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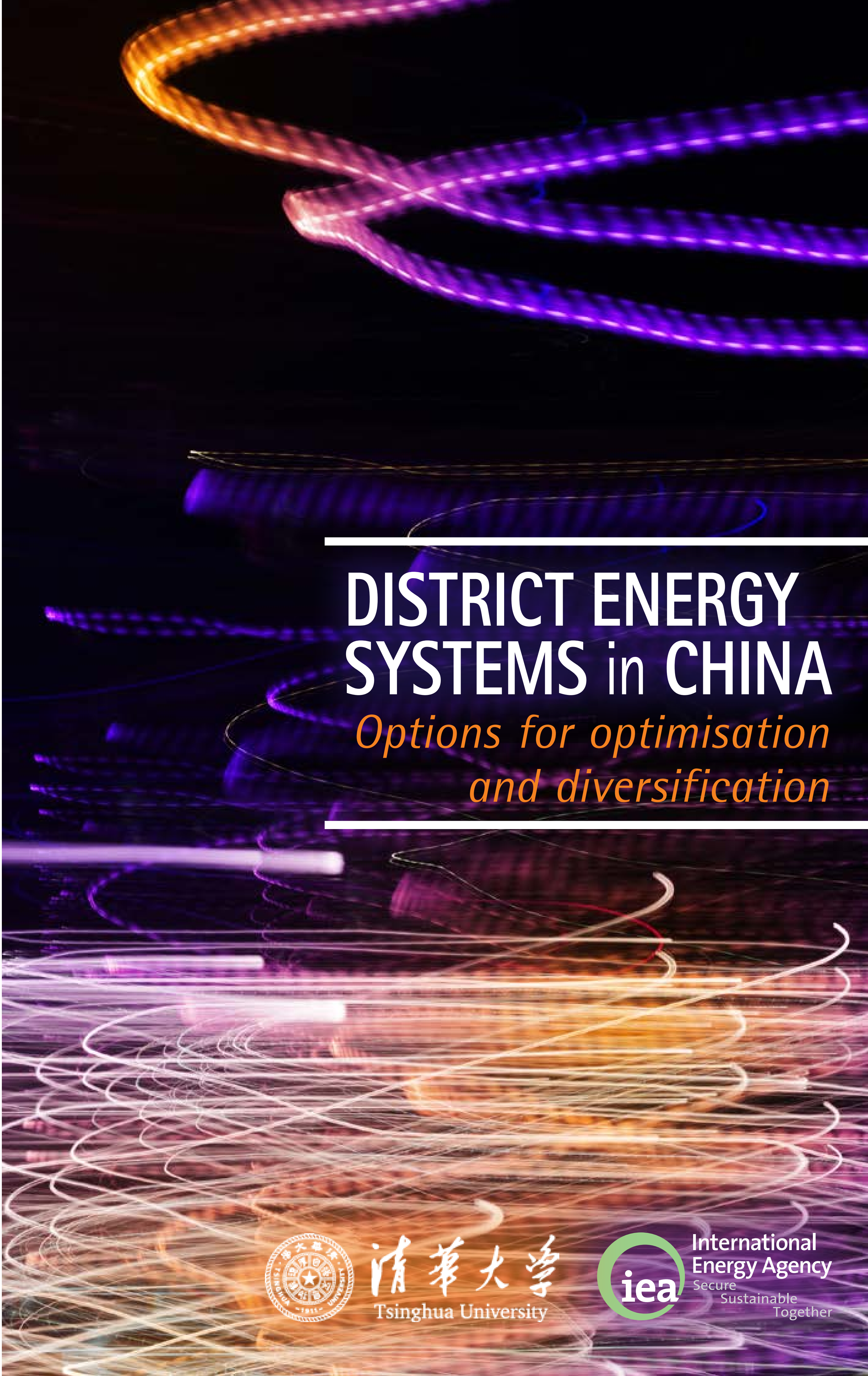

DISTRICT ENERGY SYSTEMS in CHINA

Options for optimisation and diversification

清華大学
Tsinghua University

International Energy Agency
Secure Sustainable Together

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INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA), an autonomous agency, was established in November 1974. Its primary mandate was – and is – two-fold: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply, and provide authoritative research and analysis on ways to ensure reliable, affordable and clean energy for its 29 member countries and beyond. The IEA carries out a comprehensive programme of energy co-operation among its member countries, each of which is obliged to hold oil stocks equivalent to 90 days of its net imports. The Agency's aims include the following objectives:

- Secure member countries' access to reliable and ample supplies of all forms of energy; in particular, through maintaining effective emergency response capabilities in case of oil supply disruptions.
- Promote sustainable energy policies that spur economic growth and environmental protection in a global context – particularly in terms of reducing greenhouse-gas emissions that contribute to climate change.
- Improve transparency of international markets through collection and analysis of energy data.
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The European Commission also participates in the work of the IEA.

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

The principal research activities within BERC include:

- Assessment of the current buildings status in China and strategic outlooks on buildings energy consumption and efficiency.
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BERC is involved in international exchange and co-operation projects, including its ongoing collaboration with the International Energy Agency. BERC is also responsible for the *Annual Report on China Building Energy Efficiency*, which has been published annually since 2007.

Foreword

International Energy Agency

The People's Republic of China (hereafter, "China") has the largest district energy system in the world, with more than 200 000 kilometres of networks providing heat to close to 9 billion square metres of building space, which is equivalent to more than one fourth of the total floor area of the United States. With China's rapid urbanisation and increasing demand for thermal comfort, energy use in heating and cooling systems is set to rise even higher over the coming decades, placing heavy pressure on energy supply and the environment.

Coal continues to be the predominant fuel for heat production, but a rapid switch to other fuels such as gas, geothermal or excess heat is under way. Unlocking the potential of cleaner district energy systems is key for China's urban development strategy. Modern district energy can provide reliable heating and cooling services while improving energy efficiency and reducing greenhouse gas emissions, serving as a flexible and efficient medium to transform the energy sector.

Within the context of China's urbanisation and policy framework, this report highlights cost-effective options and business models that can decarbonise and optimise district energy systems. Through clean energy measures, China can continue to make a transition away from coal and improve air quality.

The International Energy Agency (IEA) has more than 20 years of in-depth bilateral co-operation with China in a wide range of fields, including energy security, statistics, policy and analysis. China joined the IEA family as an Association country in 2015. A three-year work programme was agreed in February 2017, supported by the establishment of an IEA China Liaison office in Beijing. Most recently, in December 2017, I had the pleasure to meet with Mr. Zhang Gaoli, Vice Premier of the People's Republic of China, to discuss deepening IEA-China cooperation its cooperation during the country's economic and energy transition.

This publication benefited greatly from the strong relations that now exist between the IEA and China. With the support of the Tsinghua University Building Energy Research Center (BERC) and the National Development and Reform Commission (NDRC) of China, it builds on the IEA's expertise in clean district energy technologies.

China has entered a new era in which environmental considerations such as reducing air pollution and carbon dioxide emissions have gained great importance. More efficient and cleaner district energy can make a key contribution to mitigating climate change and air pollution, while offering numerous benefits to households and businesses alike in terms of cost and comfort.

During the IEA Ministerial meeting in November 2017, with attendance from China, participants recognised the major importance of heating and cooling in developing an economical, secure and sustainable energy sector. It is my hope that this publication will support these efforts, both in China and globally.

