. **Solar district heating**. China has abundant solar resources and favorable policies, offering broad application prospects for solar DH. As a global leader in large-scale solar DH plants, Denmark can share relevant experiences to help China accelerate the development of solar DH in China.
6. **Biomass heating**. China possesses abundant biomass resources, presenting an opportunity to convert existing coal-fired power plants into biomass plants. The retrofitting of facilities and the replacement of coal-fired boilers with biomass-only boilers have played a crucial role in Denmark's transition away from coal in power and heat production. Today biomass accounts for the largest share of renewable energy consumption for DH in Denmark, although in the future the share is expected to fall as a result of electrification in the DH sector.

7. **Large-scale heat pumps**. In order to reduce the CO_2 emissions from the heating sector in China, and reach the committed target of carbon neutrality by 2060, there will be a focus on the integration of variable renewable electricity and optimizing the utilization of surplus heat through technologies such as large-scale heat pumps. China can benefit from Denmark's substantial experience with this technology, which has witnessed significant growth in recent years.

Efficient use of surplus heat

8. **CHP surplus heat**. In China, the surplus heat generated by CHP plants has the potential to meet a substantial portion of the heat demand. Surplus heat from CHP should be considered as one of the important heating resources for future DH planning.
9. **Industrial excess heat**. Being the world's largest industrial producer, China's industrial sector contributes to almost two-thirds of its total energy consumption. A huge amount of heat demand could be matched with the excess heat from industrial processes.

Efficient energy consumption

10. **Return temperature reduction**. The return temperature in China's DH systems is considered rather high, and there is room to improve the efficiency of building heating system. Household installations such as balance valves and thermostatic radiator valves are not yet broadly applied in China. In Denmark, efficient heat units in households can bring down the return temperature, resulting in improved efficiency for heat production. In China, capacity building is essential to ensure correct design parameters of household installations in order to maintain an efficient heat supply during normal operation with a low return temperature.
11. **Heat metering and billing system**. In China, DH consumers are not being measured in terms of energy/flow levels making it difficult to monitor actual consumption and implement a consumption-based billing system. In most cases, heat consumption is billed at a flat rate fixed price based on the heated area, the category of end-users and heat sources. In contrast, Denmark has established a comprehensive incentivized tariff system, allowing consumers to earn rewards for using heat more efficiently.

Bridging the identified gaps can be achieved by implementing strategic heat planning and key policies that will enable the adoption of new methodologies, standards, procedures, and technologies. This effort can be supported by research and capacity building activities, tailored to the specific development contexts faced by the Chinese provinces.

The Sino-Danish SSC on Clean Heating Programme is committed to develop a knowledge sharing network and organize capacity building activities in order to support the achievement of a clean heating sector in China. A series of workshops and capacity building activities will focus on the efficient utilization of renewable and advanced heating technologies. It is recommended to undertake a joint pilot study for a clean and renewable heat roadmap at the provincial or city level in China to provide sound policy recommendations.

Acknowledgements

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The Report has been jointly prepared by the Danish Energy Agency (DEA) and the China Renewable Energy Engineering Institute (CREEI) under the collaboration framework of the Sino-Danish SSC on Clean Heating. DEA shares best practice from decades of green transition in Denmark through government-to-government cooperation to accelerate global green transition. Through policy research, technological innovation and standard formulation, CREEI is committed to promote green energy and sustainable development and is dedicated to building a modern energy system in China that is clean, efficient, safe and sustainable.

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1 Introduction

1.1 Background and rationale

Climate change is a global challenge that cannot be ignored. Vast carbon dioxide (CO_2) emissions are considered one of the key drivers of climate change, and the continued and increasing use of fossil fuels emerges as the primary factor behind the rise in global energy-related CO_2 emissions.

In recent years, extreme weather events have been frequent worldwide. Addressing global climate issues and reducing carbon emissions have become imperative for all nations. Nations worldwide must swiftly advance the process of energy transformation towards green and low-carbon. Countries across the world have set climate goals according to their national circumstances. 138 countries have set carbon neutrality targets, while other countries have set carbon reduction targets.

In September 2020, President Xi Jinping announced that China would "aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060". The energy sector contributes to almost 90% of China's greenhouse gas (GHG) emissions (International Energy Agency, 2021), so energy policies must steer the transition to carbon neutrality. Consequently, the primary energy consumption mix is becoming increasingly clean, with the share of coal declining by 11.5% in the past decade. However, coal remains the dominant energy source in China, and after decades of rapid urbanization, China's overall CO_2 emissions have continuously increased.

To achieve its targets, China will need to transform its energy system from being predominantly reliant on fossil fuels to being predominantly powered by green energy in less than 40 years. To do so, China can draw inspiration from Denmark, a country that started its transition from black to green almost 45 years ago. Denmark's experience demonstrates that it is possible to significantly reduce its carbon emissions while maintaining GDP growth. Denmark's green transition, initiated in response to the oil crisis of the 1970s, has evolved through strategic policy adjustments emphasizing energy efficiency, diversification in energy utilization and integration of renewables and waste energy. These measures have resulted in substantial progress towards establishing a sustainable and carbon-neutral society.

According to UNEP (United Nations Enviroment Program, 2015), DH is recognized as the most cost effective and highly efficient solution for mitigating CO_2 emissions and reducing primary energy demand. In Denmark, the development of DH played a pivotal role in addressing the energy crisis in the 1970s, propelling Denmark as one of the most energy-efficient countries in Europe. Given that China has the world's largest DH market, the transition towards a green DH system is crucial in shaping a future clean energy system in China.

While both China and Denmark have a long history of DH, the two countries have developed different heating policies, influenced by historical and geographical differences. The regulatory framework for heat supply varies in both countries. The composition of the energy mix in their respective DH sectors are quite different and there are several distinctions in the technical characteristics of DH systems between China and Denmark.

However, the two countries also share several similarities. Both countries have ambitious targets for carbon neutrality and they both experience cold winters where heating is regarded as an important service.

To study the applicability of the Danish experience in China, it is necessary to gain a basic understanding of the DH systems in both countries. The rationale of conducting a comparative analysis is to describe the current state of the Chinese heating sector and to provide a basis for forming a comparative perspective with the current conditions in the Danish heating sector. In order to define the possible or necessary changes required to achieve the future clean heating conditions, the analysis is specifically designed to highlight and address the gaps between the current and future conditions. This forward-looking perspective is broadly shaped by the current Chinese policy goals, further green transition ambitions, and insights derived from implemented measures or experiences in Denmark.

Closing the gaps will be achieved by implementing strategies and policies that facilitate the adoption of new standards and technologies, and thereby advancing clean and renewable heating. The comparative analysis focuses on well-known key areas in the entire heating industry that are urgently needed to be addressed to achieve a modern heating system from both economic and social perspectives.

A heating system is typically complex, as it intersects with many facets of the energy system and governance system. Clean heating[3], as defined by NEA, refers to the use of clean energy and high efficient energy systems to provide low energy consumption and low emission heating to high energy efficient buildings. The definition involves the whole process of heating with the goal of reducing both heating energy consumption and pollutant emissions, as illustrated in Figure 1. Achieving clean heating is not simply defined by a few parameters; it depends on numerous factors that are not always possible to influence.

[3]Clean heating was proposed by NEA during the interpretation of the "Clean Heating Plan for Northern China in Winter (2017-2021)" in 2018. Clean heating in China refers to the utilization of natural gas, electricity, geothermal energy, biomass, solar energy, industrial waste heat, clean coal (ultra-low emission), nuclear energy, and other clean heating resources (CHRs) to supply heating with low-emission and low energy consumption through efficient energy systems.
Renewable heating refers to heat supplied with non-fossil energy such as wind, solar, hydro, biomass and geothermal energy – *China Renewable Energy Law*.

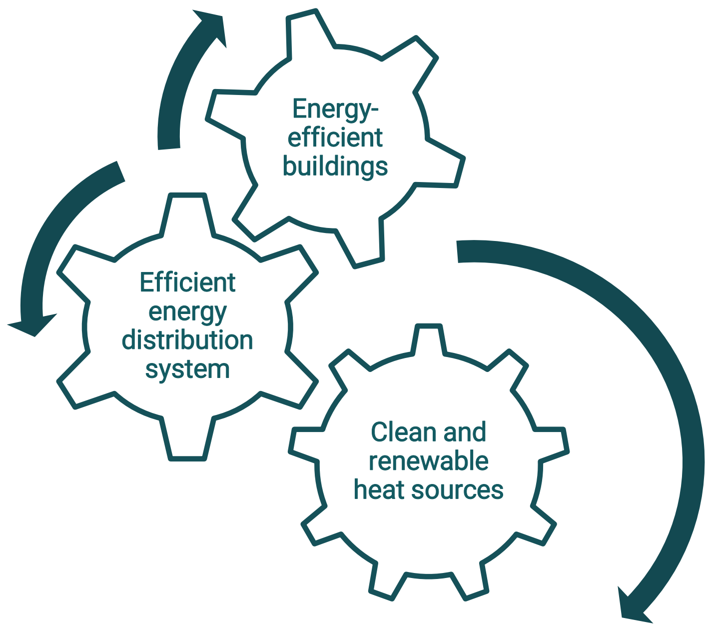


Figure 1. Main elements to achieve clean heating.

In order to achieve clean heating, we must ensure the following criteria must be met:

(1) Socio-economic feasibility: Utilize holistic heat planning methods that prioritize pollution and CO_2 reduction as the first guiding principle. Meanwhile, aim to enhance energy security and make heating more affordable for the population.

(2) Clean and efficient energy sources: Utilize CHP and excess heat from industry.

(3) Development of renewable energy: Gradually replace carbon-intensive fuels (such as coal, oil etc.) with renewable energy.

(4) Energy efficiency: Ensure energy efficiency throughout the heat supply cycle by minimizing energy losses, maintaining hydraulic balancing with control systems and optimizing energy use to reduce fuel consumption to the lowest possible amount.

The full potential of GHG reduction in the heating sector can be unlocked by integrating renewable energy into Chinese DH system. Sector coupling precisely combines the utilization of renewable energy sources with local clean heating sources. Clean heating not only can help China achieve its multiple energy and climate goals but also can play a significant role in attaining the nation's pursuit of the dual carbon targets of peaking before 2030 and reaching carbon neutrality before 2060.

1.2 Objective

This Report draws a comparison between the states of the DH sector in China and Denmark and identifies where exchanges of experiences between Denmark and China can support the development of a clean and renewable heating sector in the Chinese provinces in a meaningful way. For each of the focus areas, preliminary suggestions are made by the Sino-Danish experts on what measures can be taken to bridge the gaps between current conditions for DH and future conditions for a clean and renewable heating system in China. Even though there might not necessarily be one single and most optimal solution for each focus area, there has been suggested a set of actions that need to take place collectively.

The Report is mainly aimed at decision and policy makers in China to identify how the current gaps can be bridged and how future conditions can be achieved through the implementation of actions and policies contributing to the five-year plan of China.

The Report also aims to set up a bridge through this international cooperation programme to connect Denmark's lessons learned during the development towards low-carbon heating with China's dual carbon targets.

1.3 Methodology

The analysis has adopted the following methodology described in Figure 2.

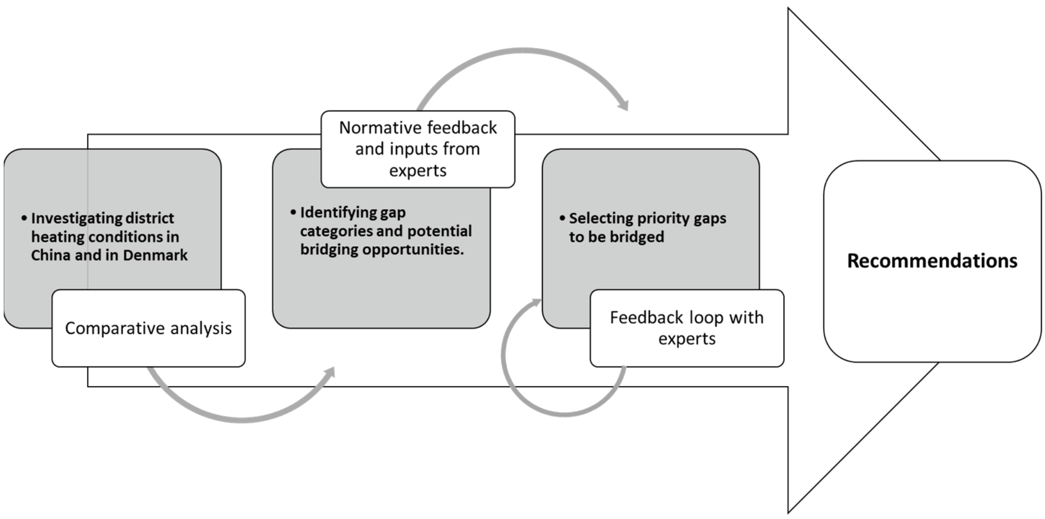


Figure 2. Methodology to analyze the comparisons in the district heating system in China.

The first step consisted of investigating the conditions for DH in China and in Denmark. Chapter 2.3 presents the main elements of the landscapes of both Danish and Chinese DH systems, and a summary of the main DH policies in China and in Denmark. In the policy analysis section, we reviewed existing policies spanning from 2005 to 2022, as defined by the Chinese government, to assess achievements in the heating sector. We identified key policies that have significantly influenced the development of China's DH since the 1950s. The policy analysis highlighted the guiding role of national policies for China's clean heating development, and leading ministries and commissions of the Chinese government on the clean heating policies since the announcement of the dual carbon targets in 2020.

Based on the differences and similarities of the conditions for DH in China and Denmark, the main gaps have been identified in China's DH system and are presented in Chapter 4. The gaps contained 19 initially selected topics highly related to clean heating. These topics can be found in Appendix II.

Through discussions on each topic with members of the expert panel and technical team of both sides, a survey poll was used to evaluate the priority of each focus point. The focus areas have been selected based on each category being rated for the level of benefit (savings, value, energy efficiency) and effort (time, cost, complexity) where high-benefit low-effort subjects creates the best results. The model used to conduct this survey is presented with a prioritization matrix as presented in Figure 3 below. The low hanging fruits are the best focus areas to look into first where the highest gains can be achieved.

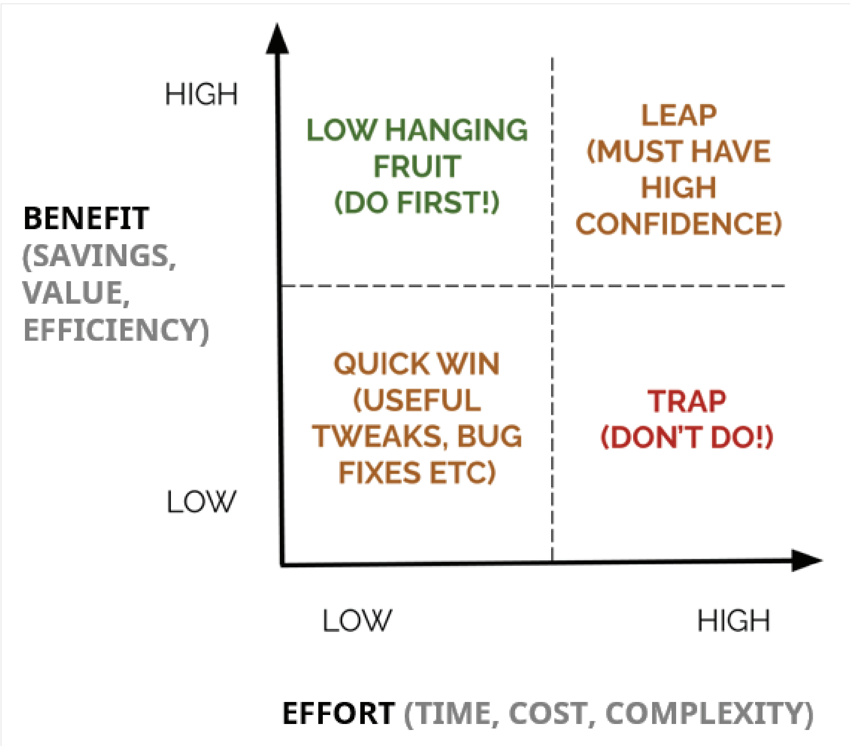


Figure 3. Prioritization matrix Benefit/Effort analysis

Afterwards, the experts discussed the priority level for each gap to assess them in more detail based on the comparative analysis of the two countries. In doing so, the focus areas that can help enabling China's clean heating sector based on lessons learned from Denmark could be selected. The selected focus areas were made into four[4] main categories as provided in the following Figure 4.

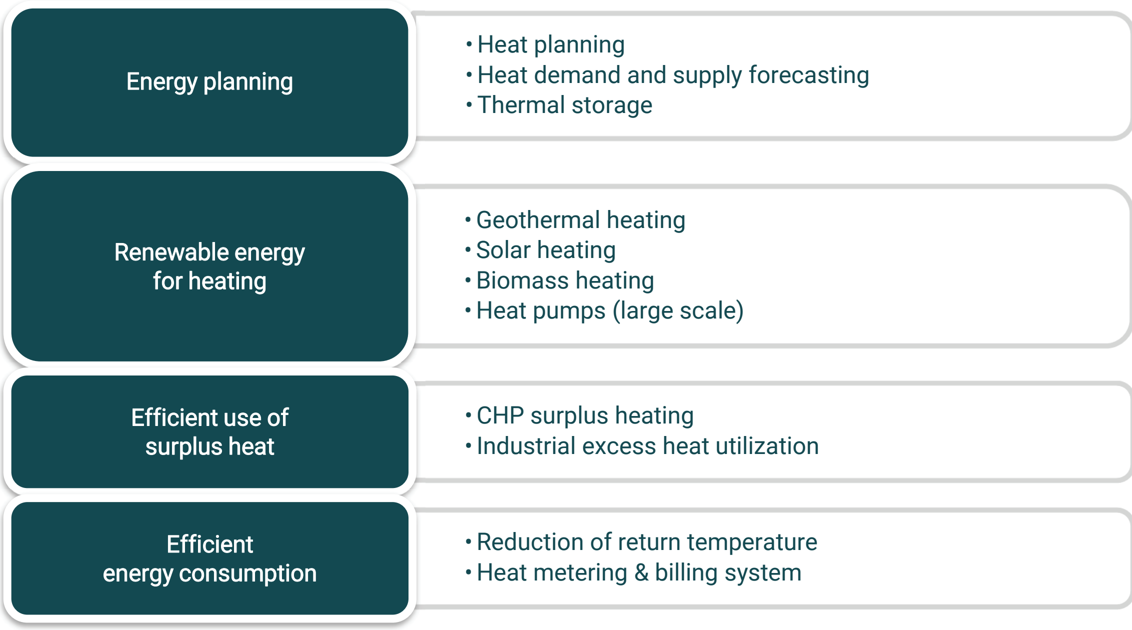


Figure 4. Four main categories and 11 focus topics in the Report

Each focus area has been investigated with regards to the current heating conditions in China, and future development conditions suitable for the Chinese context have been described to fulfill the Chinese climate and energy targets. The future conditions and potentials for gaps to be bridged have been prioritized based on normative feedback and inputs from the Sino-Danish Clean Heating experts and Chinese partners, who have taken part in defining economic, environmental and climate friendly goals that are also realistic to achieve.

The following chapters introduce the main differences and similarities in the DH landscapes in China and in Denmark and describe the main identified gaps between current and future conditions for clean and renewable DH in China, capturing insights from the Danish experience. These chapters allow for some policy recommendations in Chapter 4. The Report is completed with a conclusive chapter and appendix.

[4]The four categories listed are not an exhaustive list. For example, the sustainable use of biomass would be considered as renewable heating and the sections on industrial waste heat utilization primarily refer to excess heat from CHPs and industrial processes and not waste incineration.

2 Differences and Similarities of District Heating Systems in China and in Denmark

2.1 General introduction of district heating in China and Denmark

DH systems utilize local energy sources, as well as waste and surplus heat, and provide heating through an energy carrier (usually pressurized hot water) through an underground network of insulated pipes to end-users, which are the heating devices within various buildings. Such systems create synergies between the production and supply of heat, domestic hot tap water, and electricity, and it can be integrated with municipal systems such as power, sanitation, sewage treatment, transport, and waste. This means that heating can be low-carbon and efficient and maximize utilization of “free” energy resources. Therefore, many countries have realized the importance of DH and are accelerating investment in modern low-carbon and climate-resilient DH systems so as to cope with the challenges brought by climate change.

Denmark’s DH system is recognized as one of the most efficient in the world, with two-thirds of all Danish households connected to the system. The green transition of the heating sector in Denmark is one of the key elements of its success in reducing its CO_2 emissions since 2000 while maintaining its GDP growth.

To study the applicability of the Danish experience to China, it is necessary to have a basic understanding of the DH systems of the two countries. Chapter 4.1 describes the similarities and differences between the two countries' DH systems in terms of climate zones, heating supply and operation.

2.1.1 Climate zones

China’s vast geography results in a wide variety of climates. The national code for thermal design of civil buildings, GB 50176-2017 (MoHURMoHURD & General Administration of Quality Supervision, Inspection and Quarantine of China, 2017) divides China into five climate zones, namely Severe Cold, Cold, Hot Summer and Cold Winter, Temperate, Hot Summer and Warm Winter. Among these, the Severe Cold and Cold climate zones belong to the legally designated heating areas. These two zones cover about 70% of the national territory and include 13 provinces and two metropolitan cities, i.e. Beijing and Tianjin. Denmark has a temperate maritime climate in the northern hemisphere, with cold winters and cool summers. The climate is mild and stable, generally without extreme weather conditions.

To compare the heat consumption levels of urban buildings in Denmark and China, the concept of Heating Degree Days (HDD) is used. HDD is defined relative to a base temperature, with buildings above this base temperature not requiring heating. In China and Denmark (DMI, 2023), 18°C is commonly used as base temperature. HDD provides a simple metric to quantify the heating energy for buildings at a specific location during a certain period. The heating demands for buildings at a specific location is directly proportional to the local HDD, meaning higher HDD values indicates a greater need for heating. HDD offers a rough method to estimate seasonal heating demand.

For instance, China's industry standard "JGJ26-2018: Design Standard for Energy Efficiency of Residential Buildings in Severe Cold and Cold Zones" (MoHURD, 2018) divides Severe Cold and Cold zones into five distinct climate subzones based on different HDD ranges, as shown in Table 1. This classification effectively illustrates the varying heating demand levels among different buildings in these subzones. In winter, zones with higher HDD values require more substantial heat supply.

Table 1. HDD values for the climate subzones in Severe Cold and Cold zones of China

Climate zones	Subzones	HDD
Severe Cold climate zone	Severe Cold (A) zone	6000≤ HDD18
	Severe Cold (B) zone	5000≤ HDD18 ≤6000
	Severe Cold (C) zone	3800≤ HDD18 ≤5000
Cold climate zone	Cold (A) zone	2000≤ HDD18 <3800
	Cold (B) zone	2000≤ HDD18 <3800

For easy visual comparison, Figure 5 shows the monthly HDD18 values over the past 36 months, from June 2020 to May 2023, in Billund, Denmark and Shenyang, Beijing, and Xi'an in China. By calculating the average annual HDD18 of the four cities, it can be observed that, for structures with similar design and insulation properties, the energy required for heating in Shenyang is 1.12 times that of Billund. Additionally, the energy needed for heating in Billund is 1.2 times that of Beijing and 1.5 times that of Xi'an. Consequently, the heating energy consumption for buildings in these four cities ranks highest in Shenyang, followed by Billund, Beijing, and Xi'an. By comparing the HDD, we can gain a preliminary understanding into the heat consumption of buildings in different regions. Additionally, these changes in HDD are also associated with the climate conditions in the cities. Among these cities, Billund has a moderate climate, with a smaller yearly temperature variation compared to the three cities in China. The Chinese cities have distinct seasons with Shenyang having the coldest winter, followed by Beijing and Xi'an.