Dr. Fatih Birol

Executive Director

International Energy Agency

Foreword

Tsinghua University Building Energy Research Center

This IEA publication, District Energy Systems in China: Options for optimization and diversification is perfectly timed to appear just as China began to move towards cleaner winter heating. The dispersed large and small coal boilers in suburban area for space heating are one of the major sources of air pollution in the Northern part of China. Although the amount of coal burned by boilers is lower than the total coal used by power plants in this area, the contribution to PM2.5 emissions is at least 7 times higher than for power plants. To combat air pollution, China has implemented stringent measures to curb the use of coal from small and medium-sized boilers for residential and industrial use, prompting the switch to natural gas or electricity as a cleaner alternative. However, the high prices and limited supplies of natural gas and the high price of electricity have put policy makers in a dilemma.

What would be the sustainable and affordable options for China to replace the poor efficiency and heavy polluting coal boilers? This pioneering publication indicates options to improve air quality and decarbonise district energy system within the context of potential energy sources and local and regional synergies. Case studies included in this report also demonstrate how modern district energy system can use diverse energy sources and technologies to improve energy efficiency.

Tsinghua University and the International Energy Agency (IEA) have a long-standing relationship on cooperative activities related to energy issues. In 2015, Tsinghua University and the IEA signed a letter of intent to expand co-operation. This report on China's district energy system is an important concrete outcome of our ongoing co-operation.

Many cost-effective options are already available in the buildings sector that can reduce both energy consumption and air pollution. As indicated by this report, a clear policy framework and predictable market context are needed to support cost-effective diversification of heat sources, including renewables. Meanwhile, locally-based and tailored solutions are required to avoid unintended consequences of reform. I hope that this publication can be used as a tool to evaluate policies and programs in China.

Pr. Jiang Yi

Vice dean

School of Architecture, Tsinghua University

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Executive Summary

The People's Republic of China (hereafter, "China") has many reasons to pursue a more sustainable energy future. Energy resource scarcity and security are likely to be major incentives in coming decades to curtail energy demand growth. Air quality is another key influence on China's increasing commitment to restrict inefficient and polluting fossil fuel combustion, along with government policies to limit carbon dioxide (CO_2) and other greenhouse gas (GHG) emissions.

China's district heat network is the world's largest. In 2015, it consumed more energy than the entire United Kingdom. Coal still accounts for about 90% of the energy consumed for district heat production, and carbon emissions from district heat have increased by 30% since 2010. With enhanced conversion of energy and use of waste heat, more efficient district heating networks, including through cleaner, high-efficiency coal-fired co-generation, can better mitigate environmental impacts as compared to the dispersed coal boilers used in suburb areas for space heating, which are one of the major sources of the air pollution emissions. While progress is being made, the total impact of energy use and emissions from district heating and even district cooling – on the Chinese economy, on local air quality and health, and on the overall well-being of China's population – is nevertheless significant.

China has great opportunities of lowering the environmental footprint of its district energy system. While the country has pursued assertive public policy decisions in recent years, it is essential to elevate cleaner, energy-efficient district energy as a priority for action so that policy development and implementation can be achieved quickly.

China has already made significant progress towards many of the recommendations offered in this report. However, further action is needed to pursue key policies and technological developments that will improve the energy intensity and emissions footprint of district heating and cooling systems. There is a window of opportunity for action, given the large expected growth of district energy networks in the coming two decades, and in some cases policy could take significant time to implement. Key findings in the report are as follows:

- China had the world's largest district energy system in 2015, covering 192 721 kilometres (km) of hot water networks and 11 692 km of steam networks.
- District heat generation in China consumed more than 185 million tonnes of coal-equivalent (Mtce) in 2015, higher than national energy consumption of United Kingdom.
- The district heat network in China currently covers around 8.5 billion square metres (m^2) of buildings floor area, having nearly tripled since 2005, and it continues to expand.
- Total buildings floor area covered by the district heating network in Northern China tripled over the last decade, representing nearly all the floor area growth in the northern urban heating (NUH) area since 2005.
- As urbanisation continues, floor area in China is projected to increase another 40% by 2050, reaching more than 80 billion m^2, from 57 billion m^2 today. Floor area covered by district heating in the NUH region is growing much faster than the urban population, but there are important disparities among provinces.
- The Chinese government attaches great importance to the development of cleaner and more efficient district energy systems.
- Severe air pollution, particularly in the densely populated Beijing, Tianjin and Hebei regions, is already prompting a switch from coal to gas in some cities.

- China has significant potential to improve the overall efficiency of its district heating network by recovering excess heat.
- Energy efficiency measures – ranging from continued improvements in new building construction and deep energy renovations of existing buildings to greater deployment of heat metering and better hydronic balancing of heat distribution – can play a key role in improving the intensity of heating and cooling demand in buildings.
- China can use its abundant renewable resources, especially geothermal power and biomass, to diversify supply and reduce coal use in district heating (and cooling). In 2015, renewables supplied 28% of district heat in the European Union but only 1% in China.
- Optimising and diversifying district energy requires locally based and tailored solutions, and business models with fair prices and appropriate government regulatory environment.

This report analyses the ways to decarbonise, optimise and diversify district energy systems in the Chinese context. It is intended to provide policy makers and district energy stakeholders with the information they need to carry out improvements in China's district heating system. If implemented correctly, the transition towards more efficient, sustainable district energy in China could simultaneously support economic growth, reduce total energy consumption, cut emissions and improve environmental conditions.

Introduction

The potential for cleaner and expanded district energy systems in the People's Republic of China (hereafter, "China") is huge. Clean, energy-efficient district energy can be a key way to mitigate climate change and air pollution, while improving costs and comfort for households and businesses alike.

District energy is a proven solution for delivering heating (including hot water) and cooling services. Traditionally referred to as district heating and cooling (DHC), modern district energy is an inherently diverse system that connects multiple thermal energy users through a network of insulated pipes to efficient or renewable energy sources, such as co-generation (often referred to as combined heat and power, or CHP), industrial excess heat (IEH), municipal waste, biofuels, geothermal heat, and solar and wind energy. Because they can use diverse energy sources, including locally available resources, district energy systems are flexible, allowing for economies of scale as well as reliable heating and cooling services, without depending on a single supply source.

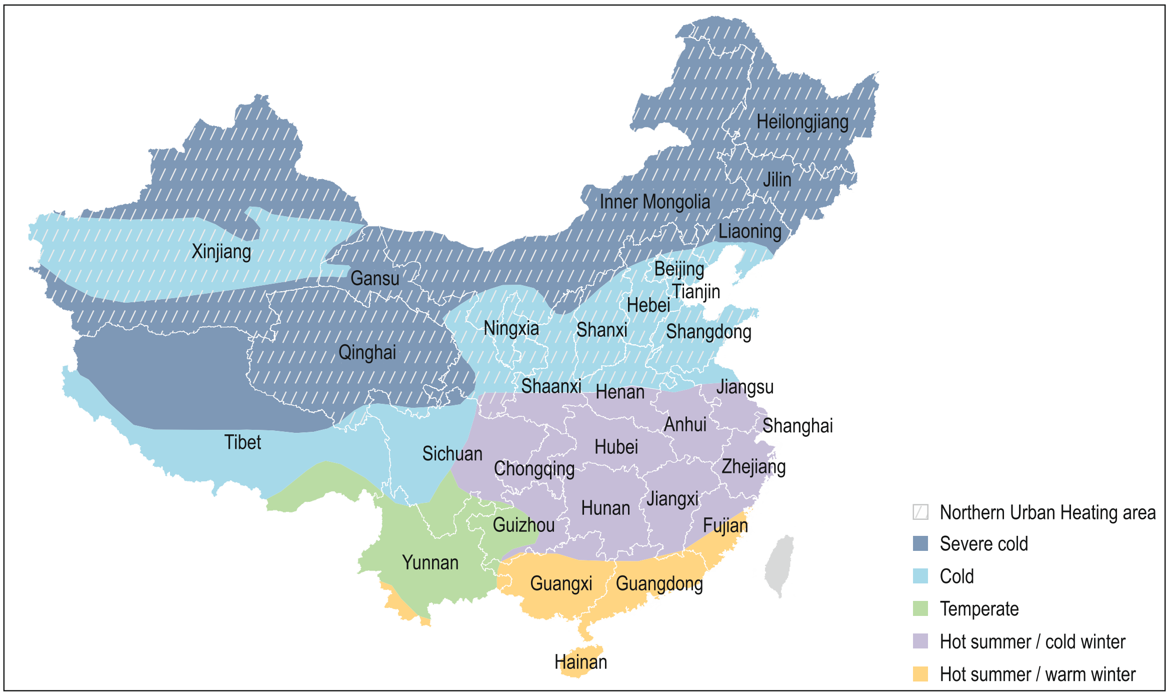
District energy already plays a critical role in many parts of China, especially for heating. The combination of fast urbanisation and increasing standards of living in China has contributed to sustained rapid growth of the built environment, and hence of heating and cooling needs. In the northern cities of China, heat is largely supplied by district heating networks for residential use, while cooling systems throughout the country are mostly decentralised, typically using mini-split air conditioners. Some district cooling networks already exist, with one of the largest systems in Guangzhou in the southern belt of China, covering nearly 5 million m^2.

The total buildings floor area of China is currently around 57 billion m^2, including around 13 billion m^2 in the northern urban heating (NUH) area (Map 1) (BERC, 2017). Around 6.7 billion m^2 in the NUH region are covered by the central district heating network, with another estimated 1.8 billion m^2 covered by smaller county and village networks (MOHURD, 2015). As urbanisation continues, total floor area in China is projected to increase another 40% by 2050, reaching more than 80 billion m^2 (IEA, 2017a). Heating and cooling of buildings (excluding sanitary hot water) are expected to continue accounting for around 40% of buildings energy demand, representing roughly 9 exajoules (EJ) in final energy demand in 2050 in the IEA Reference Technology Scenario (RTS), or around 310 Mtce.

Final energy for space heating demand in China is expected to increase by about 15% by 2030 in the RTS, then gradually decrease to 2015 levels by 2050, given China's considerable progress on implementing and enforcing building energy codes and improving the efficiency of existing buildings and the district heat network. While this does not represent a significant increase in energy demand, space heating still accounts for around 35% of total final energy consumption in buildings today, or as much as 40% of final energy demand when traditional use of biomass is excluded. Significant untapped potential remains to improve the energy efficiency of district heating in China. The primary energy consumption of heating in NUH buildings alone (around 185 Mtce, roughly 5.4 EJ) is more than 4% of China's total primary energy supply.

In contrast with space heating, space cooling energy demand in buildings could as much as triple by 2050, as growing incomes and demand for thermal comfort increase, especially in southern China and in the hot summer and cold winter (HSCW) zone. Space cooling demand in buildings has already grown by around 9% per year since 2010, and the vast majority of mini-split air conditioners sold today are far less efficient than best-performing models available in China (IEA, 2017b). District cooling is one feasible energy solution and could provide flexible cooling service delivery to buildings. However, district cooling solutions would need to be planned and structured appropriately within the context of the local energy system.

Map 1 • China's climate zones for energy consumption and the Northern Urban Heating area



This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

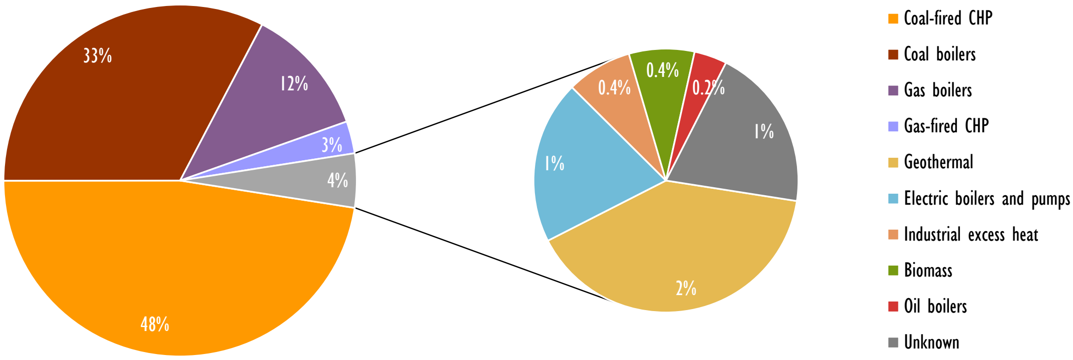
Source: adapted from GB (1993), *Thermal design code for civil building* (GB 50176-93), China.

Key message • China's climate zones have considerable impact on building energy demand, particularly for space heating and cooling. Modern, efficient district energy can help meet that demand, taking advantage of numerous energy opportunities and synergies for cleaner energy supply.

The Chinese government attaches great importance to developing cleaner and more efficient district energy systems as part of its fight against air pollution. In March 2014, Premier Li Keqiang declared a "war on pollution" during a major speech. In June 2014, President Xi Jinping called for an "energy revolution" to reform energy production, consumption and innovation, while moving faster to modernise outdated energy regulations and further promote international co-operation. In December 2016, he also highlighted the importance of district heating for the northern areas. During his report to the 19th National Congress of the Communist Party of China in October 2017, President Xi also pledged to build a "beautiful China" with a clean environment. The concept has been incorporated into the two-stage development plan for building a "great modern socialist country".

There are several challenges to improving China's district energy system, including its current dependence on fossil fuels. In 2016, 33% of total floor area was covered by coal-fired boilers for commercial heat production, and co-generation (mostly coal) accounted for 51%. Gas-fired boilers accounted for another 12%, with the remaining coming from various sources (BERC, 2017) (Figure 1). Overheating and network losses (3-5% of the total) represent around 20% of total heat production (BERC, 2017). In 2015, pollutant emissions from coal-fired district heating reached 1,074 tons for SO2, 652 tons for NOX, and 279 tons for PM 2.5, representing 5%, 3% and 4% of total energy related pollutants emissions respectively (IEA, 2016a). These shares are calculated nationwide on an annual basis, hence much higher in winter time in the NUH. Heat reforms since the early 2000s have had mixed results for building performance (in heating demand per m2). While China's buildings renovation programme has been successful, with around 1 billion m2 renovated in Northern China as of 2015 (Liang et al., 2015), the heat metering programme has been less successful, with resistance to meter use in some areas.

Figure 1 • Central heating fuel mix in China (2016, by floor area)



Sources: Building Energy Research Centre of Tsinghua University, 2017.