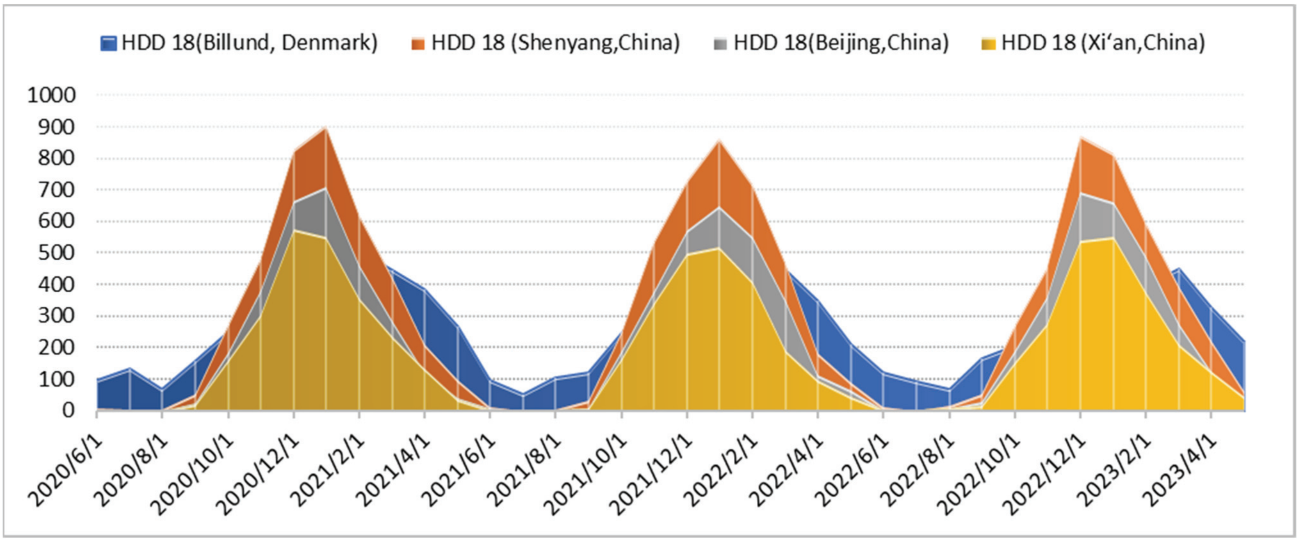
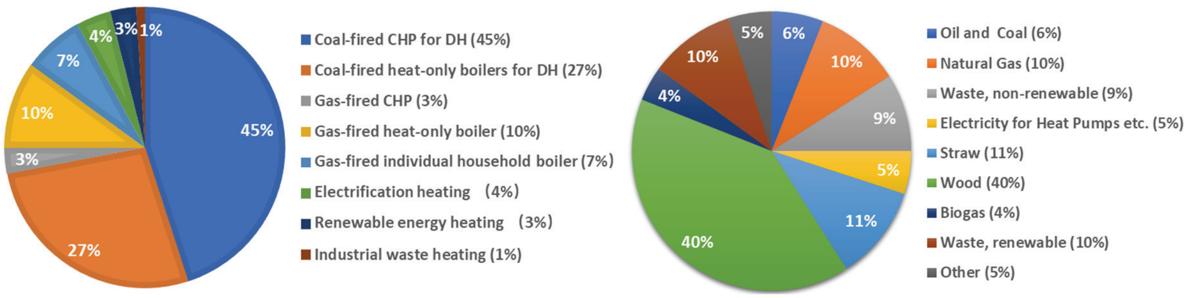


Figure 5. 2020.6 – 2023.5 HDD in Denmark (Billund) and China (Shenyang, Beijing, Xi'an)

2.1.2 Heat supply and operation

China's DH system is mainly based on coal, whereas Denmark's DH system is predominantly powered by various renewable energy sources. Figure 6 shows the fuels in the DH sectors in China (CDHA, 2021) and Denmark in 2021 (DEA, Energistatistik, 2021). Coal-fired DH in China constituted 72%, with 45% from combined heat and power (CHP) plants and 27% from heat-only boilers. In the same year, only 16% of fuel consumption for Danish DH production came from fossil fuel; the rest was from renewable and waste energy. In Denmark, CHP also plays a big role, with 66% of DH production coming from CHP plants in 2021.



Source: China District Heating Association, 2022 *Source: Danish Energy Agency, 2022*

Figure 6. Heat source structures in China (north) and Denmark in 2021

In terms of operation of DH systems in China and Denmark, China's traditional DH system operates as Push System delivering a large amount of heat at high temperature and pressure levels through large-scale substations to high-rise or multi-story building blocks. The heat supply is based on planned heat production with respect to outdoor temperature. Heat consumers have limited or no control of the heat supply due to the absence of control devices. Therefore, the building heating system typically operates under a constant flow, with the standard for indoor temperature reaching 18~20°C. Most DH systems only provide space heating, not domestic hot water.

In Denmark, DH systems operate at lower temperature (typical design supply/return is 70/40˚C) as a Pull System. In this system, the heat consumer extracts the required heat from heat generation to fulfill their heat demands. Heat supply aligns with the end-users consumption and is allocated to low heat density areas, such as single-family houses or multi-story buildings through available automatic control measures. Heat supply is comfort driven, allowing heat consumers to adjust the room temperature with the help of a control device installed at the heating unit (i.e., radiators) of the DH system. For instance, the recommended indoor temperature for living rooms is between 20-23°C in Denmark. Therefore, the heating system operates under variable flow. The DH systems provide both space heating and domestic hot water.

2.2 District heating development in China and Denmark

Despite their extensive experience with DH, China and Denmark did not develop similar policies. Danish DH systems have demonstrated significant potential for integrating variable renewable energy and waste energy. The flexibility of DH networks has enabled Denmark to effectively respond to various strategic challenges over the years.

2.2.1 Danish energy model

The Danish energy model demonstrates that through persistent, active, and cost-effective energy policies with ambitious renewable energy goals, enhanced energy efficiency, and support for technical innovation and industrial development, it is possible to sustain significant economic growth, a high standard of living, and a secure energy supply while reducing fossil fuel dependency and mitigating climate change.

To achieve its energy targets, Denmark has implemented a series of policy measures which can be categorized as informative, normative, and economic. Normative measures involve strict regulations, including elements such as the Heat Supply Act, energy-saving targets and minimum energy performance standards for new or renovated buildings. Informative measures include initiatives like energy performance certificates and public information campaigns aimed at reducing energy consumption. Economic measures may take the form of taxation or subsidy schemes that incentivize energy saving behaviors among both energy suppliers and consumers. For instance, by increasing taxes on fossil fuels and providing financial support for replacing individual fossil fuel-based installations with either DH or individual heat pumps, the transformation of heating can be promoted, thereby achieving the government’s set objectives. Additionally, reducing green electricity tax for heating is fostering the electrification of the DH sector in Denmark.

From a broader perspective, modern, efficient, and low-carbon DH systems are the result of the Danish energy model. Concerning DH, the Danish energy model incorporates five key elements:

1) The stable Danish Energy Policy since 1976 represents the national top-level policy design.
2) The Heat Supply Act, passed in 1979 and regularly updated since, provides the regulatory foundation for almost all aspects of the Danish heating sector, and legally guaranteeing that the energy policies reach the intended targets for the heating sector.
3) Municipal heat planning offers a comprehensive methodology for developing cost-effective, environmental-friendly, technically feasible DH systems while optimizing system operation.
4) The non-profit principle and price regulation ensure a balance between investor security and consumer protection.
5) The longstanding tradition of cooperation among stakeholders is based on data transparency and clearly defined responsibilities, fostering a high level of trust.

2.2.1.1 Top level design: energy policy

In Denmark, the experiences with DH began in 1903; however, it wasn't until the oil crisis of 1973/74 that the development of heat policy and rapid deployment of DH systems took place. In 1976, Denmark launched its first energy plan called "Energy Policy 1976". The main objective was to reduce dependence on oil by utilizing natural gas. Coal and renewables were also considered ways to reduce oil dependence, and consequently, a large part of the energy production initially shifted to using coal. This energy policy gained political consensus at all levels of government. At this point, there was no law regulating the heat supply in Denmark, most consumers had small oil-fired boilers or alternative individual heat sources in their homes. However, to fulfill policy objectives, increase efficiency, and reduce dependence on imported fossil fuels, Denmark set out to develop its Heat Supply Act in 1979.

Today, the Danish government has a clear ambition: Denmark should be climate neutral by 2045, and by 2030, greenhouse gas emissions must be reduced by 70% compared to 1990 levels. Key elements in achieving these targets are energy savings and efficiency, as well as increased use of renewable energy, including in the DH sector.

2.2.1.2 Legal guarantee: Heat Supply Act

The Danish Heat Supply Act was introduced in 1979 to promote the socio-economically best use of energy for heating and to reduce oil dependence by expanding the use of DH and natural gas. For the past decades, the Heat Supply Act was adjusted according to the changing energy situation and went through four stages with different focuses, see Figure 7.

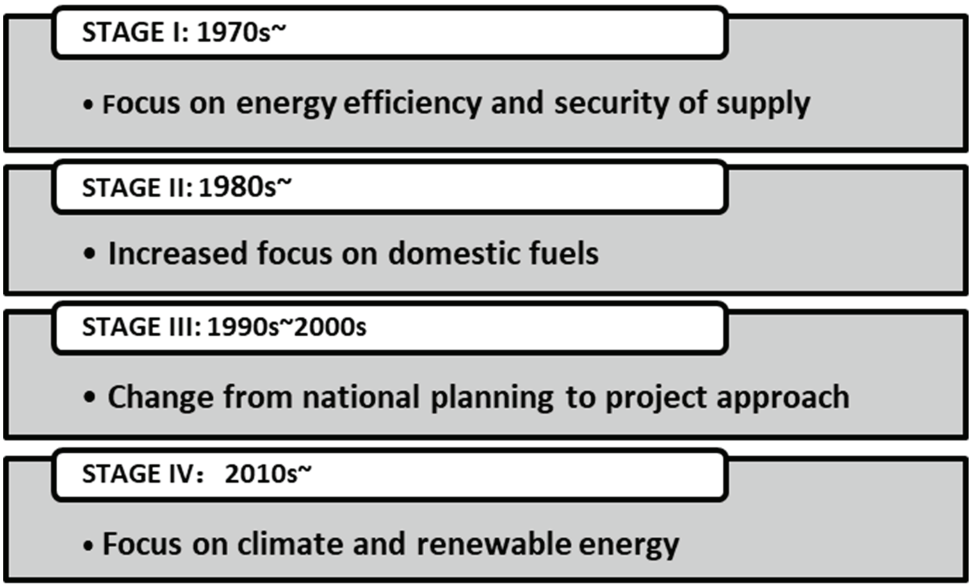


Figure 7. Four stages of Heat Supply Act with different focuses in Denmark

Heat Supply Act established specific zones for the nationwide development of DH networks and, for the first time, regulated the heating sector. It mandated municipalities to conduct an analysis on the local heating demand and available heat resources.

In short, the Heat Supply Act provides the regulatory basis for almost all aspects of the Danish heating sector. Thus, it also includes provisions regarding the form and content of heat planning in Denmark. The Act marked the beginning of a new era in Danish heat planning, and the core principles remain effective today.

2.2.1.3 Methodology on optimal design of heat supply: heat planning

Denmark has a longstanding tradition of heat planning, with municipalities playing a central role in shaping the development of the heating sector. The introduction of the Heat Supply Act mandated that municipalities should map existing heat demand, the prevailing heat supply method, and the amount of energy (fuels) used. The municipalities should also assess the future heat demand and heat supply possibilities, preparing options for future heat supply. The heat plans include "zoning" that defines which areas are to be supplied with DH or natural gas. Zoning helped pinpoint the most suitable areas for infrastructure development, preventing overinvestment. The Heat Supply Act also authorized municipalities to require households in defined DH zones to connect and remain connected to DH networks. While new connection obligations are no longer possible to enforce due to a desire to increase competition in the heating market, existing obligations remain valid.

Heat planning is a rational methodology and vital component of Denmark's energy planning. It promotes the fundamental concept of modern DH: utilizing locally available renewable energy sources, along with waste heat which could otherwise be discarded. This approach enables society to fully leverage the centralized, bulk and scalable advantages of DH. It not only takes into account environmental benefits but also ensures the cost-effectiveness of urban infrastructure operation.

In 1990, the Heat Supply Act was revised, and both DH and natural gas had expanded significantly throughout Denmark. With the completion of this expansion, heat planning shifted towards a more project-based approach. Any expansion or changes to the local DH systems or the local natural gas systems must be approved by the local authority, based on socio-economic and environmental cost-benefit analysis.

To assist local authorities in assessing the socio-economic and environmental benefits, the DEA has developed a technology catalogue and updates it regularly. The catalogue not only includes information on heat supply plants, but also details about how to calculate the distribution of heating demand throughout a year, how to assess investments in natural gas networks and DH networks, fuel price forecasts, etc. This established a standardized and comparable way for evaluating the feasibility of DH for municipalities in Denmark. The municipalities and DH utilities operate within a flexible framework, allowing them to autonomously leverage the market and choose the most cost-effective heating solutions for the entire system and its heat consumers. Heat planning helps communities share the risks associated with using various technologies and fuels, enabling them to enjoy economies of scale and more favorable fuel and equipment prices compared to individual consumers.

2.2.1.4 Heat price regulation

According to the Danish Heat Supply Act, Denmark's heat price regulation has played a crucial role in the country's DH sector. Typically, DH utilities are permitted to incorporate only the costs associated with the production and distribution of heat into their pricing, with certain exceptions. This heat price regulation serves not only to safeguard consumers against excessively high DH prices but also to guarantee that DH utilities can consistently cover their necessary expenses and safeguard their investments. DH utilities operate on a non-profit basis and are subject to regulation to ensure minimal costs.

The synergy between heat planning and pricing regulation fosters a stable market, and ensures that consumers have access to DH at reasonable prices.

In general, the DEA has established general conditions for the establishment and operation of collective heat supply, particularly DH. The objective of heat price regulation is to ensure a positive financial outcome for utility companies and favorable prices for consumers. Consequently, heat prices may vary across all heating areas in Denmark, but the principles governing their pricing are uniform and stipulated by law.

2.2.1.5 Stakeholders of the heating sector

The development of green and efficient DH systems involves multiple stakeholders throughout the process, from planning to operation. Key stakeholders include the European Union, the Danish national government, municipalities, DH utilities and consumers. The dynamic interaction among them is characterized by top-down policies and bottom-up power, as illustrated in Figure 8. Over the past decades, their roles have evolved to establish the current distribution of powers and responsibilities.

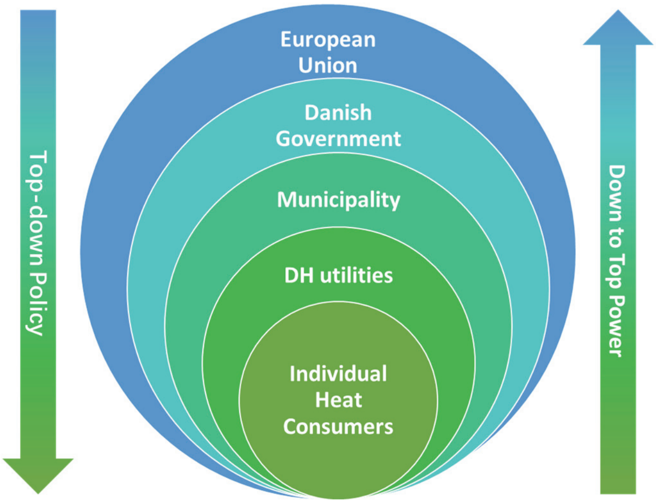


Figure 8. Danish Stakeholders in heat planning

EU: As a member state of the European Union, Denmark is subject to European energy goals and directives.

Danish government: DEA and Danish Utility Regulator (DUR) are two key entities responsible for energy policymaking and regulation within the Danish government.

DEA's responsibilities extend from energy production to end-user consumption. It is tasked with implementing national energy policies, including goals related to GHG reduction and energy efficiency. In the DH sector, DEA aims to promote DH systems that enhance the integration of renewable energy and improve overall system flexibility. One of DEA's crucial roles is to provide the framework for municipalities and regions to assess the cost effectiveness of future energy projects.

DUR oversees the DH sector and ensures compliance with various aspects of Danish utility regulation, particularly regarding pricing. All DH and CHP units are obliged to submit information to DUR regarding prices and conditions. This allows the authority to address complaints and objections. DUR primarily handles general issues such as tariffs and terms for heat supply.

Municipalities: In Denmark, municipalities and their local city councils are designated by the current Heat Supply Act as the entities solely responsible for ongoing heat planning and the approval of activities and projects undertaken by DH utilities. This implies that the city council makes the final decision on heat planning and the expansion of heat supply within the municipality. Municipalities serve as the local regulators overseeing the activities of DH utilities.

DH utilities: Danish DH utilities closely cooperate with the municipal governments. According to the Danish Heat Supply Act, the ownership of DH utilities in Denmark is primarily regulated by local municipal governments. This regulation is aimed at ensuring the effective operation of heating systems and providing appropriate heating services to local communities. It's worth noting that while there is regulation, the law does not explicitly mandate that these companies must be government-owned. Therefore, in practice, some DH utilities may be owned by either municipal governments or heat consumers. The profits of Danish DH utilities are returned to heat users in the form of reduced heat prices, rather than being shared with shareholders. DH utilities determine the prices of their heat products, covering all related costs, including financing for system expansion. However, the way they set their prices is regulated under the Danish price regulation. The companies can provide most of their infrastructure independently to maintain low heat prices for consumers and develop the system as needed, rather than waiting for available funds. If DH utilities need external financing, the costs of bank loans are very low, and the city government can act as a loan guarantor. Given the interests of heat consumers and strict scrutiny, heating companies approach changes in fixed costs for heat prices with caution.

Heat consumers: The needs of heat consumers are well reflected in local decision-making activities and cost-benefit analysis. Consumers are confident that decision-makers in DH utilities can fully and accurately represent their needs, ensuring they receive reliable and reasonable prices, as well as transparent and publicly available cost information. This assurance is further strengthened in Denmark, as in addition to municipality-owned companies, approximately 83% of Danish DH utilities are owned by the consumers through cooperatives. In Denmark, DH cooperatives are non-profit organizations focused on procuring affordable energy in smaller cities or towns. These established organizations are entirely governed by their members. Municipal ownership provides democratic control, while consumer ownership creates channels of influence. Alongside the non-profit principle, this structure ensures an efficient heat supply at the lowest possible price for consumers.

2.2.2 Heating development in China

Based on policy review and analysis, China's heating industry has undergone four stages since 1949, including periods of slow growth, rapid development, heat commercialization and energy conservation, and the more recent focus on clean and renewable heating, as shown in Figure 9. The investigation also revealed that the features of each stage are the result of policy orientation during that period. In addition, the number of ministries involved in policy formulation increased at each stage, reflecting the growing importance of the heating sector in overall energy development.

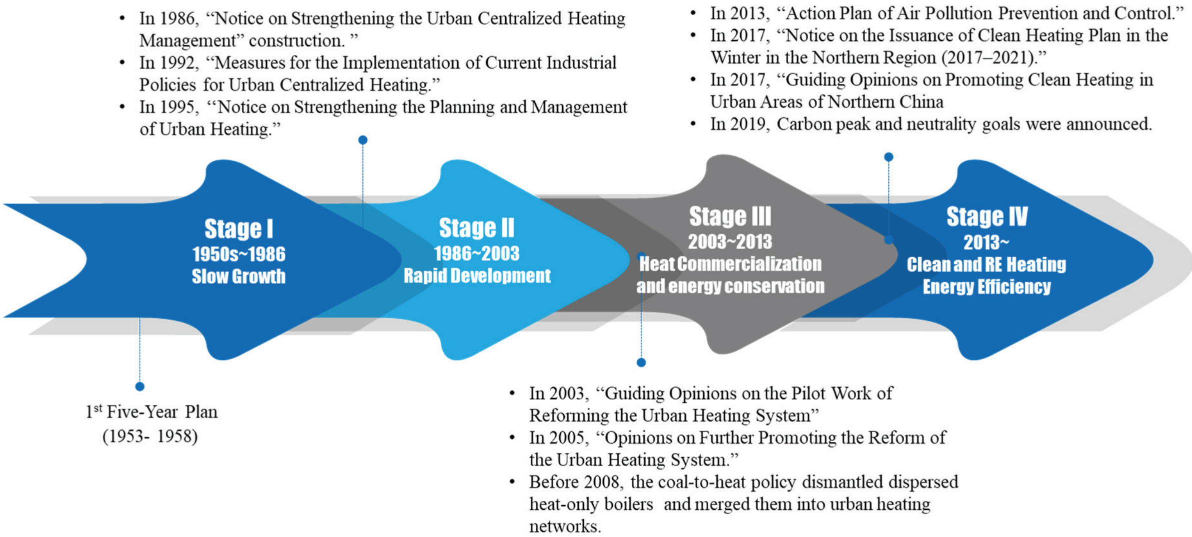


Figure 9. Four development stages of China' heating industry

2.2.2.1 Current priority for energy policy

At the General Debate of the United Nations General Assembly in September 2020, President Xi Jinping made a commitment that China would strive to reach CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060. The significant commitment has spurred action across various industries in China, actively exploring roadmaps for achieving carbon neutrality in the respective sectors. The Dual Carbon Goals serve as a crucial guideline for China's socio-economic development and transformation of its energy system in the coming years.

2.2.2.2 Heating regulation in China

Since the 1990s, the national government has enacted management regulations for urban gas, road lighting, drainage, and water supply. However, the national regulatory framework for the heating sector still needs to be incorporated. The existing provincial-level heat supply management regulations require support from overarching laws to effectively regulate the market, adapt to evolving policies and standards under the new circumstances, and provide a political foundation for a clean, efficient, safe, modern heating system.

2.2.2.3 Heat planning approach

China's heat planning is part of the urban master plan. It is developed according to the expected growth in population and building areas over the next five, ten or fifteen years. Heat planning usually follows a relatively fixed format and includes guidance, such as specifying relevant national and local policies and regulations, highlighting key aspects of the urban master plan, forecasting heat loads, and planning heat sources and networks within the designated period.

Currently, in the cold and severe cold climate regions of northern China, a significant portion of the heat source for urban heating comes from the excess heat generated by power plants. The challenges in matching supply and demand in cogeneration highlight the tremendous potential for improving the efficiency of China's CHP plants. Additionally, due to strict national requirements for energy development, some power plants that were originally designed purely for electricity generation have transformed into CHP plants through establishing or integrating with DH systems. In urban areas where excess heat from power plants cannot reach, coal and natural gas boilers are used, but there is still considerable room for overall efficiency improvement. China has set clear climate goals, strives to address pollution issues from boilers and industry, and aims for long-term independence on the imported fossil fuels, such as coal and oil.

2.2.2.4 Stakeholders of the heating sector

In terms of administration framework related to heating in China, three critical national administrations are the NEA, the Ministry of Housing and Urban-Rural Development (MoHURD), and the National Development and Reform Commission (NDRC). They are responsible for clean energy sources, building energy efficiency, and pricing mechanisms respectively within the heating sector. There is no single core government department overseeing the heating industry. Since 2013, an increasing number of joint policies focusing on clean heating have been released, with more ministries and institutions becoming involved in the management framework of the heating sector.

Other stakeholders are heat consumers and heating companies. Heat consumers in most cases pay fixed heating fees based on the heated floor area. As a vital aspect of social livelihood, state-owned heating companies could apply for heating subsidies from local financial departments for compensation of financial losses caused by charging based on the heated floor area. Municipal authorities manage heating companies in accordance with local heating management regulations.

2.3 Summary of differences and similarities in district heating landscape in China and Denmark

The main differences and similarities regarding DH systems in Denmark and China identified throughout this chapter including climate zones, technical specifications, policy frameworks, regulation, stakeholders and energy planning approaches, are summarized in Table 2 below.