Key message • With the phasing out of coal-fired boilers, China's central heating fuel mix is changing rapidly.

While progress is being made, there is still potential to improve the energy intensity of existing and forthcoming Chinese district energy systems. Better insulation and temperature control of buildings (including retrofitting existing buildings) can limit demand. Expanded use of heat meters can improve energy intensities by increasing consumer awareness of heat consumption and eventually enabling better demand response (e.g. through deployment of smart meters and thermostats). On the supply side, the efficiency and carbon intensity of heat production can still be improved, as can efficiency of delivery, for example through retrofitting heating networks. Hydronic balancing (e.g. using differential pressure controls to optimise heat distribution) can also deliver significant energy savings while ensuring more accurate temperatures.

In the context of air pollution and climate change, more stringent policies and additional targets have been put in place and highlight the need to decarbonise and clean China's heat sector. Local authorities in China are now also assessed based on their achievement of environmental targets. Improving district heat systems is therefore a high priority for action.

This report analyses the ways to decarbonise, optimise and diversify district energy systems in the Chinese context. From technology, policy and market perspectives, it analyses the options for improving district heating networks in Northern China as well as the potential for district energy networks elsewhere in China where applicable. Prepared in collaboration with Tsinghua University BERC and with contributions from the IEA China Liaison office, the report suggests ways of choosing tailored solutions suitable for Chinese cities, including examples of best practices and technologies for system modernisation. It looks at the role, benefits and challenges of improving energy efficiency and using more excess heat and renewables, as well as prospects for certain densely populated rural areas.

The report is divided into four main sections:

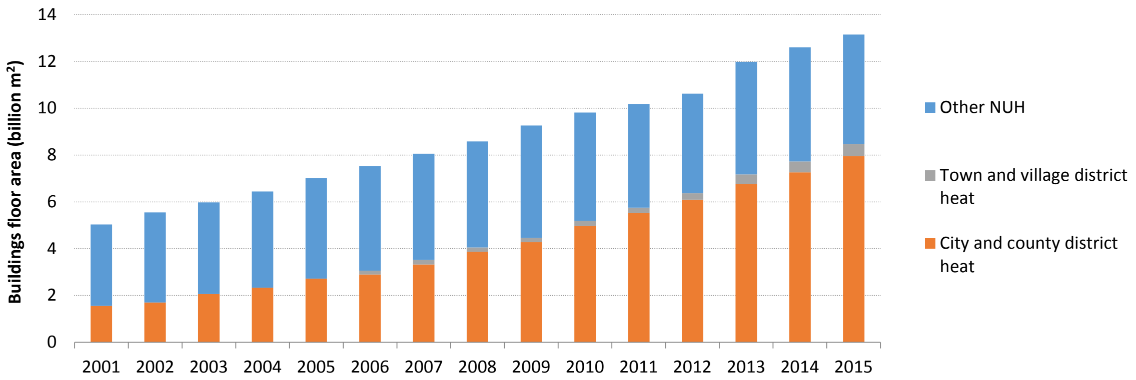
- assessment of the current situation and policy framework
- opportunities and solutions for cleaner district energy systems
- business models and pricing options
- policy recommendations in the Chinese context.

A notable selection of energy technologies and policies are critical to reducing energy consumption, emissions and other negative impacts of China's current district energy system. This report focuses on policies and priorities that can help achieve the transition towards more efficient, sustainable district energy in China while also meeting China's socio-economic objectives, including continued economic growth and improved living conditions.

District energy systems play a key role in China

China hosts the world's largest and fastest-growing district energy system (EHP, 2017; EHP, 2015). It principally consists of numerous district heating networks in northern China, which provide space heating in urban areas in winter.[1] These cover about two-thirds of floor area in the northern urban heating (NUH) areas (approximately 8.5 billion m^2) and around one-quarter of total urban floor area in China (BERC, 2016; IEA-BERC, 2015). In 2005, the district network only heated around 40% of total NUH buildings floor area. Since then, nearly 95% of NUH floor area growth has been covered by district heating additions (Figure 2).

Figure 2 • Space heating floor area coverage by district heat networks in northern urban China



Note: Other NUH represents heated floor area in NUH areas that are not connected to the district heating network. In total, NUH floor area represents around one-quarter of buildings floor area in China and nearly 40% of urban floor area.

Sources: MOHURD (2015), Statistical Yearbook of Urban and Rural Construction (城乡建设统计年鉴), China; BERC (2017), China Building Energy Use 2017, Tsinghua University, Beijing.

Key message • Total buildings floor area covered by the district heating network in northern China tripled over the last decade, representing nearly all the floor area growth in NUH China since 2005.

In 2015, China's district energy system covered 192 721 km of hot water networks and 11 692 km of steam networks. This represents around 650 gigawatts of thermal heat capacity (GW_{th}), of which 14% was for steam production. Around 49% of district heat produced in cities used co-generation, which produced around 2 012 terawatt-hours (TWh) of heat in 2015. In total, district heat produced in China amounted to 4 092 TWh of heat in 2015 (MOHURD, 2015).

District cooling, while far less common than district heat, also covers a sizeable area of buildings in southern China. Two large networks in Guangzhou city represent around 130 km of pipeline and 6 million m^2 of cooled floor area, making up one of the world's largest district cooling networks.[2] Additional district cooling or combined district heating and cooling (DHC) networks are being considered in other cities in China's southern region and hot summer, cold winter (HSCW) region.

[1] District heat in China seldom covers sanitised hot water demand.

[2] Statistics on China's district cooling networks are not complete, although studies on certain networks, the two largest networks in Guangzhou by Tsinghua BERC, help to give a better sense of the current network situation in China. As a comparison, the Enwave district cooling system in Chicago, United States, covers around 4.2 million m^2 across around 12 km of trench length (IDEA, 2012). The recently opened district cooling network in Singapore covers around 1.25 million m^2 in a network with 5 km of piping (Othman, 2016).

Rapid urbanisation fuels district energy growth

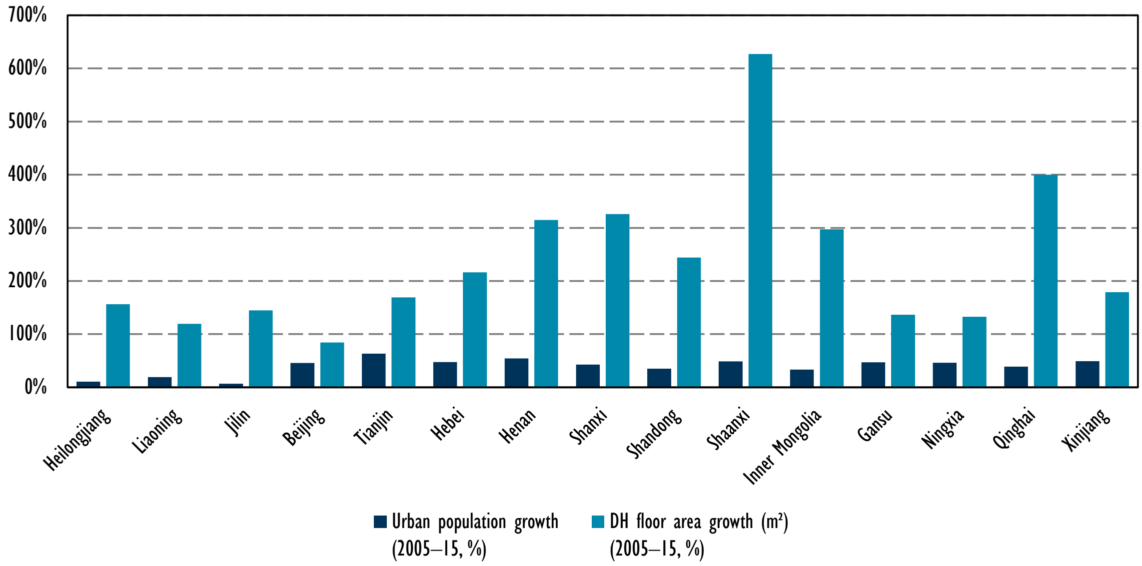
District energy growth in China over the last two decades has been spurred by China's rapid urbanisation, especially in northern urban regions. Since 2000, China's urban population has grown by 310 million people, of whom 125 million migrated to urban areas in the NUH area, including the large urban areas of Beijing, Tianjin, Hebei, Shanxi, Liaoning, Jilin, Heilongjiang, Shandong, Henan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang. More than 40% of China's urban population, or roughly 322 million people, live in the NUH area. Of the 295 cities that have more than 200 000 inhabitants, 132 are in the colder NUH areas.

Rapid urbanisation has particularly boosted energy consumption for space heating in the colder NUH areas. In these areas, heating periods can last from October or November until March or April, as long as six months in some regions. For instance, Beijing's heating season is typically from 15 November to 15 March. The coldest temperatures during the winter heating season are often below -10°C in the severe cold zone and below 0°C to 5°C in the cold zone. As a result, indoor heating is required by law in the two coldest northern zones, in contrast with the warmer southern and HSCW zones.

Urbanisation favours centralised district energy systems

Urbanisation and the parallel rise of China's middle class have stimulated demand for higher living standards. More and more people expect not only greater floor area per person but also improved thermal comfort – higher room temperatures during winter and lower temperatures during summer. Average floor area per person in the NUH region (including public and commercial space) nearly doubled from 2000 to 2015, reaching around 41 m^2. At the same time, the average number of people per urban household decreased from around 3.1 to nearly 2.8 (BERC, 2017). As a result, district-heated floor area in the NUH region expanded at more than twice the rate of urban population growth. In some NUH cities, floor area covered by district heat grew even faster (Figure 3).

Figure 3 • Urban population growth and district heat floor area growth, 2005–15



Source: National Bureau of Statistics, 2017.

Key message • Floor area covered by district heating in the northern region is growing much faster than urban population, but disparities among provinces are marked.

Rising purchasing power in cities has also fuelled demand for thermal comfort. Average indoor temperatures during winter tend to be 18°C to 22.5°C in urban areas but below 18°C in rural areas (Gong and Werner, 2014). Cooling demand, typically in urban buildings, has also increased, growing at an estimated 9% per year since 2010 (IEA, 2017a). Typically, cooling is met with individual, room-sized air conditioning units (e.g. mini-splits), although there are several district cooling networks.

By 2022, the upper middle class could account for 54% of urban households and the mass middle class 22% (Barton et al., 2013). While the middle class was previously concentrated in coastal megacities, prosperity is rising in smaller cities, particularly in the colder northern and western regions. This will stimulate additional growth in demand for heating services in buildings, along with greater cooling demand across all of China, particularly as expectations of thermal comfort grow in urban areas.

Since the 1950s, the growth of district energy networks in China has been spurred by government investments in district heat. However, district heat in NUH areas has also made technical and economic sense, as China's high urban densities – of population, buildings and energy demand – enable more efficient heating using centralised heat production and distribution. District heating has also proved to be a flexible energy source, allowing for better planning and control of heat distribution in cities, while taking advantage of technology choices that may not be possible at the individual building scale, such as co-generation and industrial excess heat (IEH) recovery.

While many older NUH buildings, particularly those built before 2000, had poorly performing building envelopes, new buildings that are more efficient have been built at a high rate, especially since the mid-2000s, improving the overall thermal performance of NUH buildings (IEA-BERC, 2015). The intensity of heat demand in NUH buildings has also been decreased by heating reforms introduced in the 2000s – including the building renovation programme under which more than 710 million m^2 were modernised in northern China between 2011 and 2014 – and the expanding heat meter market. Nearly 32 million meters had been installed in northern China by the end of 2015 (RIC, 2016). This progress offers important opportunities throughout China's expansive NUH network to further improve the efficiency of heat supply and to move towards optimised and advanced district heating.

Integrated energy and urban/regional planning could boost district energy

Urbanisation will continue to increase demand for district energy over the coming decade as an expanding, more prosperous population stimulates floor area growth. Buildings sector floor area in China could reach more than 72 billion m^2 over the next 15 years, with NUH floor area increasing by as much as 55% between 2015 and 2030, to reach 20 billion m^2 (Table 1) (IEA, 2017a; BERC, 2016).

Table 1 • Buildings sector floor area activity data in China and outlooks to 2030 (billion m^2)

	2015	2030	
		BERC	IEA
Total	57.3	72.0	74.1
Urban	33.5	54.1	55.4
NUH	*13.2*	*20.0*	--
Rural	23.8	17.9	18.7

Sources: BERC (2016), *China Building Energy Use* 2016, Tsinghua University, Beijing; IEA (2017a), *Energy Technology Perspectives 2017: Catalysing Energy Technology Transformations*, OECD/IEA, Paris.

Key message • Urbanisation will stimulate floor area growth and district energy demand to 2030.

While new urban buildings in China are significantly more energy-efficient, heating intensity improvements in the NUH region (in terms of final energy demand per m^2) are still unlikely to keep up with the 3% average annual floor area growth expected to 2030. In the IEA Reference Technology Scenario (RTS), district heat demand to 2030 increases by around 10%, to 48 Mtce (1.4 EJ) in final energy demand, which would place greater onus on the NUH district heat network to meet energy conservation and local air pollution targets (IEA, 2017a). To stabilise or even reduce total final district heat demand in buildings (e.g. as described in the IEA 2°C Scenario [2DS; IEA, 2017a]), further effort would be needed to move the NUH buildings stock towards high efficiency levels within a more integrated district energy system. This would include enhancing building envelope performance (e.g. deep energy renovations for older buildings and high-performance new building construction), increasing heating installation efficiency through proper systems balancing, and ensuring appropriate energy planning.