Table 2. Differences and similarities in the DH systems in China and Denmark

Items	Denmark	China
Climate zones	- Only one climate zone, i.e. the temperate zone of the Northern Hemisphere.	- Five different climate zones. - Among them, the Severe Cold and Cold climate zones belong to the legally designated heating areas.
District heating system	- Provide both space heating and domestic hot tap water. - Heating is available throughout the year.	- Most DH systems in North China only provide indoor heating, with around 5% also supplying domestic hot water. Domestic hot water is commonly provided by individual water heaters. - Heating season typically runs from November to March.
Heat generation	- In 2021, DH sources were: 65% renewable energy, 10% natural gas, 9% waste, 6% coal and oil. - CHP contributed 61%	- In 2021, DH sources were: 45% coal-fired CHP, 3% gas-fired CHP, 27% coal-fired boilers, 10% gas-fired boilers 10%. - CHP contributed 48%.
Distribution network	- Transitioning to low temperature DH. - DH systems are designed with a supply/return temperature of 70/40°C (today). - Reducing heat loss in distribution pipelines through various technologies, such as the pre-insulated twin-pipe (supply and return pipes within a prefabricated insulation layer, suitable for diameters below DN100).	- DH systems are designed with a design supply/return temperature of 130/70 °C. - Large pipe sizes due to high linear heat density. - Pre-insulated pipes are increasingly used to reduce heat loss.
Substation	- Building substations, or apartment unit substations. - Typical building types are single family houses and multi-story buildings.	- Large substation serves a group of buildings. - Typical building types are high-rise buildings and multi-story buildings.

Items	Denmark	China
Indoor comfort and heat billing mechanism	- Adjust indoor temperature with thermostatic radiator valves (TRV). - Pay heating bills based on actual consumption. - Heating costs include variable and fixed costs, connection fee and taxes.	- Lack of indoor temperature control devices - Heat billing is charged based on floor heating areas. Moving towards heat metering and billing based on actual consumption.
Energy policy	- First energy policy launched in 1976. - Carbon neutrality by 2045	- 2030 carbon peak and 2060 carbon neutrality targets announced in 2020.
Heat regulations	- The Heat Supply Act enacted in 1979 and regularly updated serves as a legal basis. - Heat price regulation ensures consumer rights.	- No national-level regulation for the heating sector. - The existing heating management regulations are the basis for overseeing the heating sector.
Heat planning approach	- Municipal heat planning combined with project proposals. - National guidelines for socio-economic and environmental benefits assessment.	- Part of urban master plan. - Relatively fixed format and content.
DH sector stakeholders	- Tradition of coordination among stakeholders.	- Three main national authorities.

The main findings are that despite differences in scale and design between the DH systems in China and Denmark, there are similarities. The lessons learned from the Danish DH transition from black to green could apply to the Chinese context. The next chapter explores the identified areas where future conditions for clean and renewable DH sector in China could benefit from the Danish experiences.

One significant distinction in the DH sector between the two countries lies in their regulatory framework and planning approaches. Denmark has a national heat regulation that promotes the socio-economically optimal use of DH while serving as the regulatory basis for almost every aspect of the Danish heating sector. Furthermore, the Danish heat price regulation, coupled with DH utilities operating as non-profit organizations under the government supervision, ensures both consumer protection and the financial capacity of DH utilities to cover essential expenses, such as production and maintenance costs.

China does not have a similar national regulation. It could be argued that this is related to the differences in planning approaches. Denmark has national guidelines for socio-economic and environmental benefits assessments, but the municipalities are the ones conducting the actual heat planning, utilizing their expertise in local conditions and resources to develop project proposals.

In China, heat planning is largely integrated into the broader urban planning and follows a relatively fixed format, considering population and building area growth in the next five, ten or fifteen years, along with national and local policies, heat loads prediction. As heat planning is an integral part of the broader, long-term urban planning, it may not always prioritize the most socio-economically optimal solutions. Given that planning played a central role in Denmark's transition from black to green, it is anticipated that further exchanges on experiences with regulatory frameworks and planning approaches can contribute to China's transition to a green heat supply.

3 Comparative Analysis between Current and Future Conditions for District Heating in China

Chapter 5 constitutes the main part of this Report. Within this chapter, a comprehensive elaboration is presented regarding the specific sectors in China's clean heating development that require consideration following the methodology outlined in Chapter 3.3. This is aligned with the goals of the Chinese Central Government. Furthermore, the main objective of this Report is to provide policy recommendations based on the key focus areas of clean heating in China. The chapter provides detailed explanations on the most relevant eleven topics within the four major categories, covering both the current situation and the optimal scenarios.

The future conditions in question should be understood as the optimum state of a particular field that is well-suited in a Chinese context. By achieving the desired future conditions, other technologies and focus areas can also be improved. Therefore, synergies must be considered, and one focus area might lead to another that could be perceived as a “low hanging fruit”.

3.1 Energy planning

Energy planning entails maximizing favorable factors within the context of current national and local policies. This is achieved by researching various available renewable energy sources, waste heat, and local energy demands. With a comprehensive understanding of energy supply and demand, different potential energy schemes are arranged and combined based on the principle of optimizing socio-economic benefits. The goal is to align with current energy needs, thereby exploring and formulating a locally applicable energy planning script that is technically feasible, cost-effective, and environmentally beneficial.

The overall conditions for energy planning in China are based on local climate zones determined by the Qinling-Huai River division policy that was established to divide the northern Chinese provinces into winter heating zones, as explained in Section 2.1.1. As the Northern provinces, classified into winter heating zones, vary between cold and severely cold zones. The latter experiences extremely low temperatures in the heating season, emphasizing the prioritization of stable heat supply to help the population endure harsh periods. Historically, this meant using coal as a primary fuel source in households and in local heat plants. Under the policy of coal-to-gas and coal-to-electricity fuel conversion, natural gas and electricity are being used in many provinces to reduce air pollution from coal burning and improve local air quality. However, this is also considered as a more expensive heat source.

In recent years, the Chinese provinces have dedicated efforts to optimize the utilization of local resources, and explore alternatives to coal. Harmful gases and pollutants generated from coal burning have severe impacts on health, environment and climate. High particle intensity poses risks to respiratory system health, and the substantial emissions of GHGs like carbon dioxide from coal combustion contribute directly to global warming.

As previously mentioned, coal-fired cogeneration and heating boilers account for 72% of the DH sources in China. Finding alternatives to coal while ensuring economic viability, environmental friendliness, and feasibility for centralized heating sources is one of China's primary tasks in developing clean heating, given its current climate and energy objectives. Denmark's experience in the development of heat planning, methodologies and tools used, and the integration of policies with practical projects provide valuable insights for China's clean heating development goals in the realm of heat planning.

3.1.1 Heat planning

DH can provide many advantages over individual heating systems in various scenarios. It leverages economies of scale to increase efficiency and lower costs, as well as enable large-scale utilization of local heat sources such as geothermal and industrial surplus heat. However, to fully leverage the advantage of DH, the development of existing potential heat sources in the local area should be undertaken in a controlled manner. A well-functioning heat planning system can help in this regard and has been a key factor in transitioning the Danish energy system and in improving energy security. In Denmark, DH has proven to be an important cornerstone for establishing efficient energy systems.

Holistic heat planning and management of local resources contribute the steady development of greener and more efficient DH in the provinces. A well-structured heat planning not only helps identify the optimal regions for developing or expanding DH systems, but also facilitate the effective introduction of new heat production and heat storage units. If implemented correctly, the deployment of new heat sources and storage technologies can bring about significant changes to the entire DH system.

By adopting a heat planning approach, cities can leverage local conditions and resources to develop successful projects. This approach ensures the successful transfer of best projects from one city to another, while identifying and mapping local resources available for heating. For instance, biomass-fueled heating systems often rely on the availability of local biomass resources, a factor that should be taken into account during the planning process.

Strategic heat planning also provides guidance on what and when investments should be made. Depending on the implementation, effective heat planning can contribute to socio-economic development, energy efficiency, the development of renewable energy. This also helps prevent the adoption of suboptimal solutions, ensuring that the development of local heating sector benefits the entire national energy system and aligns with national policy goals.

3.1.1.1 Current conditions

Many Chinese cities are facing the challenge of finding alternatives to replace coal. To facilitate the transition from coal to a cleaner heat supply, China needs a holistic heat planning methodology to develop new DH systems by leveraging locally available resources such as renewable energy, waste-to-energy, and industrial surplus heat. This includes upgrading and expanding existing DH systems. In areas where surplus heat from cogeneration is unavailable, exploring these available but untapped clean energy sources is particularly important. Structured heat planning can be an effective tool for identifying and determining the optimal integration of the aforementioned locally available heat sources into the heat supply.

In recent years, China has initiated a series of policies aimed at encouraging the replacement of coal in northern cities, promoting the integration of more clean energy in heating systems in local cities. These policies include developing wind power, utilizing surplus heat from industrial processes for heating, mandating greater use of biomass for heating and accelerating the development of shallow geothermal energy. While these policies contribute to the promotion of clean and renewable energy, their effectiveness can be enhanced by combing them with a structured planning system focused on implementing the national policies in the regional or local context. If properly scaled, a well-functioning heat planning system can effectively avoid the implementation of suboptimal solutions and ensure that new developments benefit not only the local context but also the larger energy system.

Currently in China, the formal documentation of heat planning methods is the "Heat Planning Standards" released by China District Heating Association in 2021. The Standards primarily outlines methods for estimating heat loads, technical standards related to heating forms, heat sources, heating networks. It also touches upon investment estimates and socio-economic benefits, although not in exhaustive details. As China has not yet established specific laws and regulations for heating management, these industry standards function as technical recommendations for heat planning.

In Denmark, the role of heat planning differs significantly. It not only serves as a regulatory tool but also constitutes an integral part of the country's heating regulations. It assists the Danish government balance the sustainability of energy development, supply security, and pricing – three essential factors. Heat planning also plays a crucial role in shaping the development of Danish heating industry to align with established political visions. By modifying heat planning regulations, the Danish government has the ability to impact heating investments. This approach has notably led to the promotion of socio-economic optimization, the establishment of fair heating prices, and coordination with other spatial planning. Through the formulation and approval of procedures and frameworks for the new development of the heating industry, Denmark's heat planning has enhanced the security of heating investments.

In China, the development procedures for heat planning in northern cities typically involve five steps: starting from applying for funding approval to determine the planning scheme and preparing for implementation. Local and provincial governments, along with various stakeholders, play their respective roles within their scope responsibilities during this process, as shown in Figure 10.

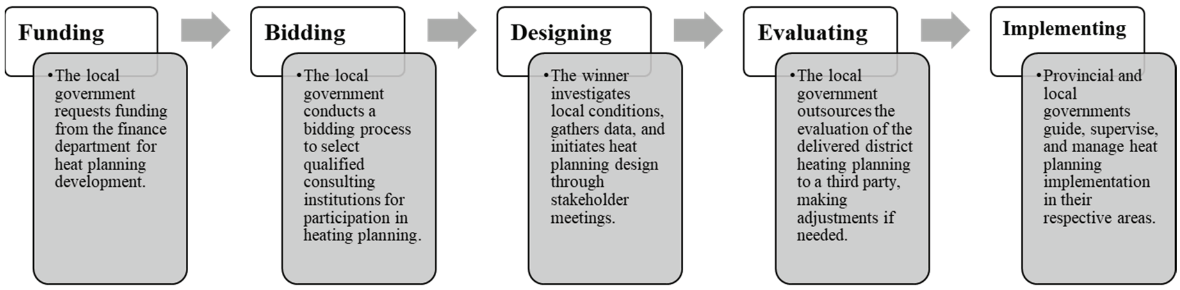


Figure 10. Typical procedures for a city heat planning in China

Initially, the local government expresses the need to develop or update heat planning. Subsequently, they apply for funds from the local finance department to support the consulting and development of heat planning. Upon approval of funds, the local government organizes the bidding, inviting qualified design institutes or consulting agencies to participate. Once the bidding process is completed, a suitable institute is selected, the heat planning enters the design phase. During this phase, the chosen institute conducts on-site inspections and engages in discussions with local stakeholders, and conducts research to understand the local conditions, aligning with relevant national, provincial, and local policies. After the heat planning design proposal is finalized, the local government commissions a third party to evaluate it, and provide feedback for adjustments or modifications. Upon successful review and approval of the planning proposal, preparations can begin for its implementation. The qualified consulting institute that won the bid, usually a design institute, plays a crucial technical role during formulation of the heat planning proposal.

The process of heat planning projects in Denmark varies depending on local conditions and circumstances, following the outline in Figure 11. Heat planning process begins when a heating company intends to undertake a new project. The DEA provides methods for project approval and investment guide. Additionally, DEA offers methods for calculating socio-economic benefits and regularly updates a technology catalogue.

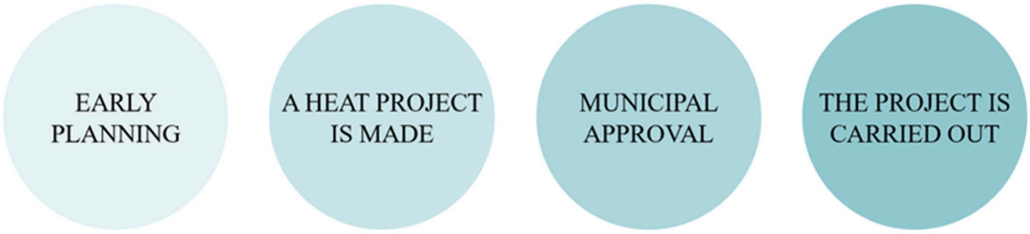


Figure 11. Usual timeline of heat planning based on the project approach

Following the specific methods set by DEA, the heating company prepares a “Project Proposal”. This proposal outlines details for constructing a new heat source or implementing a major change to existing heat sources. A major change means that the costs exceed 50% of the investment costs for a new similar heat source. In addition, based on the same heat load, the proposal must also include an alternative solution. This alternative solution might involve using a different technology, such as heat pumps, to meet the same heat load. When assuming the technical content of the alternative solution, the municipal government has a considerable flexibility. A recent transformation in the Danish heating industry is the promotion of large-scale geothermal and seawater-source heat pump applications as alternative solutions. In comparison, if the project proposal presents optimal socio-economic benefits, the project receives approval. Once approved, the heating company is legally obligated to execute the project.

Therefore, the heat planning proposal needs to incorporate economic assessments for society, the company and users. This requires following a comprehensive set of methodologies.

3.1.1.2 Perspectives for the future conditions

A possible lesson from the successful energy transition in Denmark is how best to apply a macro strategic policy for heating. Introducing heat planning tools that consider the local conditions of cities, while being consistently maintained and supported at national level, can significantly contribute to this success. The application of heat planning tools in China has the potential to accelerate clean heating development and enhance the utilization of waste heat from diverse industries, maximizing the use of local resources. Additionally, macro policies can further recognize and promote energy-saving and cost optimization opportunities arising from the integration of the heating sector with other energy industries, resulting in overall benefits.

These tools and interventions should be based on objective and impartial cost-benefit analysis, prioritizing long-term investments. They should integrate economic, environmental, and social factors to foster benefits for the energy market and local employment. Effective heat planning can help decision-makers gain a holistic view of current and future heat demands, design viable energy and economic policies and incentives, thereby promoting sustainable energy solutions and contributing to local and regional economic growth.

When considering heat planning, as well as the design and operational parameters of the heating network, a more systematic approach should be adopted. This includes incorporating historical weather data and demand forecasts to align with real operational conditions.

3.1.2 Heat demand forecast

Heat demand forecast serves as a crucial tool for day-to-day dispatch planning and optimizing operations at heat plants. A heat forecasting scheme can be used to make best use of local clean energy sources while planning for future heat demand in the supply system. This approach ensures the prioritized utilization of clean and renewable energy sources, preempting the necessity to activate peak and reserve capacity boilers, which are typically fueled by coal or natural gas.

A heat demand forecast can only be established if the following conditions are met:

- Historical measurements from the heat plant showing actual heat production and supply data.
- Meteorological data for the upcoming days.
- Local weather station data capable of displaying actual local meteorological information to correct potential deviations in the forecast for the current hour.

This heat demand forecasting method is a very flexible tool that can be used for various applications, such as automatic real-time optimization and supporting overall heat planning. There are some inexpensive software applications available in the market, suitable for utility-scale use. Alternatively, a software application can be customized in collaboration with certain research and design institutes in China. The existing software applications available in the market are often based on machine learning, primarily composed of adaptive algorithms. As the computer learns consumption patterns and local weather conditions over time, the adaptive algorithm progressively improves the accuracy of heat demand predictions. The example in Figure 12 (Dahl, Brun, Kirsebom, & Andresen, 2018) below illustrates how this adaptive forecasting performance operates.

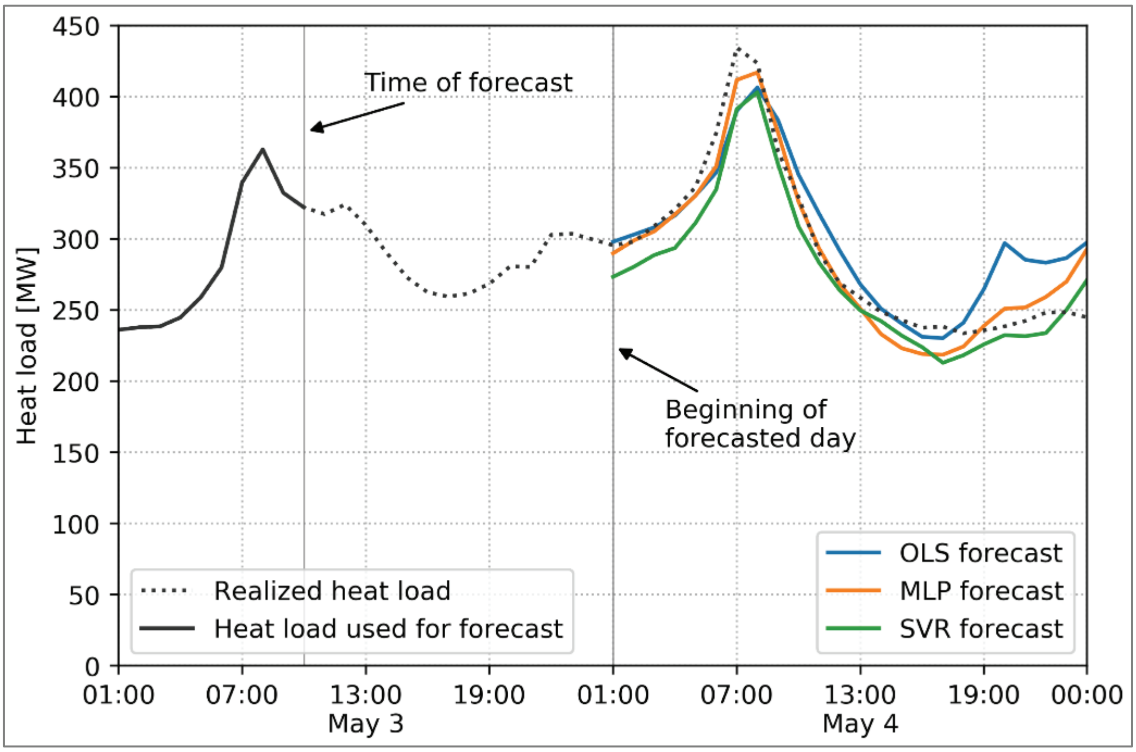


Figure 12. Example of a heat forecasting model comparing forecast to actual demand

Most of the heat demand forecasting tools available today can provide forecasts from the next hour up to 7 days, or even longer. Usually, these tools can accurately predict conditions within the next 24 hours, with varying precision for forecasts beyond this timeframe. However, by inputting historical heat demand data along with historical weather data from the past few years into the forecasting tool, the accuracy can be further improved. The quality of heat demand forecasts also depends on the quality of weather forecasts. Furthermore, forecast accuracy will be significantly reduced during unusual periods such as extreme weather conditions or sudden large changes in the network where many large consumers may provide abnormal information.

In short, Denmark has implemented a sophisticated heat demand forecasting system. This system integrates weather forecasts, historical consumption data, real-time analysis, and advanced algorithms to accurately predict heating demand. This predictive capability enables heating utilities to operate more efficient, ensuring energy efficiency, cost-effectiveness, and a reduced carbon footprint.

3.1.2.1 Current conditions

In China, heat demand forecasting is only applied on a small scale, without paying much attention to accurate heat forecasting based on actual heat demand from end-users. Most DH systems operating in China are built upon a pre-planned heat production scheme that follows the outdoor air temperature while trying to attain an indoor room temperature of 18-22°C, regardless of the actual heat demand from end-users. This makes it difficult to plan heat demand forecast as actual heat demand is measured.

Since heat demand forecasting is not well established, heat is supplied by pumping a constant amount of heat into the pipeline. Since the systems cannot incorporate heat demand forecasting, it is difficult to plan heat dispatch and maintain security of supply in the face of sudden and unexpected peaks.

Another problem stemming from the lack of advanced heat forecast is the inability to plan the ideal dispatch scheme for optimizing the utilization of renewable energy sources. This, in turn, increases dependence on fossil fuels.

Local weather stations are not consistently established in connection with heating systems in China. Especially in large DH networks covering extensive areas such as Beijing and Tianjin, local weather conditions can vary greatly from one end to the other.

3.1.2.2 Perspectives on the future conditions

In the future, a fully integrated heat demand forecast will be implemented in the system, making it possible to perform dispatch instruction and operation optimization. The collection of heat load data has become a common practice among utility companies in China to enable better forecasting in the future.

Utility personnel are further educated and better equipped to understand and use forecasting tools, avoiding potential errors. Capacity-building is necessary to maximize the potential of forecasting tools and understand the benefits of optimizing the operation.

Real-time optimization of systems can be made possible by establishing hydraulic modelling of the system and linking it to heat demand forecast. This enables users to optimize supply by significantly reducing supply temperature while performing pump optimization with optimal flow and pressure values. The use of heat demand forecasting is actively used to enable better operation of thermal storage by optimizing charging and discharging periods for intraday and seasonal storage services.

Knowledge exchange with Danish DH utilities could be organized as today most Danish DH utilities prepare heat production plans. Day-ahead plans are prepared on a daily basis and show the expected heating plan for the next two days of operation, whereas intraday plans show the adjusted heating plan with focus on the next four hours.

3.1.3 Thermal storage

Thermal storage is the practice of storing excess thermal energy in an accumulation unit after the heat demand from consumers in the network has been met – while thermal energy is still available from the system. Since the amount of energy that can be stored depends on the energy consumed, the process can be optimized through the use of demand forecasting. This allows for the utilization of optimum dispatch for electricity and heat production.

Figure 13 (iea, 2022) shows four types of thermal energy storage for DH: tank thermal energy storage (TTES), pit thermal energy storage (PTES), borehole thermal energy storage (BTES), and aquifer thermal energy storage (ATES). These are different methods used to store thermal energy.

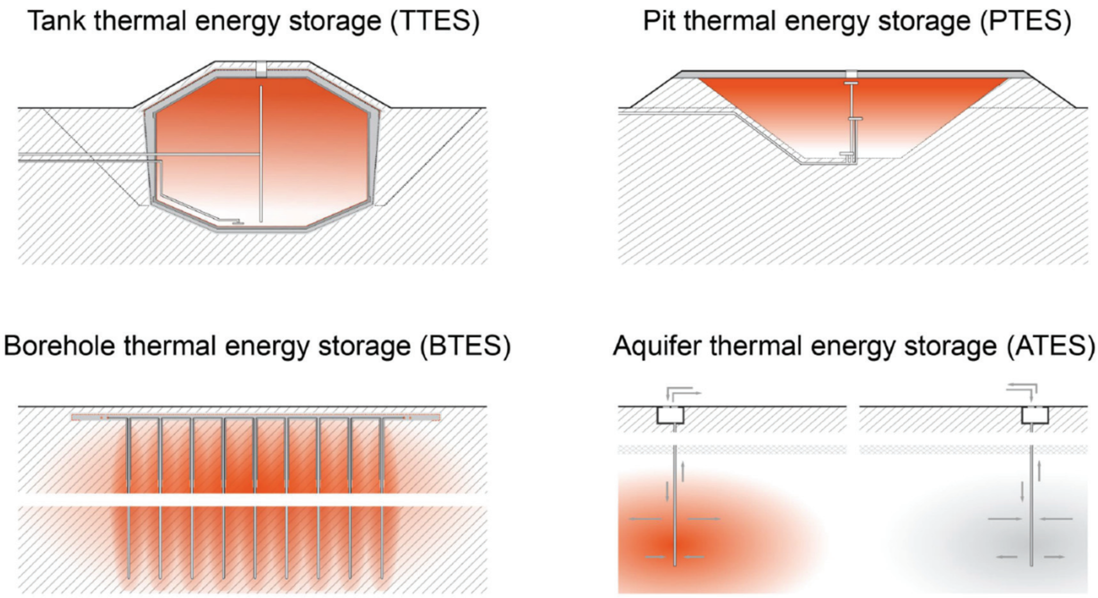


Figure 13. Four thermal energy storage methods for DH

TTES involves the storage of hot water or another thermal fluid in insulated tanks. It is typically used for short-term storage, ranging from daily to weekly cycles, making it suitable for balancing energy supply and demand over shorter periods.

PTES systems utilize insulated pits filled with water or another fluid that can store heat. They are versatile and can be designed for both short-term and long-term storage, although they are more commonly associated with seasonal or long-term energy storage due to their large capacity.

BTES systems involve the use of deep vertical holes drilled into the ground, in which pipes are inserted for heat transfer. They are primarily designed for long-term storage and are capable of storing heat for several months, typically between seasons.

ATES system uses natural underground water reservoirs to store thermal energy and is often used for seasonal storage, making it suitable for long-term storage. It stores heat or cold in an aquifer with the intent to retrieve it later, often months down the line, to match different seasonal energy demands.

Each of these thermal storage systems has its ideal use-case scenarios, and their feasibility largely depends on the specific needs of the energy system they are intended to support, as well as local geological, environmental, and economic conditions. Table 3 lists the characteristics of these four thermal storage methods.

Table 3. Characteristics of four thermal energy storage methods

	Advantages	Disadvantages
TTES	- Quick response time, suitable for daily storage needs. - Can be installed above or underground, offering flexibility in placement. - Relatively simple in design and operation.	- Limited by the size of the tank, making it less suitable for long-term storage. - Heat losses can be significant if the tank is not well-insulated. - The cost of large insulated tanks can be high relative to the amount of energy stored.
PTES	- Scalable to a wide range of sizes, making it versatile for different applications. - Can use water or gravel-water mixtures, which are low-cost storage materials. - Suitable for both short-term and long-term storage.	- Requires a large area for the pit, which can be a limitation in densely populated areas. - The insulation of the pit is crucial; poor insulation can lead to significant heat losses. - Potential for water leakage or evaporation if not properly designed.
BTES	- Suitable for a variety of locations, including urban areas. - Low visual impact as the storage facility is underground. - Long lifespan with relatively low maintenance requirements. - Can store heat for several months.	- Initial drilling can be expensive. - Efficiency depends on the thermal conductivity of the ground. - The system's performance can degrade if heat and cold recharge-discharge cycles are not properly balanced.
ATES	- High storage capacity, allowing for seasonal storage. - Efficient in terms of both energy and space, as it uses natural geological formations. - Relative low heat loss due to natural insulation of the aquifer. - Can provide both heating and cooling.	- Geological and hydrogeological conditions need to be suitable, limiting location options. - Risk of contamination to the aquifer if not properly managed. - Requires regulatory approval and extensive environmental impact assessments.

Denmark has been exploring various heat storage methods to store excess heat from energy sources with fluctuating production, such as solar power and wind power. The country has also been developing large thermal energy storage systems to store excess heat from renewable energy sources. In the case of Taars solar district heating project, Denmark in Appendix III, it highlights that long-term and short-term thermal storages are cost-efficient options to add flexibility.

In China, the use of thermal storage in the form of seasonal thermal storage (pit thermal storage) can work particularly well in provinces where solar heating resources are abundant. Similarly, in provinces with abundant wind resources, electricity-based heating can be used for direct supply and surplus heat can be stored for later use. Seasonal thermal storage can thus contribute to reducing the curtailment rate of local renewable energy sources and to increasing the share of renewables in the heat supply. An example of the use of thermal storage is presented in Figure 14 (Solar District Heating, 2022) below.

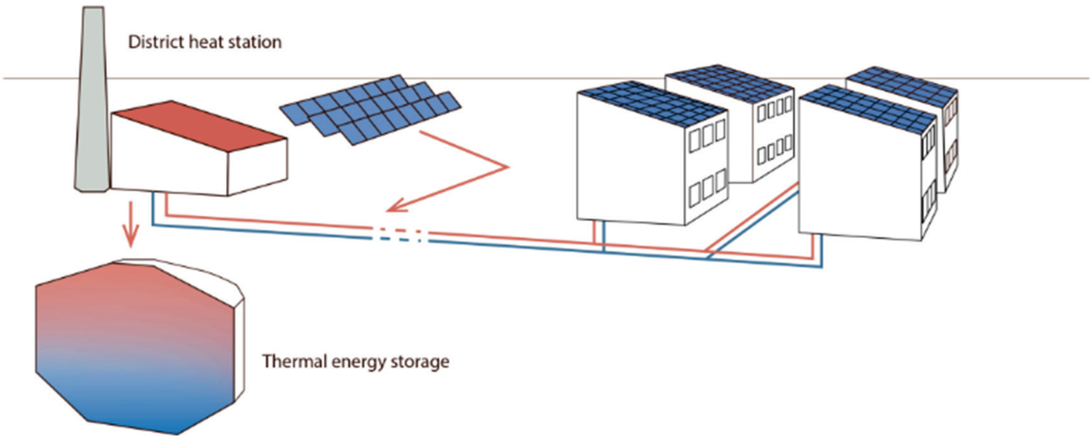


Figure 14. Thermal energy storage combined with solar heating and district heating station

Heat storage facilities in larger networks can be used to achieve hydraulic balancing of the networks. This can be done by filling up the storage tank near large consumers or substations during periods of low demand in the day and discharging when peak demand occurs, thereby reducing the critical distance. This method provides very good means to perform peak shaving and thus alleviate hydraulic stresses from the network during peak periods. Nevertheless, for this to function properly, a well-defined heat forecasting must be applied in order to allow for the planning of peak hours in advance and the utilization of intraday thermal storage.

Another method of implementing thermal storage in Denmark involves installing a heat storage tank at the consumption point in an apartment building or substations. Typically, these tanks are connected with the heat exchanger and are installed on the heat exchanger to provide improved balance of heat supply. In Denmark, this method is commonly used to balance out morning and evening peaks by steadily charging up the tank. While these two peak loads are associated with domestic hot tap water consumption, a feature which has not yet been integrated into the DH supply in China, it could prove useful in the future if and when this might become the case.

3.1.3.1 Current conditions

Energy efficient technologies for seasonal thermal storage will be implemented broadly in China in the coming years along with the rapid spread of renewable energy applications. Design practices for constructing pit storage with high quality insulation and control mechanisms can be inspired by countries like Denmark to carry out pilot studies and projects in rural areas. In some provinces such as Hebei, Qinghai and Tibet, there are small-scale pilot projects aimed at testing the effectiveness of pit storage systems.

Currently, intraday thermal storage in heat networks is not common in China and peak shaving using accumulation tanks is yet to be standardized.

DH systems in China are not yet designed to store renewable electricity from wind and solar PV as heat using large-scale heat pumps with thermal energy storage. China's fixed heating season, according to the Urban Heating Management Regulations, typically spans 3-6 months. For Beijing, the heating season usually runs from the 15th of November to the 15th of March of the following year. However, if the average outdoor temperature drops below 5°C for five consecutive days, there is a possibility of an early start or delayed end to the heating season.

The fixed heating seasons restrict DH supply during the summer and parts of the transition periods, preventing the use of seasonal heat storage in the heating system. Despite the capability of large-scale underground thermal storage to store heat for months, its effectiveness diminishes when the heating season is only a few months. Integration with domestic hot water supply allows the heating system to operate throughout the year. This integration not only facilitates the utilization of heat storage within the heating system but also contributes to reducing reliance on fossil fuels and maximizing the use of renewable energy sources.

3.1.3.2 Perspectives on the future conditions

In the future, thermal storage will be taken into account in all new DH systems, particularly to facilitate the utilization of thermal energy storage in conjunction with renewable energy sources.

Solar heating facilities in rural and peri-urban areas should always be equipped with local storage facilities, such as properly insulated pool/pit storage, to maximize the collection rate of solar thermal energy.

In the design of new DH systems, thermal storage tanks that can provide daytime energy storage and peak balancing functions should be incorporated. Thermal storage facilities should be retrofitted into existing networks, accompanied by heat demand forecasting. The installation of storage facilities should be strategically located near critical sections of the network, such as large heating zones or substations, where they might contribute to significant energy demand peaks during certain periods.

In the future, heat pump plants converting electricity into thermal energy should be built near energy storage facilities. This allows energy to be directly stored in the thermal storage devices without being influenced by the actual heat demands in the network. It is important to recognize the technical differences between the low-temperature DH systems in Denmark and the high-temperature DH systems in China, which may pose challenges. For example, it would be expensive to construct pit storage facilities when the temperatures exceed 95˚C, while the designed flow temperatures in the Chinese DH systems ranging from 110˚C to 130˚C (MoHURD, 2022). Therefore, it might be necessary to either lower the grid temperature or boost the temperature from the storage tank if the heat is recharged into the DH system through thermal storage facilities.

3.2 Renewable energy for heating

Renewable energy sources are becoming increasingly vital in the transition towards sustainable heating systems around the world. These green energy forms include geothermal resources, solar energy, and biomass, making significant contributions to residential and industrial heating.

Geothermal heating utilizes natural underground heat, supplying a steady and reliable heat source for DH networks or directly for homes and businesses. Solar thermal panels, for instance, can capture and convert sunlight directly into heat for hot water, heating, and powering certain industrial production processes. Biomass heating systems play a crucial role in renewable heating by burning organic materials such as wood chips, pellets, or agricultural residues, especially in areas rich in forestry or agricultural by-products.

Moreover, heat pumps are considered as a renewable energy technology that extracts heat from the natural environment, including air, ground, or water, to warm buildings without relying on the combustion of fossil fuels. While heat pumps do require electricity to operate, the heat they transfer is continually and naturally replenished in the environment. In Denmark, heat pumps are commonly powered by green electricity.

3.2.1 Geothermal heating

China has abundant geothermal resources with a thermal value of 3.06 $\times 10^{18}$ kWh per year, accounting for about 8% of the global geothermal energy reserves. Table 4 (Zhang, Chen, & Zhang, 2019) assesses three geothermal resources in China and illustrates the temperature level, depth, and scale of the reserves.

Table 4. Three geothermal resources and technical parameters in China

Geothermal resources	Temperature level and depth	Resources scale
Shallow geothermal	A temperature below 25°C in the shallow crust 200m below the surface.	The annual recoverable resources are equivalent to 700 million tons of standard coal.
Hydrothermal geothermal	Contained in underground water or steam at the depths of several kilometers, divided as follows: (a) high-temperature (above 150°C) (b) medium-temperature (90 - 150°C) (c) low-temperature (below 90°C)	The reserves are equivalent to 10.6 trillion tons of standard coal.
Hot dry rock (HDR)	High-temperature rock bodies, buried more than 1 km below the ground surface, with a temperature exceeding 200°C, with no internal fluids or minimal fluids.	The reserves are equivalent to 85.6 × 10^5 billion tons of standard coal.

The annual recoverable resources of shallow geothermal energy in 336 major cities in Mainland China are equivalent to 700 million tons of standard coal, which can provide heating (and cooling) for a floor area of 32 billion m^2. Figure 15 (Foresight Network, 2021) shows from 2000 to 2019, the utilization of shallow geothermal energy for heating and cooling in China has consistently increased. In 2000, only around 100,000 m^2 of floor area used shallow geothermal energy for heating and cooling. By 2004, the number reached 7.67 million m^2, with an average annual growth rate of approximately 28% since 2010. As of the end of 2019, the floor area using shallow geothermal energy in China was about 841 million m^2, ranking first in the world.

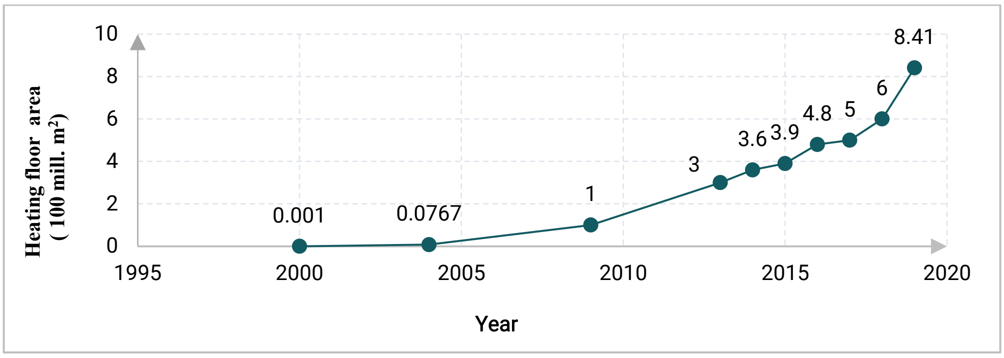


Figure 15. 1995-2020 Geothermal heating and cooling in China

Geothermal energy in China is mainly directly utilized for heating and cooling. From 1990 to 2018, the floor area heated by hydrothermal geothermal energy in China increased rapidly, reaching 165 million m^2 in 2018. In the last 10 years, the direct utilization of hydrothermal geothermal energy in China has grown at an average annual rate of 10%, with a rapid growth in Shandong, Hebei and Henan.

Regarding the policies related to geothermal development in China, since 2002, the country has successively issued several policies and plans related to renewable energy and emission reduction, which have accelerated geothermal energy development. Figure 16 (Huajing Information Network, 2021) shows that the national-level support policies for geothermal development have evolved from "accelerating technology research” in the 10th Five-Year Plan to "promoting technology applications" and, more recently, to "vigorous development” in the 14th Five-Year Plan. In fact, over the past few decades, the utilization of geothermal energy has gradually gained attention, fostering the development and investment of the geothermal energy market.

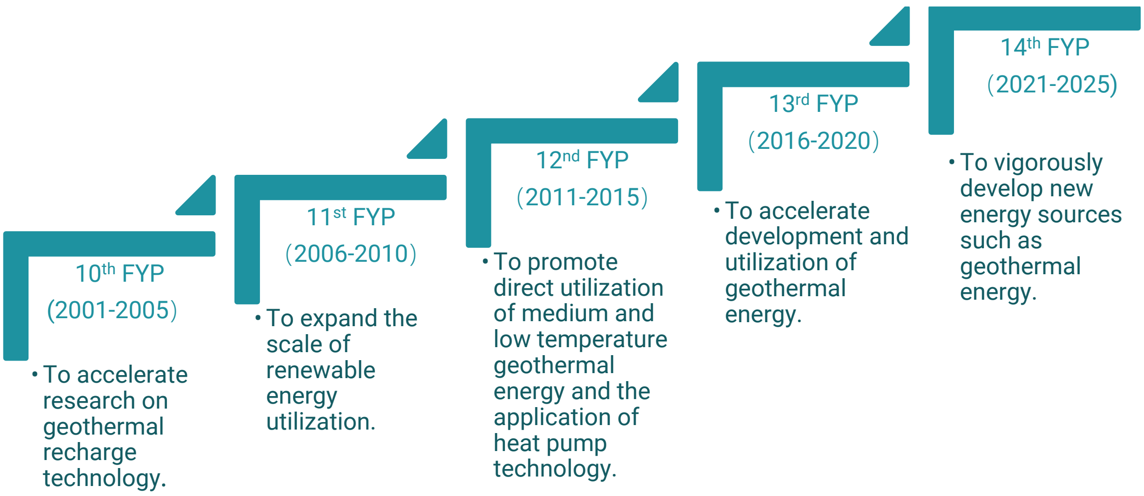


Figure 16. The role of geothermal development in five consecutive FYPs

Following the directives from the central government, provinces and cities such as Tianjin, Liaoning, Heilongjiang, Zhejiang, Anhui, Shandong, Shanxi, Guizhou, Henan, and Gansu, have set development goals for geothermal energy installed capacity and investment during the 14th Five-Year Plan period.

3.2.1.1 Current conditions

The development of geothermal energy in China is still in its early stages, with the current main bottlenecks identified in three key aspects.

Policy support. In recent years, China’s supportive policies for geothermal energy utilization, both in terms of policy measures and financial support, have not kept pace with its rapid development. Geothermal energy development is characterized by high costs, demanding technical requirements, and long investment payback periods. Developing enterprises need to have strong financial strength and operation experience. Currently, domestic investments in geothermal energy projects are primarily led by state-owned enterprises, necessitating policy guidance, cultivation, and market stimulation.

Management mechanism. To promote the development and utilization of geothermal energy, policy guidance and effective supervision are indispensable. Geothermal resources belong to mineral resources, while underground water resources are subject to regulations related to water management. There is no clear division of responsibilities, resulting in the functional overlaps between water management departments and mineral resources management departments on geothermal management. Meanwhile, there are varying degrees of disparities in management practices in different regions, which brings uncertainty and risks to geothermal development.

Technical level. Due to a late start, there are still technical bottlenecks in exploration and development of geothermal resources in China. There is a large gap in core technologies such as resource exploration, geological exploration equipment, high-temperature geothermal well drilling, and power generation processes. There are also technical and economic barriers in the field of geothermal heat pumps. The lag in the technical level has led to an increase in development costs to some extent. For example, the initial investment cost for geothermal power generation is extremely high. Before drilling, preliminary processes such as exploration account for 11% of the development costs of a geothermal project, while drilling account for about 30%. Generally, for medium and deep geothermal heating projects, the construction cost is around 90-160 yuan/m^2, and the operating costs are 5-10 yuan/m^2, exhibiting a characteristic of high initial investment and low operating costs (CREEI, 2021). In the application of hot dry rock, there have been persistent issues such as technical difficulties, insufficient capacity, and a low input-output ratio. It is worth noting that in 2021, China increased efforts in resource exploration for geothermal energy, achieving new breakthroughs in areas with favorable geothermal resources.

The development of geothermal heating in China, in addition to the bottlenecks mentioned above, also faces the following challenges:

Uneven development and underutilization of pricing mechanisms and resource location advantages pose challenges. There is a considerable disparity in the development of geothermal heating between key and non-key areas, as well as urban and rural areas. The lack of effective pricing signals hinders the formation of fair market competition, undermining support for improving the economic feasibility of geothermal heating. Moreover, inadequate investment has resulted in the untapped potential of geothermal heating market and energy-saving opportunities, preventing the full exploitation of resource location advantages.

Geothermal heating accounts for a small proportion of total clean heating and a scalable development model has not yet been established. The expansion of geothermal heating is slow and uneven across different regions. This is mainly due to the lack of clear task allocation, an overall coordination mechanism, a joint assessment system for heating project subsidies, and diverse investment and financing models. Furthermore, geothermal energy constitutes a relatively small share in the total clean heating mix. The construction procedures for geothermal heating projects are not well-established and the level of industrial clustering and commercialization is relatively low, hindering the establishment of a long-term mechanism to support scalable development model.

The construction and operation system of geothermal heating is not yet well-established, lacking a sustainable long-term mechanism. This is mainly due to challenges in the scientific and rational use of resources, thermal balance, and system maintenance. Additionally, there is an imbalance between the costs of geothermal heating, expenditures, and consumer affordability. The low level of low marketization and competitiveness further highlights the lack of a long-term mechanism for sustainable development.

3.2.1.2 Perspectives on the future conditions

Currently, the utilization of geothermal energy has evolved from being initially used as hot springs to being utilized as energy, as illustrated in the case of the Beijing Sub-Center Energy Station in Appendix III. There are three primary ways of utilizing geothermal as energy, i.e. geothermal heating, geothermal power generation, and geothermal agriculture.

Geothermal energy holds vast prospects for development in the DH industry in China. Currently, many places in China are promoting holistic heat planning. It is crucial to select suitable local heat sources for the development of clean, low-carbon, efficient, safe, sustainable large-scale heating and cooling systems. In climate zones with hot summer and cold winter, geothermal energy may play an essential role in both district heating and cooling.

In terms of the future development of geothermal heating in China, the strategy is centred around the resourceful utilization of geothermal energy. It involves the development and utilization of shallow, medium-deep, and deep dry hot rock resources. Furthermore, geothermal heating will shift from one-time utilization to comprehensive and intensive utilization, thereby enhancing resource utilization efficiency and generating greater socio-economic benefits. The development of geothermal heating is expected to transition from small-scale projects to centralized, large-scale development gradually. This transformation will involve tailored measures, optimizing and integrating multi-energy complementary systems, thereby establishing a new model for regional energy supply.

In Denmark, hot saline water found in natural underground reservoirs can be used for DH in some areas, as long as the right geological layers are present and are of a sufficient thickness. There are three geothermal plants in operation in Denmark. They are based in Thisted, Sønderborg and Amager (Copenhagen). In addition, several licenses have been granted to explore the opportunities for using geothermal energy in certain areas, leading notably to the Europe’s largest geothermal heating plant project development in the city of Aarhus. This gives good foundation for the deployment of exchanges of experience between the two countries to jointly overcome the technical, economic, and regulatory bottlenecks to the development of geothermal heating in both countries.

In the process of developing geothermal heating, China can draw inspiration from Denmark's legislative framework, such as the 'Heat Supply Act'. This involves legally defining the nature of geothermal resources, specifying the administrative roles and responsibilities of various levels of governments, and fostering a conducive environment for the growth of geothermal heating. Additionally, there should be a focus on revising policies and regulations related to geothermal heating. This calls for establishing a comprehensive regulatory and institutional framework that integrates legislation, planning, management, and standards. China may also consider adopting Denmark's market-driven heating mechanisms and explore supportive policies for geothermal heating in areas such as taxation, credit, and financing, incentivizing diverse market investments in the exploration and development of geothermal resources.

3.2.2 Solar heating

According to IEA (International Energy Agency, 2021), Denmark has been a dominant player in the large-scale DH system market, especially in solar DH, for about a decade. However, in 2020, China surpassed China and claimed the leading position with 48% of the installed collector area for large-scale systems. A large proportion of these large-scale solar plants were built for residential, commercial, or public buildings. In terms of the quantity of solar DH systems, Denmark had 124 systems, while China had 18 systems by the end of 2020.

China has abundant solar resources, with annual solar radiation ranging between 930 and 2,330 kWh/m^2, equivalent to 2.5–6.4 kWh/m^2 daily solar radiations. While solar radiation resource is rich in most places in China, the highest annual global radiation is 2,330 kWh/m^2 in Tibet. Moreover, Table 5 (Huang, Fan, & Simon, 2021) shows that the areas with abundant solar radiation are mainly located in the cold regions of China with significant heat demand. In the table, the solar fraction refers to the ratio of the effective heat obtained by a solar collector system from solar radiation to the heat load of a heating system. The solar fraction indicates how much energy can be saved using the solar heating system. Therefore, solar heating systems hold technical potential in the severe cold and cold regions of China.

Table 5. Total horizontal solar radiation level and regional distribution in China

Radiation level	Total horizontal solar radiation (kWh/m^2·annual)	Solar fraction of territory area	Region
Most abundant (I)	≥1750	22.8%	West of Inner Mongolia; West of Gansu; Tibet and Qinghai, East of Xinjiang; Ganzi of Sichuan province
Relatively abundant (II)	1400-1750	44.0%	Xinjiang, East of Inner Mongolia Northeast of China, Beijing, Tianjin, Hebei, Henan, Shanxi, East of Shandong, North of Shanxi, Ningxia, Gansu, Hainan, Yunnan
Abundant (III)	1050-1400	29.8%	North of Inner Mongolia, South of Shandong, Shanxi, Shannxi(Xian), East of Gansu, Yunnan, Hunan, Hubei, Guangdong, Guangxi, Fujian, Jiangxi, Zhejiang, Anhui, Jiangsu, Henan
Moderate (IV)	＜1050	3.3%	Sichuan, Chongqing, Guizhou

In terms of policy support, the Clean Heating Plan for Northern China in Winter (2017-2021) set the goal of reducing coal consumption over the next five years by increasing the use of renewable energy such as solar energy, heat pumps, and industrial waste heat. This plan opened a policy window for solar heating, creating conditions for its widespread application.

3.2.2.1 Current conditions

Existing large-scale heating facilities in cities have created favorable conditions for the utilization of renewable energy, such as solar energy.