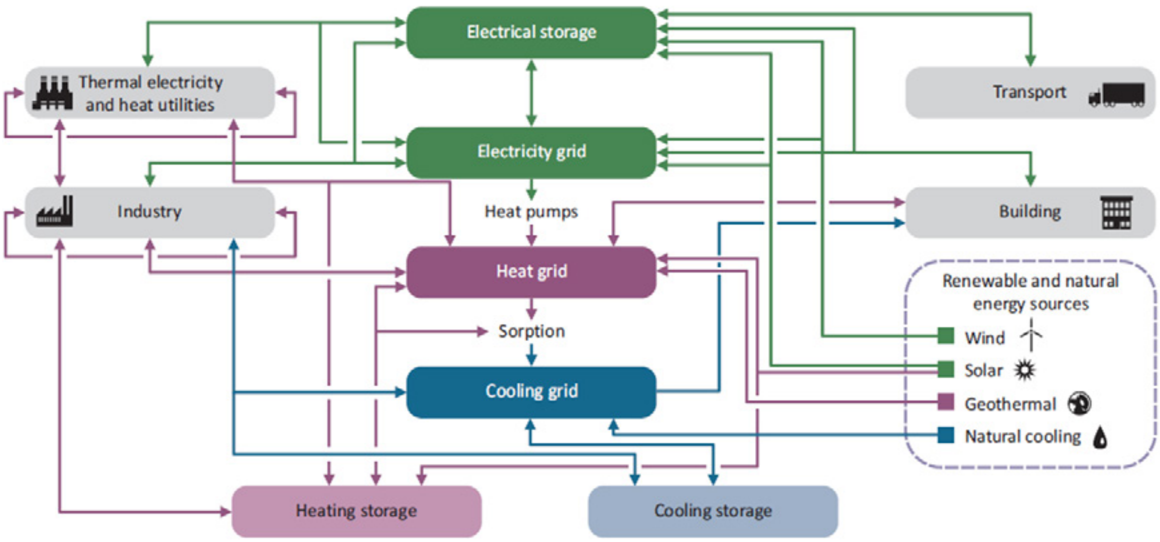
During a key meeting on urbanisation chaired by President XI Jinping in December 2013 following the 3rd Plenum of the Chinese Communist Party, the Chinese government laid out the main orientations for China's urban development. This plan to rebalance urban growth included a new urban planning and land management policy that favours the development of small- and medium-sized cities (less than 1 million inhabitants) while limiting the growth of large (1 million to 5 million) and very large cities (more than 5 million). The plan also seeks to limit urban sprawl and increase densification of cities (Xinhua, 2013).

This new urban development strategy is likely to expand district energy systems in smaller urban areas. Historically, centralised district heat networks have been promoted in large cities and counties, while biomass and heat pumps have been favoured in smaller urban areas and rural parts of the severe cold and cold zones. However, smaller district heating systems have started to appear in less populated towns and villages (within the small- to medium-sized city categories). Since 2006, floor area covered by district heat in NUH towns and villages grew by more than 350 million m^2, which is as fast as growth in city and county networks during the same period, despite the 15-fold difference in total network size.

District heating networks in China could be dramatically improved by moving towards better-planned urban areas with improved densities and greater distributed (i.e. decentralised) energy potential – including updating and improving existing NUH district heating networks. Recent efforts, including the Warming Programme by Waste Heat issued in 2015 by the National Development and Reform Commission (NDRC), are positive steps towards identifying appropriate ways to improve district energy systems in China. This includes mapping of heat demand relative to potential heat supply, such as the IEH study in Hebei province by Tsinghua University, which could be used to develop tailored local or regional plans to improve district energy systems.

Beyond identifying potential energy sources for meeting heating and cooling demand, urban and/or regional energy planning and development strategies should identify the policies and market mechanisms needed to achieve that potential. This will require co-ordination among the appropriate buildings actors, planning authorities and energy stakeholders (e.g. industrial heat providers) to support the cost-effective and energy-efficient development of integrated energy systems in urban areas (Box 1). Urban/regional planning and policy strategies would also need to reinforce the optimisation and economic feasibility of flexible energy systems, which may be complex and involve multiple actors. This includes addressing existing barriers or disincentives (e.g. market conditions that do not favour sale of excess industrial heat).

Figure 4 • Interconnections and potential energy synergies within an integrated energy system



Source: IEA (2014), *Linking Heat and Electricity Systems: Co-generation and District Heating and Cooling Solutions for a Clean Energy Future*, OECD/IEA, Paris.

Key message • Synergies across electricity and thermal energy systems offer numerous opportunities for deeper integration but require appropriate planning and policy frameworks.

Box 1 • A district heating assessment tool for local planners

The Danish Energy Agency (DEA) recently launched a district heating assessment tool (DHAT) that local planners can use to estimate the economic feasibility of district heating solutions, employing technical data and applying adjustable price projections (DEA, 2017). The DHAT will be applied in the "Sino-Danish Pilot Project on district heating and energy efficiency improvements in China", which has been signed by the DEA, the National Energy Conservation Center (NECC), the Development and Reform Commission of Shaanxi province and the government of Tongchuan in Shaanxi province, near Xi'an. The pilot project seeks to demonstrate potentials to increase energy efficiency in district heat and assess potential reductions in pollution from these measures. One critical focus of the pilot project will be to address the use of excess heat from industrial production and the challenges related to implementing IEH.

District energy systems are expected to expand

China's rapid urban development and continued prioritisation of district heating, particularly over individual use of coal boilers in urban areas, mean that district energy networks will grow larger in the coming decade. While there is no official target for floor area covered by district heating, estimates by Tsinghua University BERC suggest that it could reach as much as 20 billion m^2 by 2030. District cooling networks, while less common at a city scale, may also grow considerably in denser building developments such as business parks and university campuses.

Analysis of NUH provincial district heating data for city networks suggests that China is on track to reach these BERC estimates by 2030. By 2020, urban populations within the NUH region could increase by 35 million or more (relative to urbanisation targets). If network density (in terms of m^2 per urban dweller) were to remain the same, then district heat networks in the NUH region are likely to increase to nearly 7.3 billion m^2 (or roughly a 10% increase) by 2020 (Table 2). If network density were to increase simultaneously, peaking for instance around 30 m^2 per urban inhabitant as in Beijing and Tianjin provinces, then the district heat network could increase to almost 13 billion m^2 by 2020, or nearly twice the floor area coverage in 2015.

Those potential growth scenarios, while not definite forecasts, are consistent with historical trends, in which the NUH city heat network grew on average by 10% per year since 2005. County networks (which include growth in suburban areas outside the large prefecture-level cities) have grown on average by 20% per year since 2005, although this rate has slowed to roughly 11% per year since 2013, similar to city-level network growth rates. When all networks are taken into account, it appears likely that the NUH district heating networks (including city, county, town and village) could collectively increase by as much as 13.5 billion m^2 by 2020, nearly 60% greater than in 2015.

Table 2 • Existing and potential future district heat floor area coverage in key NUH regions

	2015			2020		
	Urban inhabitants (millions)	Urbanisation rate (%)	District heat network (million m^2)	Target urbanisation (%)	District heat network with target population (million m^2)	District heat network with peak density (million m^2)
Heilongjiang	22.4	59%	625	63%	667	847
Liaoning	29.5	67%	1,045	72%	1 123	1 123
Jilin	15.2	55%	480	60%	524	588
Beijing	18.8	86%	585	86%	585	664
Tianjin	12.8	83%	377	84%	382	458
Hebei	38.1	51%	588	60%	692	1 587
Henan	44.4	47%	224	56%	267	1 873
Shanxi	20.2	55%	541	60%	590	779
Shandong	56.1	57%	902	62%	981	2 162
Shaanxi	20.5	54%	240	62%	276	831
Inner Mongolia	15.1	60%	449	65%	486	581
Gansu	11.2	43%	161	50%	187	462
Ningxia	3.7	55%	100	60%	109	143
Qinghai	3.0	50%	5	60%	6	126
Xinjiang	11.2	47%	307	58%	379	487
NUH	**322.2**	**57%**	**6,629**	**64%**	**7 254**	**12 710**

Source: National Bureau of Statistics, 2017.