However, the application of solar energy in heating is constrained by financial, technical and economic challenges, e.g. high investment cost, land availability and purchase restrictions. In China, the high costs of land use costs pose a significant obstacle to the development of large-scale solar DH, as land for installing collectors is limited. Therefore, it is essential to install collectors on rooftops, parking lots or elevated structures whenever possible. To further enhance the utilization of solar heating, it is crucial to improve collector efficiency, expand thermal storage capacity, reduce collector costs and optimize the system for the most cost-effective heat production

Solar heating systems include two types: centralized and distributed.

In northern China, large-scale centralized heating is predominant. The high population density and expensive land in urban areas limit the available space for installing solar collectors. Although solar DH offers notable economic and environmental benefits, the integration of solar heating with existing DH networks in large cities remains a considerable long-term challenge.

In rural areas of China, on the other hand, decentralized household heating is the primary method, making distributed solar heating a viable option. When addressing challenges in integrating solar energy into rural heating systems, economic factors such as low purchasing power need to be considered. Rural areas with relatively well-developed infrastructure are suitable for prioritizing the development of solar heating. In 2020, DH areas in counties in China was approximately 1.86 billion m^2, accounting for 15.1% of the total DH areas, and in towns, it was 440 million m^2, constituting 3.6% (China District Heating Association, 2021). Low operating costs can be achieved by installing solar collectors and heat storage facilities to existing DH systems. However, in areas lacking infrastructure, additional government subsidies may be necessary.

Compared to transformations such as the Coal to Gas and Coal to Electricity, which have been implemented in rural areas to reduce coal consumption and combat air pollution, solar heating emerges as a promising technology for entirely replacing fossil fuels. This transition comes with the advantage of having the lowest operating costs in the long run, potentially requiring little to no subsidies for sustained operation.

3.2.2.2 Perspectives on the future conditions

Solar DH presents a promising prospect in China, given the abundant solar resources and favorable policy support.

According to the Clean Heating Plan for Northern China in Winter (2017–2021) jointly released by ten ministries and commissions including NDRC, NEA in 2017, it was planned to achieve a solar heating area of 50 million m^2 by 2021, accounting for 0.18% compared to the baseline in 2016. The plan opened a policy window for solar heating, and created favorable conditions for its widespread adoption. Given the vast heating demand and cheap land resources in northwestern China, assuming 3% of the total heat demand is supplied by solar energy, the solar heating area would reach 756 million m^2.

Solar heating technology is an investment-intensive yet operationally cost-effective production method, most suitable for base load utilization requiring continuous full-load operation. In Denmark, a world leader in solar DH, although its global horizontal radiation levels are lower than China (with an average annual global horizontal radiation of 1,001 kWh/m^2), 20%–50% of its annual energy supply comes from solar heating in solar DH systems, complemented with production facilities with relatively lower capital costs but higher operational costs. The Taars case presented in Appendix III illustrates the future development of solar DH in Denmark, a concept equally applicable to China.

The solar-assisted ground-source heat pump system offers a reliable solution within the context of solar DH. In those under-performing ground-source heat pump systems, incorporating a solar collector field as supplement source proves effective in enhancing system efficiency and lowering operational costs. Moreover, combing solar DH with heat pumps, preferably driven by wind power, would constitute an efficient and environmentally friendly DH solution.

Given the low population density, limited resources, and stringent environmental requirements in specific regions such as Tibet, the deployment of solar DH should be prioritized, as demonstrated in the Langkazi case in Appendix III. Rural villages and small towns with well-established infrastructure, including DH networks, stand out as the most promising market for solar DH in the next five years. As seasonal heat storage technologies mature and practical experience accumulates, the application of solar DH can expand to industrial parks and large residential communities in the sparsely populated northwestern regions of China.

3.2.3 Biomass heating

China possesses abundant biomass resources and has established a market for solid biomass heating fuels such as wood pellets (from forestry residues) and briquettes (from agricultural residues). However, the current demand primarily comes from the industrial sector. The availability of biofuels varies by geographic location, with the largest potential for biomass development being found in China's provinces, namely Shandong, Henan, Hebei, Heilongjiang, Jilin and Jiangsu.

In terms of policy support, as previously mentioned, the Clean Heating Plan for Northern China in Winter (2017-2021) set a goal to reduce coal by increasing the utilization of renewable energy, including geothermal heating, biomass heating, as well as solar heating, in the next five years.

3.2.3.1 Current conditions

The higher availability of agricultural residues in northern provinces, where heat demand is concentrated, suggests that these residues are likely to be more extensively used for DH compared to forestry residues. However, they are currently underutilized, mainly due to the challenges in establishing fuel supply chains for transporting these scattered resources to locations where they can be effectively used. In some cases, this leads to field burning, resulting in significant emissions of air pollutants.

In terms of biomass heating development, several challenges persist:

Lack of coordinated planning hinders the formation of synergy in policies. Although there are numerous policies for biomass heating, they are scattered across various government departments, lacking top-level design and unified planning. Consequently, these policies fail to generate synergy. As a result, some policies are not effectively implemented, and there may even be contractions among policies, constraining the healthy development of the biomass heating industry.

The economic incentives for biomass heating are insufficient and its multiple benefits have not been fully realized. As a strategic emerging industry, biomass heating lacks economic stimulus policies, making it challenging to compete with traditional fossil fuel-based heating in the market. Despite its clear advantages in reducing greenhouse gas emissions and improving air quality, biomass heating has not yet gained the market position it deserves, and its full value has not been adequately acknowledged in the market. Due to the maturity of fossil fuel markets, especially in China's coal market, the benchmark prices for fossil fuels are still very low. Therefore, relying solely on biomass is not competitive with coal. It is necessary to formulate relevant policies that emphasize the socio-economic and environmental benefits of biomass fuels.

The regulatory framework for standards is weak and emission standards are stringent in the biomass heating industry. The lack of authoritative standards hinders the standardized development of the industry, creating challenges in the implementation and supervision of these standards. Additionally, there is a lack of comprehensive information and data statistics, preventing the formation of an effective supervision system. The emission standards for biomass household stoves are unreasonably high. This poses challenges for universities, research institutes, and enterprises engaged in the development and manufacturing of biomass pellet-fuel stoves. This situation is detrimental to the healthy and orderly development of the industry.

Replacing coal with biomass is a viable solution provided that emission control systems are improved to significantly reduce the local concentration of inhalable particulate matters. This is the only concern as biomass itself is considered carbon-neutral according to relevant international regulations. Hence, issues related to fuel quality and their impact on local pollution levels may need to be addressed. Preliminary development of Chinese biomass fuel quality standards should be considered in order to maintain consistency in fuel quality. Furthermore, as mentioned above, emission standards on biomass boiler should be enforced.

3.2.3.2 Perspectives on the future conditions

Apart from geothermal and solar thermal heating, biomass also has tremendous potential in China. Existing coal-fired power plants in China can be retrofitted into biomass power plants by replacing coal boilers with biomass boilers. This approach can significantly reduce installation costs, and the previously planned investments for constructing coal-fired power plants can be restructured for other purposes.

Transportation challenges associated with huge biomass supply need careful consideration. As illustrated in the Yangxin case, Shandong Province in Appendix III, counties and towns in the rural areas could potentially serve as ideal location for new biomass CHP plants.

There are a few key signs showing the direction of future development of biomass heating in China.

First and foremost, in alignment with the diversified biomass energy utilization strategy outlined in the national 14th Five Year Plan for Renewable Energy Development, there is a push for a transition from solely biomass power generation to combined heat and power generation (CHP). This shift places a stronger emphasis on biomass heating as a primary example in non-electricity applications. The scope is gradually expanding to cover comprehensive energy services such as transportation, gas supply and fuels.

Secondly, biomass heating is poised to achieve integrated and coordinated development across industries. On the one hand, it will be combined with clean energy sources such as natural gas, wind power, solar power, geothermal energy, and hydrogen to enhance overall energy efficiency, and become a crucial component of China's future new energy system. On the other hand, it will closely integrate with modern agriculture, ecological governance, energy transformation, rural revitalization, and urban-rural integration, fostering a green and low-carbon development cycle to support China's strategic goals of carbon peak and carbon neutrality.

Thirdly, biomass pellet fuel holds immense market potential for clean heating in rural areas. In northern China, where straw resources are abundant, biomass pellet fuel could become a significant and cost-effective alternative to bulk coal in rural areas. Compared to clean energy sources like natural gas and electricity, biomass pellet fuel has a price advantage. Looking ahead, China's biomass briquette fuel industry is expected to significantly replace bulk coal heating in rural clean heating applications, presenting vast development opportunities.

Fourthly, biomass heating technology is evolving towards higher efficiency and increased value utilization. In the future, while promoting the widespread application of biomass cogeneration, the integration of advanced thermal storage technologies will notably improve the efficiency of biomass energy utilization, fostering ongoing industry upgrades. Concurrently, the exploration of circular economy models such as "gas → fertilizer → electricity → heat" for biomethane multi-production will increase product added value and enhance the market competitiveness of the biomass heating industry.

The Danish experience shows that biomass can play a crucial role in transitioning power and heat production away from fossil fuels to renewables, serving as an effective method to reduce GHG emissions. In 2021, solid biomass in the shape of wood, straw and biogenic waste accounted for 65% of the Danish renewable energy consumption, and was key in transitioning away from coal in power and heat production. Approximately two-thirds were used for electricity and DH, and the remaining one-third was used for individual heating. The increased use of biomass for power and heat production is a significant factor in reducing GHG emissions in Denmark. However, it is anticipated that this proportion will decrease by 2030, partly due to the growing use of heat pumps and the decrease of power generation from CHP plants, thereby reducing future demand for biomass.

In terms of biomass development, China can draw valuable insights from Denmark's practices, including the following key strategic approaches:

Provide direct financial support and tax exemptions at the national level, such as one-off construction subsidies, to enhance project technical and economic feasibility, stimulate market investments. Additionally, implement financial incentives like government guarantees and low-interest loans to support these initiatives.

The Heating Supply Act in Denmark positions renewable energy for heating as a crucial direction for the transformation of heat supply. This Act exempts biomass CHP plants from energy taxes and outlines a clear path for the technological transition in heating.

Implement measures such as demanding residents in areas covered by DH to connect to the DH system, in order to ensure the scale of the DH network. Additionally, introduce mechanisms like “energy-saving account” for users to improve building energy efficiency. It can act as an effective supplement to market-based heating supply methods, enhancing economic benefits.

Establish a systematic monitoring and evaluation system which will ensure the effective implementation of economic incentive policies and lay a foundation for dynamic policy adjustments.

Moreover, it is worth noting that the use of biomass does not always result in a reduction of GHG emissions, as demonstrated by emissions from the country of origin. This is particularly relevant for Denmark, where over half of the wood biomass used is imported. While it is estimated that Denmark could eventually meet its current biomass demand from domestic resources, this would require converting the portion currently covered by imported wood biomass into the use of agricultural residues. Furthermore, several prerequisites need to be met, such as successful improving efficiency, transitioning to longer-stemmed straws from grains, increasing straw collection rate, promoting the use of fast-growing tree species (DEA, 2020). Therefore, when considering which biomass resources to utilize, particular attention should be paid to their sources and acquisition methods.

In addition, the sustainable use of biomass needs to be evaluated not only in terms of GHG emissions, but also in consideration of its availability. Though considered as a renewable energy source, biomass resources are not infinite. Even if all the solid biomass resources available were used for DH in the northern urban areas in China, it would still only make a minor contribution to the substantial energy demand within these areas. When considering the utilization of biomass for energy production, priority should be given to its potential application in other sectors, and whether it can be replaced by other clean and renewable technologies. As such, biomass should be regarded as one of the low-carbon fuel alternatives for coal substitution in DH.

3.2.4 Heat pumps (large scale)

Large scale heat pump systems can utilize heat from different heat sources depending on geographical location and local resources. Heat from sources such as surplus heat from industries and data centers, as well as heat from oceans, surface water, soil, air, sewage etc., can be collected and extracted to serve as sources for DH.

It is important to emphasize that the purpose of using large scale heat pumps is to harness electricity from renewable energy, not from coal. An efficient heat pump system should include thermal storage facilities to store energy for use when needed. Especially in regions with shorter heating seasons, incorporating seasonal storage is a suitable option.

The costs of large-scale heat pumps are often perceived as high, but recent developments have proven that projects can achieve lower capital expenditures (CAPEX) due to optimized system design and material usage. Furthermore, newer systems have demonstrated improved coefficient of performance (COP). With such improvements, operational costs have significantly decreased leading to a shorter payback period.

With the emergence of new technologies, innovative methods of extracting heat directly from thermal sources are gradually becoming mainstream. This includes the interconnection of new industries such as data centers with heating systems, where heat is supplied to the heating system by cooling the servers in data centers. Another important technology is the development of seawater source heat pumps, which involve the application of corrosion-resistant materials such as titanium and stainless steel in equipment.

3.2.4.1 Current conditions

China has implemented some large-scale heat pump projects integrated with municipal DH networks. The case of Hefei Binhu Science City in Anhui, China is highlighted in Appendix III. However, since the heating season only last for several months rather than the entire year, without the presence of thermal storage facilities, heat pumps cannot be used in the summer to alleviate the renewable electricity curtailment.

There is a lack of technologies and expertise in planning, system design, construction and operation of large-scale heat pumps. These are important factors that will impact the system's ability to maintain a high level of supply security and a high COP.

Seawater source heat pumps require careful planning and the use of corrosion-resistant materials and equipment to prevent corrosion of heat exchangers that collect energy from saltwater.

Heat pumps as integrated production units in DH systems rely on the heat source. The temperature, flow rate, volume, and other parameters of the heat source will determine its potential efficiency. The required supply water temperature for the heat pump will depend on the temperature level of the DH system it serves. The higher the supply water temperature needed by the heat pump, the lower its efficiency. Therefore, reducing the temperature levels of DH networks will increase the efficiency of heat pumps. In Denmark, the 4th generation DH (Lund, et al., 2014) highlights the need to lower the temperature levels of DH networks to adapt to future energy systems with a high share of renewable energy, where large-scale heat pumps will play an essential role.

3.2.4.2 Perspectives on the future conditions

To better utilize and store surplus green electricity, it is crucial to consider the use of renewable energy electricity during the energy planning phase. By combining energy planning with efficient thermal storage facilities and energy forecasting, renewable energy can be maximized. In

Denmark, renewable energy dominates power generation, and indoor heating is primarily provided by DH, leading to exponential growth in large heat pumps. A notable example is the Støvring case in Appendix III, where air-source heat pumps replaced gas-fired boilers.

Collecting heat from urban sewage systems and utilizing it through sewage source heat pumps is an efficient heating source that can find broader applications in urban areas. The Odense case in Appendix III provides a good example of such project in Denmark. To plan future interconnected project across various sectors, it is essential to coordinate with the city and municipal sewage planning department.

Furthermore, China has abundant available marine and surface water sources capable of meeting seasonal cooling and heating demands. Most major coastal cities have significant energy demand for both cooling and heating.

3.3 Efficient use of surplus heat

From a national perspective, the surplus heat generated by power generation and industrial production s is one of the most abundant heat resources available in China. As urbanization advances and the demand for heating in large cities continues to grow, harnessing this surplus heat resource around major urban areas becomes increasingly important.

Theoretically, Figure 17 (Cleaner heating in Northern China: potentials and regional balances, 2020) presents the available surplus heat resources from different types of utilities and the local heat demand in each province in northern urban areas. In the upper half of Figure 17, the surplus heat potential from CHP and industrial surplus heat (ISH) far exceeds the total heat demand, especially in provinces such as Inner Mongolia, Shanxi and Hebei, while Beijing is the only city with relatively limited surplus heat. In the lower half of Figure 17, it is clear that, theoretically, surplus heat from CHP and ISH is sufficient to cover the current heat demand in northern urban areas, including Beijing, Tianjin and thirteen provinces.

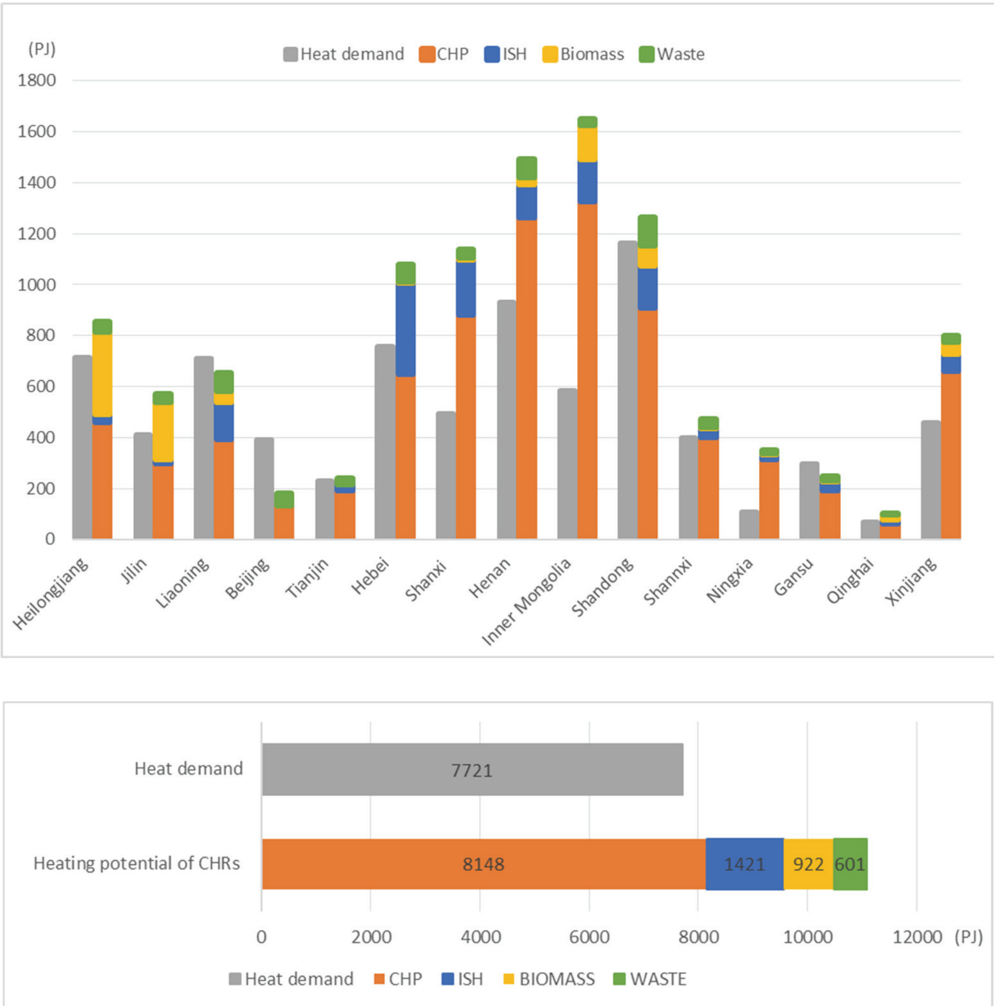


Figure 17. China's Clean Heating Potential vs. Northern Urban Heat Demand

In reality, there are still several pressing issues to address regarding the utilization of surplus heat from CHP and industrial processes. One notable challenge is the mismatch between the distribution of heat sources, i.e., CHP and industrial waste heat, and the geographical distribution of heat demand. One solution is to transport the heat through long-distance transmission pipelines (Li, Pan, Xia, & Jiang, 2019). Research suggests that it is feasible to match heat supply with demand within a transmission radius of 150 km. However, significant investments may pose a big barrier to the construction of extensive transmission pipelines, particularly in rural areas or regions with unique geographical challenges but high heat demand. Therefore, a thorough cost-effectiveness analysis tailored to each specific case is essential. While in theory, the surplus heat from CHP and industrial processes might be sufficient to meet overall heat demand, it might not be economically feasible to transport the heat for long distances in every scenario.

In order to tap into these vast resources, it is essential to implement optimal policies and regulations coupled with appropriate technical solutions. For example, a study highlights that in the future, the main function of thermal power plants in China is power peak shaving, with CHP plants playing a dual role of meeting the demand for power peak shaving and providing building heating. To achieve this goal, the cogeneration of thermal power plants must be transformed from the current "fixed electricity by heat" to "combined heat and power production" (Yin, S., Xia , J., & Jiang, Y. (2020)). Optimal policies and regulation will create conducive market conditions for power companies, industries, and heat supply utilities to cope with the challenges. To enhance the utilization of surplus heat for heating, it is necessary to establish transparent regulatory framework conditions that reflect the actual costs of electricity, fuel and heating. This will make it easier to unlock the potential of surplus heat as a cost-saving and energy-efficient means, while facilitating the tracking and documentation of the obtained benefits.

3.3.1 Surplus heat from thermal power plants

As of 2021, CHP accounts for approximately 50% of the heat sources in northern China, with 45% coal-fired CHP and 3% gas-fired CHP. CHP technology can efficiently generate heat and electricity simultaneously, and is regarded as the most efficient way of heat production. With the development of flue gas treatment technologies, CHP plants can achieve near-zero emission of pollutants, making them more environmentally friendly. CHP has seen widespread adoption in the era of energy conservation and emission reduction, becoming the primary heat source in northern China.

Despite China's significant potential in utilizing surplus heat from thermal power plants, fully tapping into this resource requires more refined heat planning methodology and appropriate management measures. Theoretically, the surplus heat generated in certain northern provinces could sufficiently cover the total heat demand in the aforementioned major cities. This clearly indicates that existing surplus heat can be utilized to address a wider range of heat demand, thereby reducing reliance on coal and gas boilers.

Figure 18 (Zheng, W., Zhang, Y., Xia, J., & Jiang, Y. (2020)) shows that the provinces with the greatest potential and most abundant resources for utilizing surplus heat from thermal power plants are Inner Mongolia, Shandong, Hebei and Shanxi. In certain northern provinces, the surplus heat potential far exceeds the heat demand of the urban areas. Although these thermal power plants may be situated away from urban areas due to the need for air pollution control, it is still possible to supply heat through well insulated transmission pipelines to the urban areas. In provinces and cities such as Beijing, Liaoning, Jilin, Heilongjiang and Xinjiang where the surplus heat resources are insufficient to cover local heat demand, there is a need for building new heating capacity to supplement the gap in surplus heat supply. For large cities like Beijing, it is advisable to install long-distance transmission pipelines to facilitate the utilization of surplus heat from thermal power plants and industrial sources in Hebei province. Furthermore, the adoption of electric heating technologies such as heat pumps can be a viable option, contributing to local efforts to mitigate further air pollution.

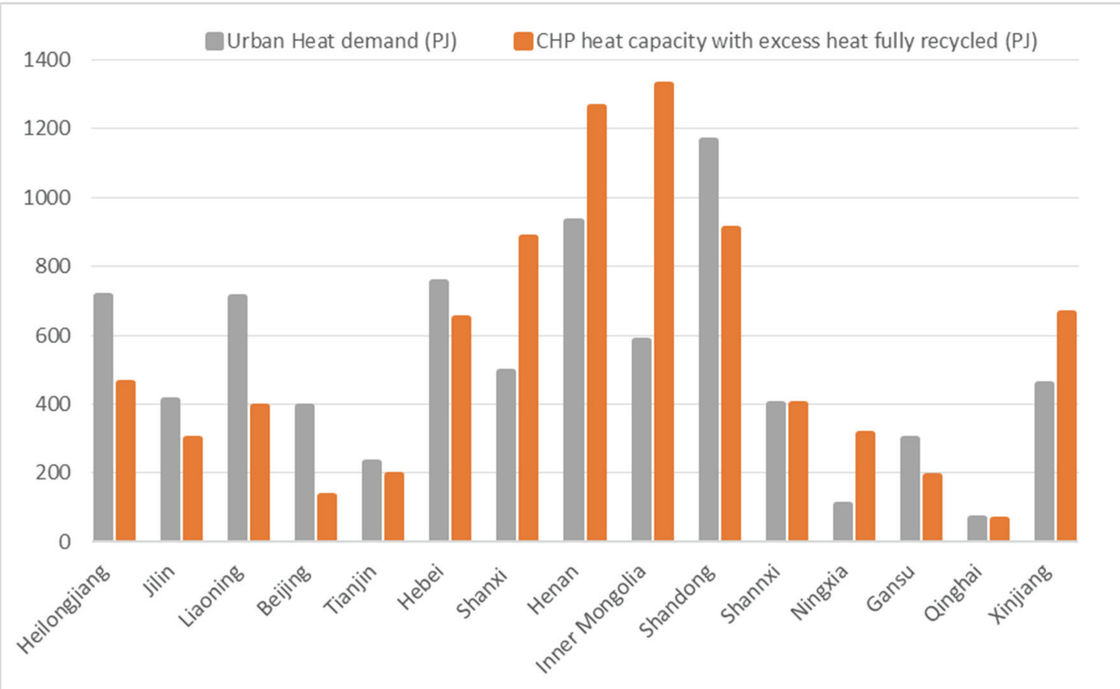


Figure 18. CHP surplus heat capacity vs. urban DH demand

3.3.1.1 Current conditions

To fully exploit the surplus heat from thermal power plants, it is necessary to maximize the utilization of this heat resource within the base load before considering the use of heat boilers, especially those fueled on coal or natural gas. It is important to note a significant distinction between thermal power plants and CHP plants in their "green" credentials and energy efficiency. This contrast reflects the difference between the CHP plants in Denmark and the thermal power plants in China. Conventional thermal power plants normally generate electricity for the grid by burning coal or fuel oil and utilize the produced excess steam (low-pressure steam) to provide heating to users around the power plants. On the other hand, CHP plants usually utilize clean fuels and are the most fuel-efficient in the combined production of heat and power. Figure 19 shows the coal consumption in China's thermal power generation and heating (China National Bureau of Statistics. (2020)), as well as its proportions in the total annual coal consumption from 2002 to 2020. Over the past two decades, along with economic growth and rapid urbanization, annual coal consumption kept increasing, although its growth started slowing down from 2015. The changes indicate that policies aiming at coal reduction and substitution have achieved some success, contributing to the air pollution control. Moreover, during this period, the average shares of coal consumption for thermal power generation and heating in the total annual coal consumption were approximately 47% and 6.2% respectively, and both exhibited a declining trend.

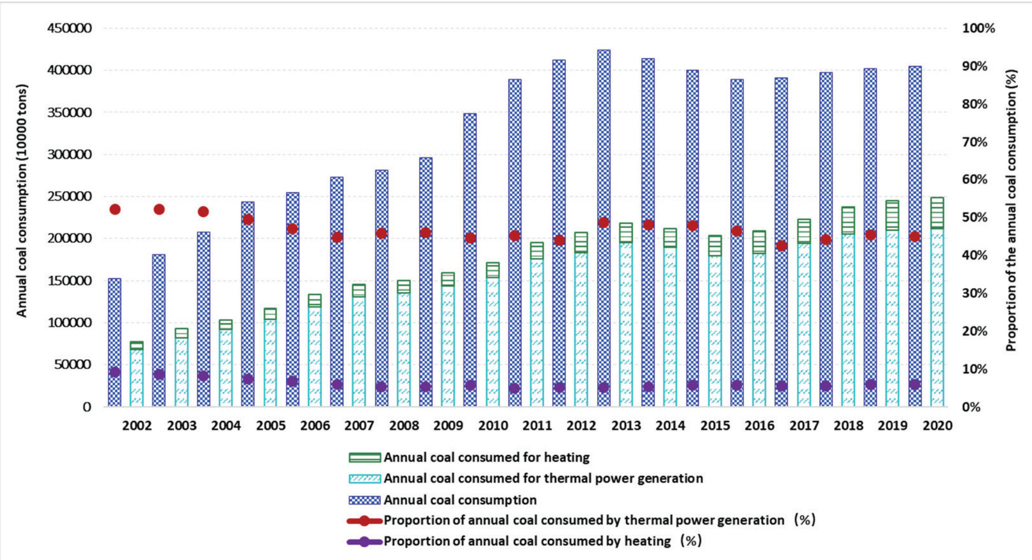


Figure 19. China's coal consumption in power and heating (2002-2020)

Therefore, coal and natural gas remain the main fuels for China's thermal power plants, posing a major challenge to fossil fuel substitution in the thermal power sector as China strives to achieve its low-carbon goals.

Amidst efforts to combat air pollution and achieve carbon peak and carbon neutrality targets, China has adopted rigorous measures to control the construction of new coal-fired power plants. In this evolving landscape, thermal power plants are shifting towards becoming peak shaving power plants, accommodating the rise of renewable energy electricity and offering crucial support.

However, in the operational mode of cogeneration units, where electricity output is fixed based on heat, especially during the peak periods of electricity consumption in winter, the conflict between electricity and heat becomes more prominent. If the thermal power plant operates at its maximum heating capacity, the electricity output remains fixed and cannot be adjusted. Conversely, if electricity output is reduced for peak shaving, the heating capacity decreases accordingly.

In China, the current proposed solution involves thermal power plants transitioning from their current operational mode to adopting sector coupling of heating and electricity. Moreover, power plants are recommended to incorporate heat storage facilities.

Due to increasingly stringent national energy policies, many power plants that were previously designed only for electricity generation, without providing heating, are now planning to undergo renovations to become CHP plants connected with DH systems. In urban areas without access to surplus heat from power plants, coal and natural gas boilers are still widely used, but there is significant potential for overall efficiency improvement. China has set clear climate goals and is committed to reduce its long-term dependence on fossil fuels such as coal and oil, aiming to achieve energy independence by addressing air pollution from boilers and industries.

Currently, not all surplus heat generated from thermal power production is fully utilized. One factor contributing to this under-utilization is insufficient hydraulic capacity within the heating networks. This deficiency refers to the limited ability of the pipes to efficiently transport the heat carrier, and the pipes are not designed optimally to ensure a heat supply consistent with heat demand. Additionally, temperature in the heating system fluctuate daily and seasonally, so does the electricity demand.

Unlike electricity storage, thermal energy can be economically stored. Ideally, a flexible energy storage system should be in place, capable of adjusting its output between maximum heat and maximum electricity based on demand. Therefore, it is necessary to build large-scale heat storage facilities to store surplus heat from CHP plants for on-demand use.

This data and information demonstrate that China's energy transformation holds immense potential. The success of China's energy transition will not only bring about significant changes within the country but also have a profound global impact.

3.3.1.2 Perspectives on the future conditions

When planning DH in the future, surplus heat from CHP plants and industries must be considered as key heating sources. By 2060, it is projected that the urban heating area in northern China will reach 20 billion m^2, with DH accounting for 80%, or 16 billion m^2 (Jiang Yi, Tsinghua University. (2021)). In a 2060 low-carbon heating roadmap (Xia Jianjun, Tsinghua University. (2021)), the surplus heat from CHP plants and industries is explicitly recommended as the primary heat source, with CHP surplus heat considered the main source, followed by industrial surplus heat from iron and steel, metallurgy, chemicals, and other industries.

Although the majority of Chinese DH systems were designed and planned along large centralized CHP plants, there are still many heat-only boiler stations scattered around the networks. These boilers are usually fueled with coal or natural gas, and their heat production costs are higher than that of using surplus heat from CHPs. It is therefore necessary to optimize the systems and their operation to increase the utilization of surplus heat.

As coal-fired CHP plants are set to be decommissioned in the future, there is a need to consider how the future base loads will be covered. The most plausible way to covering these baseloads in the future is through the electrification of heating. Heat pumps and electric boilers powered by renewable electricity are expected to be the main heat sources. In large-scale heating networks, the installation and construction of relevant pipelines and equipment should be executed across various sections of the network to maintain optimal hydraulic conditions for heating.

To enhance the flexibility of CHP plants, it is essential to integrate thermal storage facility. In the Danish CHP systems, this facility, known as “heat accumulator”, is an essential component of a modern CHP system. It is used for short-term storage of water-based energy, normally for 1~3 days. Almost all CHP plants in Denmark are equipped with heat accumulators. Large heat accumulators allow for a complete shutdown of the plant during weekends when electricity prices are often lower than on weekdays. These accumulators serve to compensate for daily load variations in heat demand, mainly caused by night setback. Consequently, they help minimize the start–stops and reduce the reliance on more expensive heat sources during daily peak load periods.

Furthermore, heat accumulators can also decrease the need for peak load capacity in the DH system. During periods of low electricity prices, such as at night, heat can be produced at lower cost using electricity and stored in the heat accumulator. Subsequently, during periods of high electricity prices, such as in the morning, the stored heat can be supplied from the heat accumulator. This allows the CHP plant to operate at optimal electricity and heat production ratios. In the event of an electricity shortage, the power plant can generate electricity while temporarily pausing heat production, and the thermal storage tank can supply heat.

The heat accumulator increases the flexibility of CHP plants, adjusts the imbalance between the supply and demand in the urban energy system, and lays a solid foundation for the sector coupling of power and heating.

3.3.2 Industrial surplus heat utilization

As the world's largest industrial producer, China's industrial energy consumption accounts for nearly two-thirds of the total energy consumption. In current industrial production process, a huge amount of energy is lost, mainly through cooling towers and cooling fans. This waste heat dissipation leads to huge water and electricity consumption in industrial sectors.

Industrial energy saving and clean heating are two crucial aspects of energy efficiency and environmental protection. Obviously, industrial surplus heat (ISH) has the potential to meet the huge energy demand for residential heating. Therefore, utilizing ISH for DH presents significant advantages and can address multiple issues. According to research from Tsinghua University (Tsinghua University Building Energy Efficiency Research Center, 2017) shows that widespread utilization of ISH has the potential to cover up to 70% of the heat demand in northern China. Furthermore, the research indicates that if ISH sources are within a radius of 30 kilometers from urban areas, they can become viable heat sources.

According to the statistical data from 2020, ISH is divided into six categories (Huajing Information Network, 2021). Among these, waste heat from high-temperature flue gas and cooling media accounts for 50% and 20%, respectively. Other sources include waste water and waste gas, accounting for 11%. Chemical reaction waste heat, combustible waste gas, waste liquid, and waste heat together make up 7%. High-temperature products and furnace slag represents 4%.

Regarding the distribution of ISH resources, Figure 20 presents the top seven energy intensive industries in China (Insight Research Institute, 2021), reflecting a great potential of ISH utilization in the country. In terms of the potential of available waste heat resources within the seven industries, the top six provinces are Hebei, Jiangsu, Shandong, Liaoning, Shanxi, and Henan.

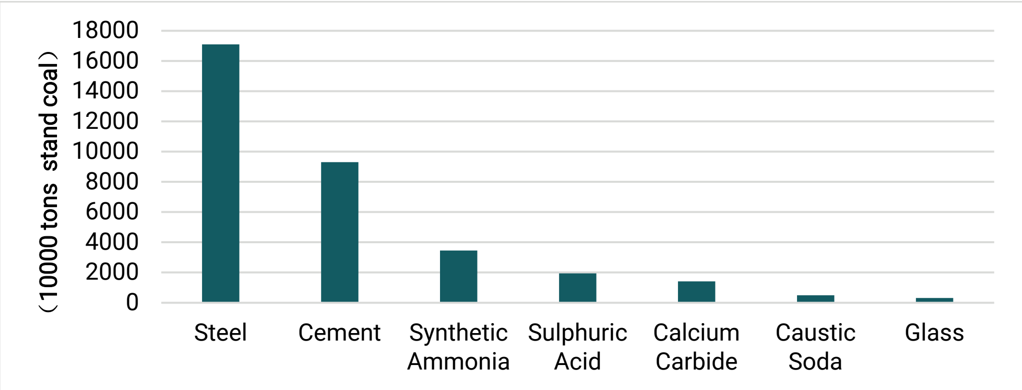


Figure 20. [5]Top 7 energy intensive industrial sectors in China

[5] Note that the y-axis is 100,000 and not 1,000 or 1,000,000.

In October 2015, NDRC and MoHURD issued the” Implementation Plan on Waste Heat for Heating Projects” (refer to Appendix I). This plan underscores the importance of conducting a comprehensive investigation into ISH resources available with the aim of optimizing and promoting their utilization. The primary objectives of the initiative were to enhance energy efficiency, effectively recover and utilize low-grade waste heat resources, reduce coal consumption, improve air quality, and address the rapidly growing demand for heating (including both space heating and domestic hot water) amid environmental challenges in the urbanization process. The policy support resulted in a record surge in waste heat retrofit projects in 2017 with the majority of the projects taking place in major industrial provinces such as Hebei, Shanxi, Shandong.

3.3.2.1 Current conditions

China's utilization of ISH is still in its early stages. The disparity between the ultimate goal of the "Waste Heat for Heating Projects" and the current scientific development level of waste heat for heating in China can be summarized as follows:

There are indications that China lacks essential official statistical data on ISH resources. To enhance the utilization of ISH, competent authorities may need to introduce regulations, compelling industrial enterprises to report relevant data on waste heat available. This involves collecting detailed production data and information on medium parameters, energy flow and waste heat utilization during production processes. The data collected should be comprehensive and detailed to ensure a broad coverage.

Large enterprises and numerous small factories should all be included in the statistics. Random sampling audit must be conducted to ensure the accuracy of the data. Accurate data can facilitate the development of IHS utilization. It can highlight the potential for utilization and serve as a basis for evaluating the costs, profits and socio-environmental value. Combined with spatial mapping, it can also be integrated with heat planning to better support the development of the heating sector.

Although there are many waste heat recovery projects for heating in China, technical specification and the evaluation criteria have yet to be established. Through evaluation and comparison of existing projects, a demonstration project can be selected as a model. Furthermore, the financial department need to allocate funds to foster the development of relevant technologies, such as technologies for waste heat collection and efficient heat transmission.

In terms of project operation and market mechanisms, it is essential to accelerate the development of ISH utilization. It should be encouraged to explore innovative business model, such as public-private partnerships (PPP) and clean development mechanism. It is necessary to introduce relevant policies that encourage collaboration between industrial enterprises to cooperate with the heating utilities.

Another obstacle to the efficient utilization of ISH is the lack of holistic heat planning that can effectively integrate local surplus heat resources with renewable energy and thermal storage. Due to the inherent instability of ISH supply, maintaining a consistent heating output may be challenging. Therefore, a holistic heat planning is needed to leverage thermal storage and balance potential irregularities in heat supply.

Furthermore, there are lingering challenges that need to be addressed. For example, there is a need to improve communication between potential ISH supplier and heating utilities so that they can jointly execute the project and reap mutual benefits. Additionally, it is essential to explore a model for shared costs and responsibilities related to the project operation.

3.3.2.2 Perspectives on the future conditions

According to the” Implementation Plan on Waste Heat for Heating Projects”, it is estimated that the potential value of China's ISH resources will reach 293 billion yuan by 2026.

To achieve clean, safe, and efficient development of heating, it is necessary to change the current heat source model and fully release the potential of surplus heat generated by industries such as iron and steel, nonferrous metals, chemicals and oil refining.

Establishing a clear management system for the ISH utilization in China could yield numerous benefits. It has the potential to inspire proactive engagement from government authorities, heating utilities, and enterprises possessing waste heat resources in implementing waste heat for heating projects.

From a regulatory perspective, there is also an opportunity to review and re-evaluate the heating pricing mechanism in order to create a more transparent pricing model for the energy and heat supply companies. This, in return, can contribute to the development of ISH utilization.

Recovering ISH, especially under low-temperature conditions, requires advanced technologies. Drawing upon inspiration from Danish DH cases, such as the case of HOFOR and Novozymes as described in Appendix III, technologies associated with the collection and extraction of waste heat for low-temperature heating are of great importance. Effective low-temperature heat supply demands efficient transmission and distribution networks within heating systems, as well as highly energy-efficient buildings with low heat demand. Therefore, the utilization of low-grade waste heat should include a holistic consideration of heat sources, heating networks and end users. At the same time, maintaining waste heat production capacity is essential to ensure a stable heat supply. Moreover, technical requirements and costs associated with medium to long-distance transmission should be taken into account, given that industrial plants are often situated far away from local heat demands.

By employing holistic heat planning tools and methodologies, it is essential to consider the synergy and coordinated utilization of various heat sources. In most northern regions, there is considerable potential to replace unclean and inefficient heat sources with ISH. At the same time, it is crucial to consider electricity, heating and natural gas in a holistic approach in order to promote their coordinated planning and development.

3.4 Efficient energy consumption

To improve the overall energy efficiency of a heating system, planners and policy makers must adopt the perspective of end users, ensuring that the energy supply is driven by the actual demand on the consumption side. The amount of energy supply is subject to the actual amount of heat demand at specific times and its variations throughout the day. Optimizing the energy consumption contributes to the efficiency improvement of the entire energy system while ensuring optimal utilization of energy resources. The benefits derived from optimizing energy efficiency include but are not limited to:

- Increasing heat production efficiency and more energy output per unit of energy.
- Decreasing heat loss, especially in pipes.
- Optimizing energy consumption through heat metering, preventing energy waste from over-use, and decreased return temperature.
- Improving hydraulic capacity, lowering pressure losses in the system and allowing more flow.
- Reducing heat temperature from heat sources by increasing the system's water capacity, thus minimizing heat losses in the pipes.

The overall efficiency not only affects the economic interests of end users and energy companies but also contributes to environmental and climate improvement by reducing fossil fuel consumption or optimizing rated load values.

Improving the energy efficiency of the DH system will enhance its heating capacity, making it feasible to expand the existing system, such as providing heating services for new areas.

3.4.1 Return temperature reduction

Reducing the return water temperature is crucial for DH systems as it improves the efficiency of heat generation, particularly in CHP plants. The lower the return temperature, the greater the temperature difference between the supply and return water, leading to higher efficiency of heat exchangers and the overall DH system. Moreover, a lower return temperature indicates an overall lower temperature in the transmission and distribution networks, thereby minimizing heat losses during transmission. This is because the heat loss rate from the pipes to the surroundings is directly proportional to the temperature difference between the pipes and the surrounding environment. A lower return temperature in the DH systems can facilitate better integration of renewable energy resources, enabling a more effective utilization of various low-grade heat sources.

In Denmark, various measures have been implemented in DH systems to maintain low return temperature. This is crucial for enhancing overall system efficiency and facilitating the integration of renewable energy resources. These measures include:

- Improving the insulation of buildings and upgrading heating systems inside buildings to operate efficiently at lower temperature.
- Utilizing high-efficiency heat exchangers and advanced substation controls for precise adjustment of heat delivery in response to real-time demand.
- Implementing variable flow operation in secondary pipes to reduce circulating water volume.
- Using advanced control systems to optimize water temperature based on outdoor temperature forecasts and current heat demand.
- Encouraging consumers to use heat at off-peak times or when renewable energy availability is high, balancing the system and maintaining lower return temperature.
- Integrating thermal storage solutions to decouple heat production from consumption, utilizing surplus heat and reducing return temperature during low-demand periods.
- Dividing the heating network into areas with separate supply temperatures, allowing areas with different heating requirements to receive heat at optimized temperature.
- Raising public awareness among end-users on the importance of maintaining a low return temperature and how their behaviors can impact system efficiency.

Installing necessary control devices ensures that water doesn’t flow too quickly into the return pipes, allowing more heat to be absorbed and utilized by end users. Some indoor systems are even equipped with circulation pumps and three-way valves to circular water within the system, providing additional heat and ensuring more efficient operation at the end user side.

These initiatives have significantly enhanced the overall effectiveness and sustainability of the Danish DH systems, aligning with Denmark’s national goals of energy efficiency and carbon neutrality. Currently, the measured return water temperature in the DH systems in China is considered relatively high, underscoring the imperative to enhance the efficiency of indoor heating systems.

3.4.1.1 Current conditions

Currently, the design parameters for household heating installations requirement improvement. Many heat exchange stations either lack control measures or have valves installed but unable to regulate, making it difficult to lower the return water temperature.

For some consumers, especially those without any differential pressure regulators installed, the excessively rapid flow rate of the supplied water hinders effective heat exchange.

The design of the supply water temperature is often overly conservative, being much higher than the actual heat demand of consumers. Methods to reduce the supply water temperature are particularly beneficial for lowering the return water temperature.

3.4.1.2 Perspectives on the future conditions

By installing effective control devices and replacing outdated and inefficient equipment with high energy-efficiency devices, it is possible to increase the temperature difference between the supply and return water at end users. This, in turn, effectively reduces the return water temperature.

The behavior of end users can maintain the efficient operation of the heating system. For instance, in heating systems where end-user control devices are in place, it is advisable to avoid setting the heating equipment to high levels, thus preventing excessive heat consumption. Additionally, unnecessary heat loss due to open windows should be avoided. An effective solution to this issue is the use of thermostatic valves on radiators. These valves can automatically adjust based on indoor temperatures, providing consumers with a means to regulate their heating levels. Furthermore, while installing various necessary control devices to enhance efficiency, energy-saving behavior among heat consumers can be incentivized by the tariff that reflects the consumer’s actual heat consumption.

The ideal condition for any heating system is to reduce and maintain the return water temperature as low as possible. By saving energy through the behavior of heating consumers, consumers can save money on heating bills, and heating utilities can improve system energy efficiency while minimizing heat loss.

3.4.2 Heat metering & billing system

In the context of a heat metering system, it is crucial to measure energy consumption of end users. Heat metering enables an understanding of end users’ energy consumption patterns, serving as a baseline for implementing future energy efficiency measures. To gain a more comprehensive insight into end users’ consumption patterns, measurement data can be obtained directly from users through the installation of devices such as heat meters. These measurements should include parameters such as heat consumption, flow rate and both supply and return water temperatures.

The database is also a crucial component of the heat metering system as it can store measurement data, and provide recorded value to meet potential future needs. The data can assist heating utilities in understanding abnormal situations among end users and formulating plans to enhance energy efficiency.

In China, heat consumption for most buildings is predominantly charged at a fixed rate based on heating area (m^2) and user categories. There are currently no incentives to encourage end users to engage in independent energy-saving practices. However, this can be addressed by implementing heat metering and billing systems that are based on actual energy consumption.

In Denmark, the heat metering and billing systems have undergone further development. When the supply and return water temperature difference is too low, it can be an indication that the end-user's heat exchange level is insufficient or their energy efficiency is poor. In such cases, additional charges are applied to the heating bills to encourage consumers to upgrade and improve their end devices. With the continuous upgrading of heat metering billing systems, heat consumers can promptly monitor the energy consumption levels in their buildings and observe the energy-saving effects resulting from changes in their consumption behavior.

3.4.2.1 Current conditions

During China's heating reform period, in order to promote a billing mechanism based on actual heat consumption, MoHURD issued the "Technical Regulations for Heating Measurement" in 2009 (MoHURD, 2009), which introduced a variety of heat metering methods based on the end-user side of the heating system to accommodate the diverse heating systems in China. However, it should be pointed out that an important prerequisite for heat metering and billing based on actual consumption is that the heating system has established thermal and hydraulic balance to match heat supply with demand, thereby improving the efficiency of the heating system. To achieve hydraulic balance in the heating system, it is necessary to have controllable and measurable regulating devices to detect, analyze, and adjust relevant parameters such as system flow, temperature, pressure, etc. This ensures a comprehensive understanding of the entire system's operation and helps avoid scenarios of excessive or insufficient heating.

China's heating systems typically operate under a planned heating mode, ensuring that buildings reach standard room temperature at certain outdoor temperatures. The current DH systems in China connect various buildings with different hydraulic distances through large heat exchange stations. Due to the lack of necessary control measures, individual buildings cannot obtain the exact amount of heat needed. This results in some buildings receiving excessive heating, while others experience insufficient heating. Alternatively, heating companies may install static adjustment devices that cannot cope with the dynamic variations in actual heat demand at the end-user side.

To enhance energy efficiency, there is a need for the system to transition from supply-driven to demand-driven. This entails adjusting the heating system, installing necessary control devices, and establishing hydraulic balance within the system to match the actual heat demand at various end-user points.

Furthermore, without automatic control devices, it is impossible to measure heat supply, flow, and temperature, making it difficult to understand the consumption levels at the end-user points. This is crucial for establishing a heating system that bills based on actual energy consumption. Without access to temperature values, optimizing at the end-user level for better hydraulic balance conditions becomes challenging, making it difficult to reduce return water temperature and enhance system efficiency.

3.4.2.2 Perspectives on the future conditions

Energy efficiency measures can effectively alleviate the tight demand for heating in buildings. Measures to improve energy efficiency include optimizing the energy efficiency of new buildings, retrofitting the heating systems of existing buildings, expanding heat metering deployment, and achieving hydraulic balance.