Key message • While there are no official targets for district heating coverage, the NUH district heating network is still likely to continue growing, consistent with historical trends.

Heat demand will continue to increase

The average space heating intensity (in terms of final energy consumption per m^2) of buildings connected to the district heat network in northern China was around 130 kilowatt-hours (kWh) per m^2 in 2013. That energy intensity can vary considerably, depending on building age, design and occupant behaviour. For instance, the average performance of city network buildings (typically dense, high-rise, multi-family units) is about 15% better than county network buildings (often less dense, low-to mid-rise buildings with greater thermal exposure per m^2).

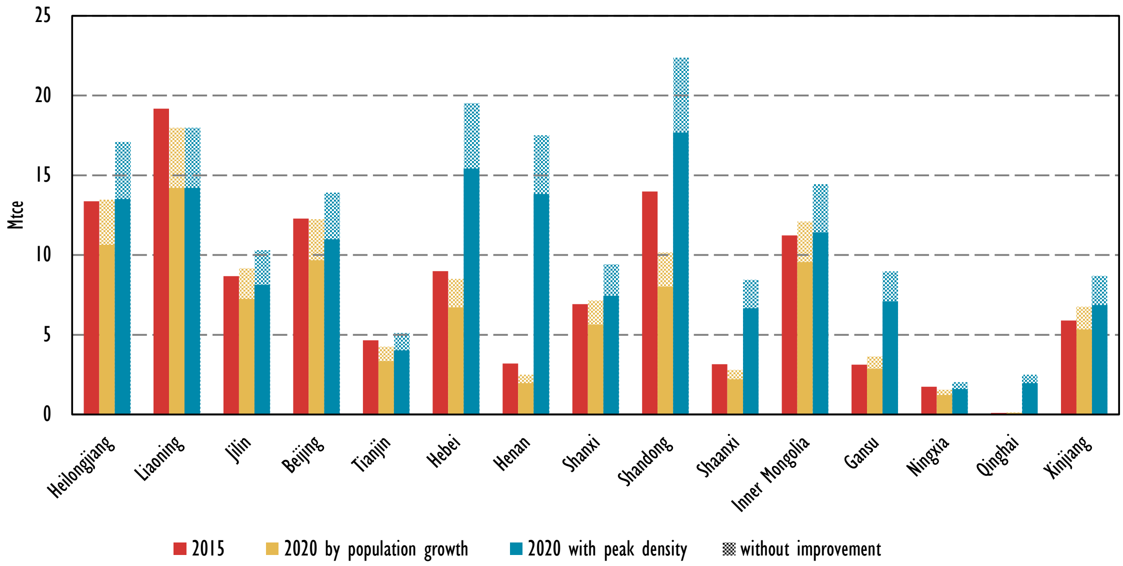
District heating energy intensities also vary considerably relative to the average heating degree-days (HDD) for the provinces. For instance, the average energy intensity per person per HDD in Heilongjiang and Jilin is around 1.0 kWh, while in Shanxi and Shandong it is closer to 0.5 kWh. Considered from a floor area perspective, Shanxi's district heating energy intensity is actually similar to that of Heilongjiang and Jilin (at around 0.033 kWh/m^2/HDD), while Shandong's energy intensity is nearly 60% more intense (0.050 kWh/m^2/HDD).

Several factors, from building type and performance to perceived thermal comfort and household purchasing power, can influence the overall energy intensity of district heating in NUH buildings. Aggregated statistics do not give an accurate picture of building energy performance and district heating energy intensity, but estimates show that the average energy intensity of district energy networks (in terms of delivered energy per m^2) improved by roughly 4% per year since 2005.

While overall energy consumption per unit of floor area has decreased over the past decade, the substantial growth in total floor area (roughly 11% per year since 2005) has continued to increase heat demand in absolute terms. This is likely to be the case through to 2030: the IEA estimates in the RTS that district heat demand will increase by another 10% by 2020 and an additional 5% beyond that by 2030 (IEA, 2017a).

In the principal city networks in the NUH region (Table 2), district heating demand could increase by as much as 50% by 2020, against the backdrop of expected population growth and potential densification of local district heating networks in terms of total coverage (in m^2) per person (Figure 5). This scenario is unlikely, however, given historical improvement rates in the average district heating energy consumption per m^2 in the NUH networks. If historical improvement rates were to continue to 2020, district heating energy consumption could stabilise relative to expected urban population growth. At the same time, even if building performance were to improve, total district heating energy demand could still increase by around 20% to 25% if network densities were to reach 30 m^2 per urban inhabitant, the current level in Beijing.

Figure 5 • NUH energy consumption (city networks) in 2015 and potential demand growth in 2020



Notes: Population growth represents urbanisation targets by 2020 at the provincial level and does not include any further densification of the district heating networks beyond the urban population increases. Peak densities represent district energy demand growth relative to urban population growth with additional densification of the district heat networks (to roughly 30 m^2 per person). The improvement scenarios illustrate the influence of continued building energy performance gains of roughly 4% per year to 2020.

Key message • District heating energy demand could increase considerably across some NUH provinces, depending on population growth and increased network densification strategies.

Differences between the principal city networks (not accounting for the rapidly growing county, town and village networks) give a useful indication of potential implications of network densification in some NUH provinces. In some of the coldest provinces with high network densities (e.g. Heilongjiang, Liaoning, Jilin and Beijing) significant district growth in heating energy demand is unlikely, given their existing high network densities and high level of building connectivity to the district heat network. In other provinces, such as Hebei, Henan and Shandong, district heating energy demand could increase considerably, depending on planning and policy strategies to increase district heating connections and densities.

As district heating in northern urban China is predominantly fuelled by coal, demand growth could place heavy pressure on energy supply chains and the environment. Without assertive efforts to improve the energy intensity of building heat demand alongside improved and cleaner heat generation, total primary energy consumption for heating in northern China could reach 250 Mtce (7.3 EJ) in 2030 (BERC, 2015), or roughly 35% higher than in 2015. This is far from BERC's proposed target of around 140 Mtce (4.1 EJ) (BERC, 2016), which takes into account China's objectives to limit total energy consumption by 2030 as per the 2016 *Strategy of Energy Production and Consumption Revolution* (NDRC, 2016a).

Demand for cooling is growing rapidly

Urbanisation and rising expectations of thermal comfort have both boosted space cooling demand in China over the last decade. Since 2005, space cooling energy consumption in China increased nearly threefold, reaching an estimated 30 Mtce (0.9 EJ) in 2015, or more than all the electricity consumption in Australia and New Zealand that year (IEA, 2017a). That demand growth – nearly 10% average annual growth in cooling energy consumption per person – paralleled 8.5% average annual growth in gross national income (GNI) per person in China since 2005.