In addition, providing end users with automatic control devices can inspire them to save energy. Heating utilities can also establish an effective communication mechanism with heat consumers and invite them to participate in energy-saving initiatives to achieve two-way energy saving and mutual benefits.

3.5 Summary of comparative analysis: current vs. future district heating in China

The gap analyzed in this chapter revolve around 11 topics selected in collaboration with the Sino-Danish clean heating experts who have participated in the panel discussions and a survey poll comparing each topic.

The selected topics are divided into four main categories, as outlined in the following overview:

Energy planning

1. **Heat planning**. To facilitate the transition to clean and renewable heat supply for DH, China could benefit from Denmark's experience in holistic strategic heat planning that

relies on tools considering both local conditions, overall energy systems and policies simultaneously.

2. **Heat demand forecasting**. Heat demand forecasting can be a flexible tool useful for heat planning as well as for day-to-day operational optimization. In China, heat demand forecasting has not been widely applied, whereas software applications are available and commonly used in Denmark. The benefit of deploying a heat forecasting scheme include the optimal utilization of local clean energy sources and proactive planning of future heat demands in the supply system.
3. **Thermal storage**. Seasonal thermal storage technology is gaining popularity in Denmark, but has not yet reached an appropriate scale in China. Such technologies can store excess thermal heat, including surplus heat from renewable energy sources, CHP plants and industries, when the heat demand from consumers is low in the DH network.

Renewable energy for heating

4. **Geothermal heating**. According to available data, China possesses abundant geothermal resources, including shallow geothermal, hydrothermal geothermal, and hot dry rock. Moreover, the national government has also released relevant policies to promote geothermal utilization in recent years, highlighting enormous potential and promising prospects to develop geothermal resources in China. This creates an excellent foundation to engage in international cooperation and overcome technical bottlenecks by drawing lessons from practical cases in other countries, such as Denmark.
5. **Solar district heating**. China has abundant solar energy resources and favorable policies, presenting a significant opportunity for the widespread adoption of solar DH. Denmark, being a global leader in the large-scale solar DH plants, can share its value experiences and lessons learned to accelerate the development of the solar DH market in China.
6. **Biomass heating**. China has abundant biomass resources and existing coal fired power plants in China could be converted to biomass plants. Retrofitting the existing plants and replacing the boilers with biomass only has been key in transitioning away from coal in power and heat production in Denmark, where today biomass accounted for the largest share of the Danish renewable energy sources used.
7. **Large-scale heat pumps. I**n order to reduce CO2 emissions in China's heating sector and achieve the pledged goal of carbon neutrality by 2060, it is antipated that technologies such as large heat pumps will be used for grid integration of renewable energy and efficient use of surplus heat in the coming years. China could benefit from the Danish experience with this technology, which has seen robust development in recent years in Denmark.

Efficient use of surplus heat

8. **CHP surplus heat**. In China, the available excess heat from CHP plants can be used to cover a significant proportion of the demand. Surplus heat from CHP plants should be considered as one of the important heat resources when planning DH in the future. Combing this approach with thermal storage utilization will enhance the flexibility of CHP plants, fostering the sector coupling of power and heating.
9. **Industrial excess heat**. China is the world's largest industrial producer, with the industrial sector accounting for nearly two-thirds of the total energy consumption. A substantial amount of heat demand could be met by the currently wasted surplus heat from industrial processes.

Efficient energy consumption

10. **Return temperature reduction**. The return water temperatures in China's DH systems are considered rather high, suggesting inefficiencies in buildings or indoor heating systems. Comprehensive plans for hydraulic and thermal balance, including automatic control devices, intelligent heat exchangers, and thermostatic valves, are not extensively implemented in China. Conversely, in Denmark, the utilization of efficient indoor heating devices has successfully lowered the return water temperature, thereby enhancing overall heating efficiency. Capacity building is crucial to ensuring the correct design parameters of indoor heating systems in China to maintain an efficient heat supply during normal operation with low return temperature.
11. **Heat metering and billing system**. In China, consumers' heat consumption is not measured according to actual energy usage, posing challenges in monitoring heating patterns and implementing a consumption-based billing system. In most cases, heat consumption is billed at a fixed rate based on the heating area and user categories. Denmark has implemented an incentive billing system which allow consumers to obtain returns through more efficient heat usage.

4 Policy recommendations

An important feature of the Danish energy model is its emphasis on cultivating interactions across various sectors and systems to establish synergies, rather than focusing on individual sectors and concepts. Through effective public-private partnership, supported by stable political and regulatory frameworks, Denmark has successfully reduced the monopolistic nature of heating infrastructure by implementing principles of public ownership and non-profit initiatives. This approach has not only catalyzed crucial innovation and breakthroughs in energy concepts but also created a secure investment environment, ensuring a level-playing field for DH. The Danish energy model is centered on three key elements: energy efficiency, renewable energy, and system integration/development and electrification. The synergy and consistent integration among these three aspects play a vital role.

1) Improving energy efficiency makes it possible to meet energy demands with renewable energy; as otherwise, the initial costs of renewable energy would be excessively high.
2) An integrated energy system can effectively balance the relationship between renewable energy and conventional energy in terms of utilization, energy storage and surplus heat recovery, ensuring the security of supply.
3) The substantial growth of CHP and DH electrification has contributed to the integration of high proportion of wind and solar power in Denmark's energy system.

Closing the identified gaps between China's current heating industry and a clean, efficient, and secure heating system can be achieved through the implementation of key policies. The policies will catalyze new methodologies, standards, procedures, and technologies, contributing to the development of renewable energy and clean DH supply, along with efficient heat distribution and optimization of heat supply and demand. To achieve this, firstly, a national legislative framework for heating should be established to ensure the implementation of national energy policies. Secondly, strategic heat planning approach should be implemented at the different scales of public authorities. Thirdly, the use of local renewable and clean energy as heat sources should be incentivized. Finally, the optimization of heat production should align with the end-user demand.

Establish a legislative framework for heating

In Denmark, the Heat Supply Act has defined the regulatory framework for the development of cost-effective DH systems, serving as the backbone of the Danish regulatory toolbox for DH for more than 40 years. China could learn from this successful example to develop a national heating regulation. This would ensure the implementation of national energy policies, offer robust legal support for provincial heating management regulations, and establish a legal basis for the implementation of local heat planning. This approach would help address the challenges arising from the high and complex management requirements in modern DH system.

Adopt a holistic heat planning approach

The Danish experience has demonstrated that well designed heat planning facilitates the establishment of DH networks in regions with accessible and almost cost-free surplus heat from power plants or other sources. To create a more energy-efficient and flexible energy system, there is a need for greater integration among power, heating, natural gas, and industries. This integration should leverage the advantages offered by DH systems, such as their ability to flexibly and extensively utilize local resources – an advantage which independent or individual heating systems lack.

China needs to adopt a holistic heat planning approach. This involves conducting comprehensive, long-term socio-economic and environmental impacts of potential heating options, analyzing their cost-effectiveness, soliciting input from investors, and implementing economic incentives to encourage the adoption of green, energy-efficient solutions, with the aim to achieve energy conservation, climate and environmental targets.

Considering the unique characteristics of local heat resources and heat demand, China should formulate a clear national guideline for heat planning. These guidelines would encourage local governments to formulate heating plans tailored to their specific conditions, following the national guidance. Local authorities should play a key role in implementing clean DH. Given that China is a vast country, the resources available and the current status of regional DH systems vary across provinces. The guidelines should highlight the importance of cost-effective solutions based on socio-economic assessments and clearly define the rights and responsibilities between heating utilities and local authorities.

Implement policies and incentives to transform DH systems, encouraging the use of local clean heating sources and reducing reliance on coal and natural gas

China should accelerate the promotion of clean and renewable energy as the primary heat sources for DH. This transformation requires a comprehensive approach, considering local resources and potentials. Energy policies should set clear goals for the development of renewable energy and clean heating, with economic incentives driving implementation. In terms of incentive mechanisms, effective policy tools from Denmark, such as taxing fossil fuels (e.g. applying carbon tax to non-DH) and providing subsidies for renewable energy and clean heating technologies, or subsidies for key technologies enabling the integration of renewable electricity to the heating sector, such as large heat pumps and thermal storage technologies, can inspire the transition in China. This green transition of DH should be coordinated with the green transition of the power sector, as DH systems can increase the flexibility of the entire energy system and improve the integration of renewable energy.

Develop a consistent regulatory framework to optimize heat production and efficient end-user consumption

Effective energy policies addressing district heating and energy efficiency must holistically consider information, regulations, and economic measures, balancing investments in heating infrastructure and energy conservation. Denmark's comprehensive energy agreement includes a wide range of measures covering renewable energy, energy efficiency, and the entire energy system. In recent years, Denmark has prioritized to expand DH networks, increase the share of renewable energy in heating, replace outdated oil or gas boilers with heat pumps, improve energy efficiency standards for new buildings, and accelerate the energy retrofitting of existing buildings. Demand-side management plays a key role in achieving the green transformation of DH systems. Denmark encourages end users to save energy through incentive policies such as a heat metering and billing system and incentive heat pricing linked to lower return water temperatures. China needs to improve the pricing mechanism that reflects market supply and demand and combine it with actual consumption data to encourage consumers to save energy and increase efficiency.

In order to further support these policy recommendations, joint workshops on pathways for the transition from gray to green DH and on the sector coupling of power and heating will be held as part of the Sino-Danish Strategic Sector Cooperation for Clean Heating in China.

Continued knowledge sharing to further support clean heating transition in China

This Report, a joint effort from DEA, CREEI and the expert panel, can be served as a solid foundation for continued knowledge sharing between regulatory bodies, research institutions and enterprises in both countries. Joint workshops and capacity buildings such as training courses and study trips, will be organized. In order to provide sound policy recommendations, we suggest joint study on clean and renewable heating planning roadmap at the provincial or city level in China should be carried out.

The established Sino-Danish Clean and Renewable Heating Cooperation Centre will continue developing training materials and organize capacity-building activities with a focus on the efficient utilization of renewable and advanced heating technologies.

5 Conclusion

This Report performs an analysis of the current conditions for district heating (DH) in China and in Denmark, and investigated the main focus areas that can support effective solutions to achieve clean heating in China in the future, drawing insights from the Danish experiences. This leads to suggestions for cooperation on activities that can facilitate the implementation of such solutions, contributing to favorable future conditions for a clean and renewable heating sector in China, in alignment with the climate targets set by the Chinese government.

Though both China and Denmark have a long experience with DH, historical differences in heating policies have shaped distinct characteristics and conditions in the two countries. The comparative analysis has identified eleven focus areas where solutions inspired by Danish DH best practices could enable clean heating in China.

Closing the identified gaps between China's current conditions for DH and future conditions for clean and renewable DH can be achieved through the implementation of strategic heat planning and key policies. This will catalyze new methodologies, standards, procedures, and technologies. Such efforts can be supported by research and capacity building activities, specifically designed at the provincial level, considering the diverse development contexts across Chinese provinces.

In return, the advancements and DH projects undertaken in China could inspire the future development of the DH sector in Denmark. It is expected that Denmark will achieve almost 100% renewable energy DH by 2030, driven by the electrification of heating systems with the rapid deployment of large-scale heat pumps, continuous development of solar heating and geothermal heating, as well as efficient utilization of industrial surplus heat.

The establishment of the Sino-Danish Clean and Renewable Heating Cooperation Centre, and its virtual platform launched on March 1, 2023, will act as a knowledge network facilitating the collaboration. The Sino-Danish Strategic Sector Cooperation for Clean Heating Programme will carry out a set of capacity building activities until October 2025 in order to support the implementation of actions to enable the transition towards clean heating in China.

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Appendix

I. Description of district heating policies in China (2005-2022)

Year	Leading Ministry	Title	Main district heating related content
2004	NDRC	Medium-long Term Special Plan on Energy Saving	Heat metering and billing (in large and middle-sized cities).
2005	P. R. China	Renewable Energy Law	Integrate biomass heat into the heating network.
2006	SC	Decision on Strengthening Energy Conservation Work	Heat as a commodity, promote heat metering and consumption-based billing scheme.
2006	MoF	Interim Measures for the Management of Special Funds for Renewable Energy Development	Support heating and cooling technologies using renewable sources including heat pumps
2007	NDRC	11th FYP on Energy Development	Switch from distributed boilers to centralized heating, energy saving standards for new cogeneration
2007	NDRC, MoHURD	Interim Measures for the Administration of Urban Heating Prices	Allow non-public capital in heating facility investment, construction and operation, with heating price set by local governments. Where conditions permit, heating prices can be determined through negotiations between heat producers and users.
2010	SC	Guiding Opinions on Promoting Joint Prevention and Control of Air Pollution to Improve Regional Air Quality	Prohibit thermal power plant construction except CHP plants in urban areas, expand centralized heating, and enhance pollution prevention and control for centralized heating boilers.
2012	NDRC	12th FYP on Energy Development	Actively promote natural gas cogeneration; accelerate energy-saving retrofit of urban heating networks.
2012	NDRC	Notice on Coal-fired Plant Retrofit and Upgrading	Support the retrofit of coal-fired power plants for heat and power
2012	MoHURD	12th FYP Special Plan on Building Energy Conservation	Development of gas cogeneration, heat network renovation
2013	SC	Action Plan for the Prevention and Control of Air Pollution	Shutting down small coal-fired boilers, expanding centralized heating.

Year	Leading Ministry	Title	Main district heating related content
2013	NDRC, MoHURD	Action Plan for Green Buildings	In the "12th Five-Year Plan" period, complete heating metering and energy-saving renovations for over 400 million m^2 in existing residential buildings in northern heating areas. Implement energy-saving renovation in urban heating systems and deepen the reform of urban heating systems.
2013	NEA, MoHURD, MoF, MLR	Opinion on Geothermal Energy Development	Where resources available, geothermal energy promoted for urban energy and heating.
2014	NDRC, MEE, NEA	Action Plan for Energy Conservation, Emission Reduction and Upgrading of Coal-fired Power Generation (2014-2020)	Emission standards for coal-fired units above 300MW; centralized heating replacing distributed boilers; surplus heat utilization.
2015	NDRC	Implementation Plan on Waste Heat for Heating Projects	By 2020, replace coal-fired heating with low-grade waste heat for 2 billion m^2. Implement waste heat for heating demonstration projects in 150 selected cities.
2015	NEA	Notice on the Development of Wind Power for Clean Heating	Promote air pollution prevention and control and explore wind power for clean heating.
2016	NDRC, NEA, MoF, MoHURD, MEE	Administrative Measures for Cogeneration Plants	Specification on cogeneration plants according to city size
2016	NDRC, NEA	13th FYP on Energy Development	Promotion of tri-generation and biomass cogeneration; geothermal heating; low-grade excess heat utilization.
2016	NDRC, MLR[6], NEA	13th FYP on Geothermal Energy	Open heat market access to geothermal companies; geothermal heating/cooling development goals.
2016	NDRC	Energy Supply and Consumption Revolution Strategy (2016-2030)	Development of district energy and biomass heating.
2017	MoF, MoHURD, MEE, NEA	Notification on Supporting Clean Heating Pilot Projects in Northern China	500M to 1 billion CNY subsidies for clean heating pilot projects in “2+26” pilot cities, depending on city type.

[6] The Ministry of Land and Resources is now the Ministry of Natural Resources.

Year	Leading Ministry	Title	Main district heating related content
2017	MoHURD	13th FYP on Buildings Energy Saving and Green Buildings	By 2020, improve new urban building energy efficiency by 20%. Implement clean heating projects, adding over 2 billion m^2 of solar heating and 200 million m^2 of shallow geothermal applications nationwide.
2017	NDRC	Opinions on Clean Heating Price Policies in Northern China	Adhere to the policy of "enterprise-led, government-driven, and affordable for residents."
2017	10 ministries and commissions including NDRC, MoHURD, NEA, etc	Clean Heating Plan for Northern China in Winter 2017-2021	By 2019 and 2021, clean heating rate in northern China reaches 50%, and 70% respectively, replacing 74 million and 150 million tons of bulk coal (including inefficient small coal-fired boilers).
2020	SC	Guiding Opinions on Promoting the Development of the Western Region in the New Era and Forming a New Pattern	In the new era, there's a shift in the energy sector, emphasizing graded use of coal, quality improvement, and promoting the development of renewable energy and energy storage.
2020	MoF	Interim Measures for the Management of Special Funds for Clean Energy Development	Special funds support the clean development and utilization of renewable energy and fossil fuels.
2020	MEE	2020-2021 Autumn-Winter Air Pollution Control Plan for Beijing-Tianjin-Hebei and Surrounding Areas, and Fenwei Plain	Before the 2020 heating season, efforts focused on replacing coal with electricity, gas and promoting the treatment of loose coal and ensuring energy supply.
2021	SC	Opinions on Completely, Accurately, and Comprehensively Implementing the New Development Concept and Doing a Good Job on Carbon Peak and Carbon Neutrality	The Opinion is a key management policy guiding the 1+N policy system for carbon peaking and neutrality. It, along with the "Action Plan for Carbon Peak Before 2030," shapes the overarching strategy for both stages. The "N" includes plans for different sectors and industries, along with support, finance, standards, and assessments.
2021	SC	Action Plan for Carbon Peak Before 2030	
2021	NEA	Notice on Implementing Renewable Energy Heating According to Local Conditions	Implement renewable energy heating planning, promoting various technologies like geothermal, biomass heating, and cogeneration based on local conditions.

Year	Leading Ministry	Title	Main district heating related content
2021	NDRC, MoHURD	Notice on Strengthening the Renovation of Urban Old Residential Areas and the Construction of Supporting Facilities	Prioritizing the renovation of facilities such as water, electricity, gas and heat supplies that have potential safety concerns
2021	MEE, NDRC, MoHURD, NEA	Comprehensive Air Pollution Control Plan for Autumn and Winter in 2021-2022	Expanding from the "2+26" cities, add cities from provinces such as Hebei, Shanxi, Shandong, and Henan. Promote clean heating at the district, county, and town levels.
2021	NEA	Opinions on Promoting the Development and Utilization of Geothermal Energy	By 2025, increase geothermal heating (cooling) area by 50% compared to 2020, and double it by 2035 compared to 2025.
2021	SC	Opinions on Deepening the Battle Against Pollution	Expand clean heating pilots, enhance clean heating in the north, conduct air pollution control in Beijing-Tianjin-Hebei and Fenwei Plain, and strengthen pollution control on straw burning and coal-fired heating in the Northeast.
2022	NEA	Action Plan for Improving Energy Carbon Peak and Carbon Neutrality Standardization	By 2025, China plans a robust energy standard system for green and low-carbon transformation. Tasks include standardizing non-fossil fuels, improving the power system, improving standards for new energy storage, hydrogen tech, efficiency, and enhancing carbon emission reduction standards in the energy industry chain.
2022	NDRC, NEA	14th FYP for Renewable Energy Development	By 2025, non-electric utilization of solar energy, geothermal energy, biomass heating and biomass fuel will exceed 60 million tons of standard coal.
2022	NDRC, NEA	Opinions on Improving the System, Mechanism, and Policies for Green and Low Carbon Energy Transformation	Support renewable energy in buildings, promote heat metering reform, encourage intelligent heating facilities, promote heat billing, prompt electric enterprises and users to access low-cost electricity during off-peak periods, and implement gas pricing policies supporting clean heating in northern rural areas during winter.
2022	MoHURD	14th FYP Action Plan on Ecological Protection and High-Quality Urban and Rural Construction in the Yellow River Basin	Expand clean heating in the Yellow River Basin, prioritize phasing out coal-fired small boilers, and utilize clean energy sources. Improve urban heating systems, achieve interconnected heating networks, and reduce heat loss by 2.5% by 2025 compared with 2020 in cities along the Yellow River.

II. Comparative analysis table

The Report initially selected the following 19 topics relevant to district heating systems. Following the methodology in Chapter 4.3, the technical team and expert panel selected 11 topics across four categories, detailed in this Report.

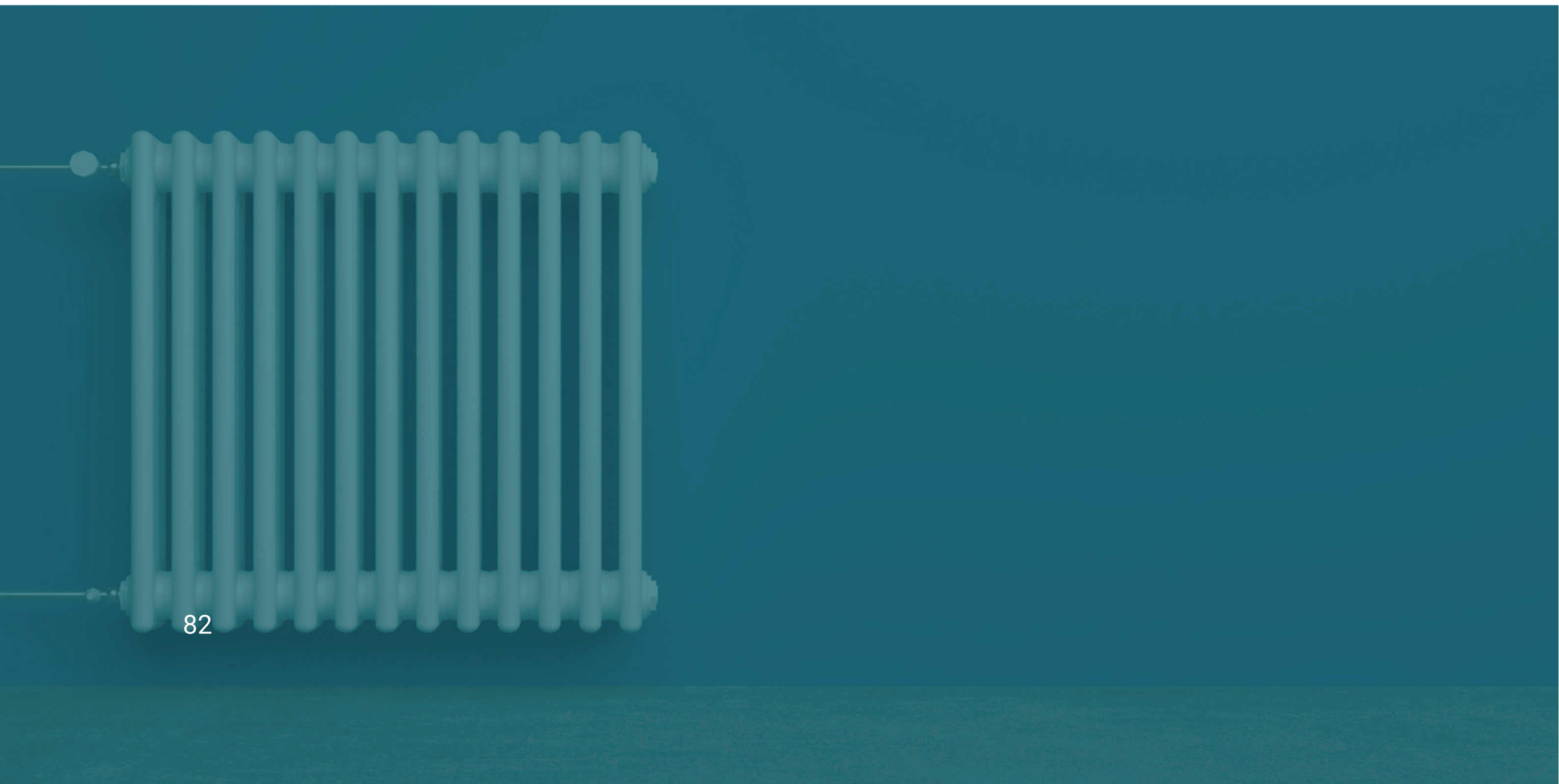
Category	No.	Topics related to district heating	Introduced in the report
Heat planning	1	Heat & demand forecasting	Yes
	2	Heat planning	Yes
	3	Heating seasons	No
Clean heat source	4	CHP surplus heating	Yes
	5	Industrial surplus heat utilization	Yes
	6	Biomass heating	Yes
	7	Geothermal heating	Yes
	8	Solar heating	Yes
	9	Thermal storage	Yes
	10	Large scale heat pumps	Yes
	11	Small individual heat pumps	Yes
	12	Waste-to-energy	No
Heating network	13	Return temperature reduction	Yes
	14	Hydraulic balancing	No
	15	Pipe system renovation	No
	16	Temperature balancing	No
End users	17	Heat metering & billing systems	Yes
	18	Incentive tariff systems	No
	19	Supply of domestic hot water	No

III. Case studies

This section showcases a total of eight clean heating case studies from both China and Denmark. These cases are introduced based on project overviews, technology, economy and environment benefits. For more information, please refer to the individual case descriptions or access the cases through:

https://c2e2.unepccc.org/collection/sino-danish-clean-and-renewable-heating-cooperation-centre-library/

Country	No.	Location	Case
China	1	Shandong, Yangxin	Biomass clean heating
China	2	Tibet, Langkazi	Solar centralized heating
China	3	Anhui, Hefei	Binhu Science City
China	4	Beijing	Beijing Sub-center 6# Energy Station
Denmark	5	Odense	Wastewater for green district heating
Denmark	6	Copenhagen	Industrial waste heat for district heating
Denmark	7	Støvring	Replacement of gas boiler for large-scale heat pump
Denmark	8	Taars	Future development of solar district heating



Biomass clean heating Yangxin, China

Project Location	Yangxin,Shandong, China
Renewable/Clean Energy	☑ Biomass ☐ Geothermal ☐ Solar Energy ☐ Waste/Surplus Heat
Applied Technology	▪ CHP for district heating ▪ Biomass boiler for distributed heating ▪ Biomass stove for decentralized heating

Yangxin County, located in Binzhou City, Shandong Province, is one of the "2+26" pilot cities in China's "Clean Heating Plan for Northern China in Winter". The local waste resources in Yangxin County mainly come from pear tree branches, crop straw, sawdust from furniture factories, and cow dung from livestock farms. In 2020, by utilizing waste resources, Yangxin County completed biomass clean heating transformation for 81,000 households, leading to over 80% of rural households adopting clean heating.

TECHNOLOGY: The project aims to utilize local biomass resources with a plan known as the "Yangxin approach," involving on-site collection by farmers, nearby processing by enterprises, and widespread local utilization. According to local conditions, three technological routes have been adopted:

1) Biomass CHP for district heating: A 30MW biomass CHP plant has been established to promote central heating in counties, urban areas, and villages. It also provides heating for greenhouses.

2) Biomass boilers distributed clean heating: Enterprises manage and operate biomass heat-only boilers under an Energy Management Contract (EPC) arrangement, supplying heating to public buildings, residential homes, and village structures. This has led to the emergence of a new business characterized by distributed renewable energy heating services.

3) Decentralized clean heating with biomass stoves for households: In remote rural areas with dispersed populations and unsuitable for gas pipelines, decentralized heating using household biomass briquettes and stoves was promoted to replace bulk coal effectively.

ECONOMY: For users, under the current subsidy policy, the retrofit cost of biomass clean heating was reduced by 38% and 3.2%, respectively, compared to coal-to-gas and coal-to-electricity conversions. This results in savings of ¥5,140 and ¥280 CNY, while usage costs were reduced by 52% and 51%, respectively, leading to savings of ¥2,140 and ¥2,080 CNY.

ENVIRONMENT: In 2019, the average PM10 concentration dropped by 4.1% year-on-year, and the average PM2.5 concentration decreased from 70 μg/m³ in 2017 to 55 μg/m³.

LINK: https ://c2e2.unepccc.org/collection/sino-danish-clean-and-renewable-heating-cooperation-centre-library/

Solar centralized heating Langkazi, China

Project Location	Langkazi,Tibet, China
Renewable/Clean Energy	☐ Biomass ☐ Geothermal ☑ Solar Energy ☐ Waste/Surplus Heat
Applied Technology	▪ Solar district heating ▪ Thermal storage ▪ Electric boiler for the backup heat source

Langkazi Town, situated in a high-altitude and severely cold area at an elevation of 4,200 m and a boiling point of 84 °C, faced a pressing need for heating. In 2017, both local and central governments initiated the construction of a large-scale solar district heating plant. Prior to this, buildings in the area had no heating systems installed. The project's objectives include demonstrating the reliability and applicability of the deployed system and serving as a best practice example for addressing heating challenges in Tibetan urban regions. This pioneering project achieved 100% solar heating throughout the heating season, making it the world's first large-scale solar district heating project with a 100% actual solar operation guarantee rate.

TECHNOLOGY: The project comprises a collector array, buffer storage, electric boilers, DH network, and indoor heating terminal units. It is executed in two phases. The first phase, completed in November 2018, included a collector with an area of 22,275 m^2 tilted at 40°. A 15,000 m^3 water pit storage is employed for short-term storage due to efficiency concerns at this elevation. Solar heat can be directly supplied to the DH network or stored. The DH network operates with favorable low supply/return temperatures of 65/35 °C for solar thermal heat supply. Two electrical boilers (2 × 1.5 MW) serve as backup heat sources. Initially, the first phase connected 26 communities with an 82,600 m^2 building floor area to the DH network. The second phase will expand the collector area by 14,525 m^2 to accommodate additional consumers in the near future. The collector array is located approximately 2 km south of Langkazi Town.

The heating season in Tibet spans from September 23 to May 31 (251 days total). During this period, the outdoor design temperature is −14.4 °C, while the indoor design temperature is maintained at 18 °C. The DH network exclusively provides space heating and is inactive during the summer. Future plans may include adding domestic hot water to increase the summer load. The solar collector field aims to cover over 90% of the heat demand.

ECONOMY: Langkazi Tibet Solar Heating is a fully subsidized project, receiving a grant of 175 million CNY from the central government.

ENVIRONMENT: This project in Langkazi County pioneers a new approach to renewable heating in plateau areas. It not only enhances the living conditions of Tibetan communities but also marks the end of a historical reliance on burning cow dung for heating.

LINK: https ://c2e2.unepccc.org/collection/sino-danish-clean-and-renewable-heating-cooperation-centre-library/

Hefei Binhu Science City
Anhui, China

Project Location	Hefei Binhu Science City, Anhui Province, China
Renewable/Clean Energy	☐ Biomass ☑ Geothermal ☐ Solar Energy ☑ Waste/Surplus Heat
Applied Technology	▪ Geothermal source/Sewage source heat pump ▪ Energy/ice/water Storage ▪ Combined Cooling, Heating and Power (CCHP) fueled by natural gas

The Hefei Binhu New Area Core Region District Energy Project aims to build three energy stations for heating and cooling, covering a planned energy supply area of 3-5 million m^2. This project utilizes diverse complementary energy sources, including ground source heat pumps, sewage source heat pumps, water and ice storage, and natural gas-driven CCHP systems to optimize energy distribution. The project follows a "three stations and two networks" approach, establishing three district energy stations to provide mutual backup and ensure a stable and reliable energy supply.

TECHNOLOGY:

1) Regenerated water source heat pump system: The Tangxi River Reclaimed Water Plant supplies water that meets the requirements of sewage source heat pump. It processes 231.5kg/s of water daily, maintaining stable outlet water temperatures of 12 ℃ in w inter and 25 ℃ in summer, effectively meeting cooling and heating needs throughout the day.

2) Combined cooling, heating, and power system: This energy supply system utilizes gas as fuel, efficiently using hot water and high-temperature exhaust gas to fulfil cooling, heating, and electricity demands, thereby enhancing overall energy utilization efficiency.

3) Ground source heat pump + water storage system: By using cooling and heating units along with energy storage devices, energy is stored during low electricity tariff periods and released during peak air conditioning loads.

4) Large temperature difference energy supply mode: The district energy system incorporates various complementary energy supply forms, enhancing transmission energy efficiency. The sewage source heat pump units, ground source heat pump units, and centrifugal chiller units are connected in series to form a large temperature difference energy supply mode. This reduces water flow, pipeline diameter, water pump energy consumption, resulting in lower initial investment, and operational costs.

ECONOMY: From 2019 to 2020, the summer cooling supply reached 113.698 million kWh, with an electricity consumption of 4.44 million kWh. The off-peak electricity consumption accounted for 55.06%, while peak hours accounted for 16.41%. The average electricity price was 0.53 yuan/KWh. In winter, heating supply reached 5.418 million kWh (affected by COVID-19), with an electricity consumption of 2.6684 million kWh. Off-peak electricity consumption was 75.36%, and peak hours was 4.55%. The average electricity price was 0.44 yuan/(KWh). Electricity costs significantly reduced during the initial operation of the project, ensuring good economic viability.

ENVIRONMENT: Operational data analysis demonstrates that the district energy system saves an average of 21.6% energy compared to decentralized air conditioning systems, leading to reduced operational costs and carbon dioxide emissions. Furthermore, the removal of numerous air conditioning facilities enhances building aesthetics and effectively mitigates the urban heat island effect.

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Beijing Sub-center 6# Energy Station
Beijing, China

Project Location	Beijing, China
Renewable/Clean Energy	☐ Biomass ☑ Geothermal ☐ Solar Energy ☐ Waste/Surplus Heat
Applied Technology	▪ Ground source heat pump ▪ Water storage ▪ Combined cooling, heating and power (CCHP)

The Beijing Sub-center 6 # Energy Station provides district heating and cooling to an area of approximately 565,600 m2. The system has a cooling load of 37.5MW, a heating load of 18.4MW, and consists of 12 substations. During winter, the energy station supplies hot water at 50/40 ℃ to meet heating needs, while in summer, it provides cold water at 6/13 ℃ for cooling purposes.

TECHNOLOGY: The energy station relies on ground source heat pumps and energy storage (water) to handle the base load, supplemented by various energy sources such as natural gas CCHP, gas boilers, electric refrigeration, and municipal district heating for peak load management, ensuring a secure energy supply. Additionally, an intelligent control platform and a simulation platform were established to enhance automatic control and energy utilization efficiency, enabling functions like load forecasting, operational strategy optimization, precise energy control, and technical training.

ECONOMY: Natural gas consumption primarily supports the operation of two gas-powered lithium-bromide water chiller-heater units and two gas boilers. Compared to conventional methods (conventional urban electricity generation + gas boiler heating + electric refrigeration and cooling), the actual gas consumption of this solution is only 34% of conventional technology. Electricity is mainly used in gas boilers, circulating pumps, water supply pumps, water treatment equipment, etc. In comparison to the conventional approach, the actual electricity consumption of the project is 13% lower. Additionally, the project leverages the local peak-valley electricity price difference and employs a 20,000 m3 energy storage tank to reduce operational costs. Therefore, this project achieves a 29% energy savings compared to the conventional approach.

ENVIRONMENT: In comparison to conventional urban power generation, individual gas boilers for heating, and separate electric refrigeration and cooling, the Combined Cooling, Heating, and Power (CCHP) system reduces total urban pollutant emissions. The use of natural gas as fuel aligns with Beijing's clean fuel policies. Natural gas is employed for power generation, with waste heat used for heating and cooling loads, reducing emissions from coal-fired municipal power plants. On-site power generation decreases losses from long-distance power transmission. The waste heat generated during power production is efficiently utilized, resulting in a higher overall energy utilization rate compared to thermal power plants. This project reduces CO2 emissions by 6225.44 tons, representing a 26% reduction compared to conventional energy supply methods.

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Wastewater for green district heating Odense, Denmark

Project Location	Odense, Denmark
Renewable/Clean Energy	☐Biomass ☐Geothermal ☐Solar Energy ☑Waste/Surplus Heat
Applied Technology	▪ Large-scale heat pump ▪ Wastewater utilization ▪ District heating

Fjernvarme Fyn's latest heat pump system, powered by treated wastewater at Ejby Moelle Renseanlæg in Odense, brings about greener district heating and a healthier water environment. These large electric heat pumps are now capable of meeting the annual heat demand of 5,000 households, equivalent to approximately 5% of Fjernvarme Fyn's annual heat production. Notably, this marks the largest electric heat pump system in Denmark based on treated wastewater.

This project represents a vital stride in Fjernvarme Fyn's journey toward environmentally friendly district heating. Among numerous other initiatives, this new large-scale heat pump system actively supports the phase-out of coal and other fossil fuels. Additionally, the project benefits the local ecosystem, as the treated wastewater imparts its excess heat to the district heating supply before returning to the nearby river, benefiting the aquatic life and microorganisms residing there.

TECHNOLOGY: The project is the result of a comprehensive analysis and collaborative planning effort between Fjernvarme Fyn and VandCenter Syd. It harnesses the heat-pumping capabilities to extract heat from a resource that may not have a high temperature. Treated wastewater serves as a dependable heat source, typically warmer than both air and seawater.

ENVIRONMENT: Denmark boasts a significant supply of renewable energy in its national grid, powering these large-scale heat pumps. By efficiently utilizing surplus heat, this project significantly contributes to environmental sustainability. The active heat pump system at Ejby Mølle reduces CO_2 emissions by an impressive 30,000 tons annually.

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Industrial waste heat for district heating Copenhagen, Denmark

Project Location	Copenhagen, Denmark
Renewable/Clean Energy	**☐Biomass ☐Geothermal ☐Solar Energy ☑Waste/Surplus Heat**
Applied Technology	▪ **Large-scale heat pump** ▪ **Surplus heat from production process** ▪ **Diverse energy and technology mix**

HOFOR (Greater Copenhagen Utility) serves approximately 670,000 customers in Copenhagen with district heating (DH) and aims to provide competitive and carbon-neutral DH services. Novozymes, a global leader in biological solutions, specializes in producing industrial enzymes and microorganisms.

Despite these considerations, the heat pump contributes to a more diversified energy mix in the DH system and lowers overall costs. Both HOFOR and Novozymes are highly satisfied with the project, and the heat pump is expected to operate for at least 20 years (estimated technical lifetime).

TECHNOLOGY: The collaboration between HOFOR and Novozymes led to the planning and installation of a 4 MW heat pump, which commenced operation at the end of 2020. This heat pump utilizes surplus heat generated during Novozymes' enzyme production process to supply district heating to around 6,000 local residents in Copenhagen. By doing so, the heat pump has reduced HOFOR's reliance on natural gas, oil, and biomass for DH production, contributing to a more diverse energy and technology mix. Additionally, it has reduced water and electricity consumption in Novozymes' cooling towers, as the heat pump provides both cooling for Novozymes and heating for HOFOR's DH network.

A recent optimization project has fine-tuned the heat pump's operation by considering hourly variations in electricity prices. This flexible and optimized approach has significantly lowered the electricity costs and enhanced the project's overall economic viability.

ECONOMY: The investment cost for the heat pump amounted to approximately DKK 35,000,000. At the time of the final investment decision (FID), the estimated simple payback period for the heat pump was 8 years.

ENVIRONMENT: The annual CO2 reduction is estimated to reach up to 2,000 tons per year. However, it's worth noting that the Greater Copenhagen DH system already relies on 85% carbon-neutral DH production. As a result, in addition to displacing natural gas- and oil-based DH production, the heat pump also partly substitutes biomass-based DH production, which is already carbon-neutral.

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Replacement of gas boiler for large-scale heat pump Støvring, Denmark

Project Location	Støvring , Denmark
Renewable/Clean Energy	☐Biomass ☐Geothermal ☐Solar Energy ☑Waste/Surplus Heat
Applied Technology	▪ Surplus heat from CHP ▪ Large-scale heat pump ▪ District Heating

The Støvring Combined Heat and Power (CHP) plant originally operated as a natural gas-fired CHP facility, utilizing both oil and coal as fuels. To increase the integration of renewable energy sources, reduce greenhouse gas (GHG) emissions, and ensure competitive heating prices for future consumers, the Støvring CHP plant made a strategic investment in a large-scale electric-powered air-to-water heat pump in 2020. This transition expanded the plant's role in the electricity markets, transforming it from a sole electricity producer to a dual-role player, producing and consuming electricity within relevant markets. The heat pump now covers approximately 80% of the heat demand in a typical year, equivalent to 64,500 MWh/year.

TECHNOLOGY: Key technical details include a 7.3 MW large-scale heat pump (electricity-driven, air-to-water) with a coefficient of performance (COP) ranging from a maximum of 3.5 to a minimum of 2.6. The annual heat production capacity stands at 64,500 MWh/year.

ECONOMY: The project involved an investment of approximately 42 million Danish kroner (kr), with estimated yearly savings of around 5 million kr. The payback period for the investment is approximately 5.36 years. Additionally, production costs witnessed a 48% reduction in 2020, and an anticipated 67% reduction in 2021:

Gas: 332 kr./MWh of heat

Heat pump: 171 kr./MWh of heat (2020) and 108 kr./MWh of heat (2021)"

ENVIRONMENT: The implementation of this project led to a significant reduction in GHG emissions, with CO_2 emissions decreasing from 21,674 tons CO_2eq/year to 4,324 tons CO_2eq/year.

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Future development of solar district heating Taars Denmark

Project Location	Taars, Denmark
Renewable/Clean Energy	☐Biomass ☐Geothermal ☑Solar Energy ☐Waste/Surplus Heat
Applied Technology	▪ Solar energy ▪ Thermal storage ▪ District Heating

In the envisioned smart cross-sector energy system of the future, integrating intelligent electricity, thermal, and gas grids will lead to greater synergy between solar thermal heat supply and other technologies. For instance, we'll witness enhanced coordination between electric heat pumps driven by wind power and the conversion of excess wind energy into heat (power-to-heat). The digitization of these systems offers opportunities to reduce the overall cost of decarbonizing district heating by optimizing operations and introducing innovative business models. Future developments are expected to prioritize the optimal utilization of existing technologies rather than focusing primarily on component development.

Large-scale solar thermal systems integrated into district energy systems can thrive within 4th generation district heating networks offering supply temperatures of 40–50 ˚C or even lower. Lower supply temperatures enhance collector efficiency and storage capacity while maximizing utilization.

TECHNOLOGY: In a groundbreaking pilot plant located in Taars, Denmark, which commenced operations in August 2015, a unique combination of flat plate solar collectors (FPCs) and parabolic trough solar collectors (PTCs) was implemented. The facility comprises 5,960 m2 of FPCs (half of which are single glazed without foil, and half are single-glazed with foil) alongside 4,039 m2 of PTCs connected in series. Each collector type operates within a temperature range that maximizes its efficiency (FPCs between 40 and 75 °C, PTCs between 75 and 95 °C). As renewable electricity sources like photovoltaic and wind power increasingly penetrate electricity grids, the imbalance between electricity supply and demand is expected to grow. To address this, long-term and short-term thermal storage solutions prove cost-effective, particularly considering the higher expense associated with electricity storage. Seasonal heat storage can serve both solar heat and excess electricity converted to heat, increasing the number of load cycles and reducing storage costs.

ECONOMY & ENVIRONMENT: Economic and environmental potential analyses of solar-assisted central heating plants in the EU residential sector indicate that a solar fraction exceeding 90% is attainable for many EU climate zones. Moreover, the long-term price stability of large-scale solar thermal systems, characterized by very low operation and maintenance costs, is an often overlooked advantage. While solar thermal heat supply has traditionally carried financial risks, adopting risk-minimization strategies can transform this perceived disadvantage into an asset. In energy systems with a high share of renewables, solar thermal heat supply will compete with other renewable technologies. In such contexts, the value of reducing CO2 emissions compared to fossil fuels becomes less critical and needs to be supplanted by other factors, such as alleviating the strain on limited renewable resources like biomass.

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IV. Sino-Danish Clean and Renewable Heating Cooperation Centre

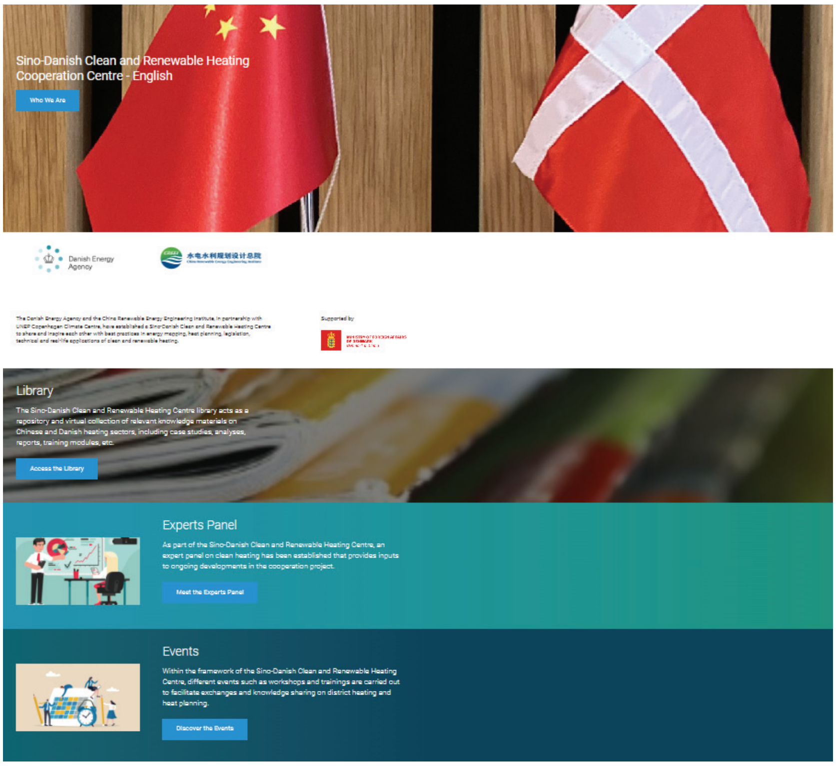
The Danish Energy Agency and the China Renewable Energy Engineering Institute, in partnership with UNEP Copenhagen Climate Centre, have established a Sino-Danish Clean and Renewable Heating Cooperation Centre to share and inspire each other with best practices in energy mapping, heat planning, legislation, technical and real-life applications of clean and renewable heating.

UNEP CCC is a collaborating center operating under an agreement between the Ministry of Foreign Affairs and the UN Environment and with over 30 years of leading international research and advisory work on climate, energy and sustainable development.

The Sino-Danish Clean and Renewable Heating Cooperation Centre is dedicated to facilitating a professional knowledge network, creating a foundation for cross-sectional exchange on clean and renewable district heating between regulatory organizations, research institutes, and business from Denmark and China.

Its virtual platform has been launched on March 1, 2023. The content on the platform is all provided bilingually provided in English and Mandarin. The main content for the platform includes:

- Presentations on various topics of energy planning, mapping, and specific technologies, benefits and outcomes and potential applications in China.
- Case studies for specific technologies applied in Denmark, and their potential applications in China.
- Project and Expert Panel introduction link: https://c2e2.unepccc.org/sdrhcc/



List of graphs

I. List of abbreviations

ATES	Aquifer Thermal Energy Storage
BTES	Borehole Thermal Energy Storage
CAPEX	Capital Expenditures
CHP	Combined Heat and Power
CHRs	Clean Heating Resources
COP	Coefficient of Performance
CREEI	China Renewable Energy Engineering Institute
DEA	Danish Energy Agency
DH	District Heating
DUR	Danish Utility Regulator
GHG	Greenhouse Gas
HOB	Heat Only boilers
HP	Heat Pump
ISH	Industrial Surplus Heat
LCOH	Levelized Cost of Heating
MEE	Ministry of Ecology and Environmental of P.R.C
MHRSS	Ministry of Human Resources and Social Security of P.R.C
MNR	Ministry of Natural Resources of P.R.C
MOF	Ministry of Finance of P.R.C
MOFCOM	Ministry of Commerce of P.R.C
MOHURD	Ministry of Housing and Urban-Rural Development of P.R.C

MOIIT	Ministry of Industry and Information Technology of P.R.C
MOJ	Ministry of Justice of P.R.C
MOST	Ministry of Science and Technology of P.R.C
MOT	Ministry of Transport of P.R.C
MPS	Ministry of Public Security of P.R.C
NBS	National Bureau of Statistics
NDRC	National Development and Reform Commission of P.R.C
NEA	National Energy Administration of P.R.C
PBOC	The People's Bank of China
P. R. C	People' Republic of China
PTES	Pit Thermal Energy Storage
SAT	State Taxation Administration of P.R.C
SAMR	State Administration for Market Regulation of P.R.C
SC	The State Council of P.R.C
SSC	Strategic Sector Cooperation
TTES	Tank Thermal Energy Storage
TWh	Terawatt hour (10^{12}Wh)

II. List of figures

III. List of tables