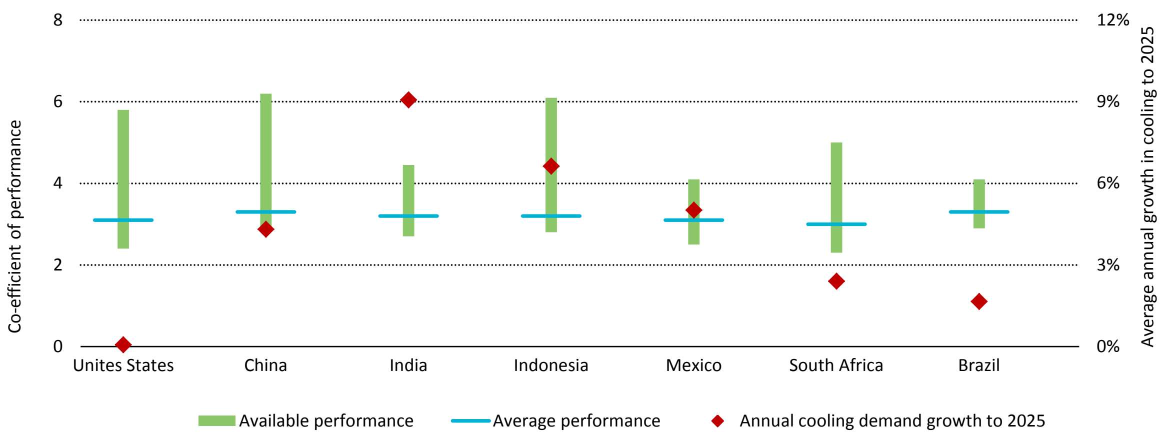
Cooling demand in China's buildings sector could double by 2030, matching an expected doubling in income growth by 2030 (IEA, 2017a). While purchasing power and demand for thermal comfort are the principal factors behind this expected growth, cooling equipment efficiencies are another influential factor. Currently, the typical split-package (e.g. mini-split) air conditioning unit in China has a co-efficient of performance (COP) of around 3.3. This is not much higher than the minimum available COP of 2.9 and is far from the best available technologies on the market with COPs above 6.0 (Figure 6).

District cooling networks could meet some of China's rapidly growing cooling demand, potentially taking advantage of synergies across local energy systems in the same way as advanced and high-efficiency district heating systems. Those synergies can include use of off-peak cooling generation (e.g. use of variable renewable energy sources with ice storage) and other locally available energy opportunities (e.g. natural cooling from rivers or excess heat using adsorption chillers).

However, district cooling solutions should be considered within the same integrated energy systems planning framework as modern district heating solutions, ensuring that the overall performance and advantages of district cooling exceed the benefits of high-performance stand-alone cooling equipment. For instance, while natural cooling in the district cooling network in Paris has achieved operational COPs as high as 20 during certain periods, the overall annual COP is still roughly 4.0 (IEA, 2014).

Similarly, tests of a district cooling plant with a high-efficiency chiller in Singapore showed a COP of around 4.2 when ice storage was used (Hida et al., 2008). Those COPs are comparable to medium-efficiency split-package air conditioning units, though the efficiencies alone do not necessary reflect other operational benefits, such as economic savings from cooling production during off-peak periods. Altogether, district cooling investments in China should be considered from a wide range of perspectives to ensure they make sense within the local context.

Figure 6 • Typical energy efficiency ratios of split-package air conditioning units in 2015



Notes: Co-efficient of performance (COP) represents the energy efficiency ratio (watts in cooling equivalent per watt of electricity consumption): the higher the COP, the greater the energy efficiency. Annual average growth in space cooling demand represents the expected change in useful cooling energy demand between 2015 and 2025 under the RTS.

Key message • Cooling demand is likely to continue rapid historical growth in the coming decade, but significant potential lies in improving the typical performance of cooling equipment in China.

Policy framework is fostering further development

More than 20 policy documents, regulations and support measures relating to district energy have been issued in China since 2005, essentially to support centralised heating development (Table 3). District energy policy typically involves seven government bodies: the State Council (SC), the NDRC, the Ministry of Finance (MoF), the Ministry of Housing and Urban-Rural Development (MOHURD), the Ministry of Environmental Protection (MEP), the Ministry of Land and Resources (MLR) and the National Energy Administration (NEA).

The development of district energy systems, notably for district heat, is included in several of China's Five-Year Plans (FYP). The 11th FYP set a target penetration rate for centralised heating of 40% by 2010 (NDRC, 2007). The plan also set energy saving targets for new co-generation and encouraged heat metering in large and medium-size cities. Installation of heat meters was further promoted in the 12th FYP on energy saving and emissions reduction, which set a target of equipping at least 400 million m² with meters in the NUH area (SC, 2012). The 12th FYP for building energy saving echoed the need to improve heat metering and accelerate district heat network renovation (MOHURD, 2012), while the 12th FYP for energy development focused on gas co-generation development (NDRC, 2012a). The 13th FYP, for 2016–20, put more emphasis on cleaner heat sources, such as biomass co-generation or geothermal, as well as low-grade excess heat and tri-generation (electricity, heating and cooling) (NEA, 2016). In 2016, the first FYP on geothermal energy set a target of covering 1.6 billion m² with geothermal heating by 2020 (NDRC, MLR and NEA, 2016), and the 13th FYP on building energy saving and green buildings plans a 15% decrease in energy per m² in the NUH region by 2020. Incremental floor area covered with shallow geothermal heat should reach 200 million m² by 2020 (MOHURD, 2016).

On the technological side, China's regulatory framework has been raising standards for coal-fired heat while also promoting cleaner sources. Since 2006, MoF has issued support for heating and cooling technologies using renewables, including surface, ground and wastewater heat pumps. In 2010, heat networks were opened to biomass heat; and in 2016, the FYP on geothermal energy mentioned the opening of heat markets to geothermal companies (NDRC, MLR and NEA, 2016). In 2013, a joint document issued by MoF, MOHURD, MLR and NEA promoted development of geothermal energy for urban energy and heating in areas where resources are available. In 2010, MEP banned the construction of coal boilers in urban areas that did not provide co-generation and increased air quality measures for existing boilers.

The development of centralised heating is also viewed as part of the strategy to decommission coal boilers. In 2014, NDRC set emissions standards for coal-fired units above 300 megawatts (MW). Coal-fired co-generation should reach 28% of coal-fired electricity generation capacity by 2020. NDRC also issued a notice on excess heat utilisation to replace 2 billion m² of coal boilers (equivalent to 50 Mtce, roughly 1.5 EJ) (NDRC, 2015). In 2017, MoF set up a subsidy scheme for clean heating pilot projects in NUH areas for pilot projects favouring cleaner coal use, gas or electric boilers. In May 2017, additional subsidies were put in place by MoF and local governments were encouraged to attract more private capital. Measures have also been taken at the local level. In 2015, for instance, Beijing decided to build four large gas co-generation plants (Beijing Municipal Government, 2015). In December 2017, NDRC, MORHUD, MEP and NEA released a plan on clean heating in NHU (2017-2022) to switch smaller coal-fired boilers to cleaner energy sources and curb coal-fired heating. The plan aims to cut coal consumption by 74 million tons in three years and 150 million tons in 5 years, with around 50% of total area covered by district and clean heating (NDRC, 2017b).

Table 3 • Main district energy policy documents, regulations and support frameworks

Year	Ministry	Title	Main district energy related content
2005	NDRC	Medium-long term special plan on energy saving	Heat metering for pricing (in large and middle-sized cities)
2006	SC	Decision on energy saving improvement	Heat as a commodity, price based on heat quantity
2006	MoF	Administrative measure on support to renewables in buildings	Support to heating and cooling technologies using renewable sources including heat pumps
2007	NDRC	11th FYP on energy development	Switch from distributed boilers to centralised heating; energy saving standards for new co-generation
2007	NDRC, MOHURD	Administrative measure on urban heat pricing	Allow non-public capital in heat facilities investment; price set by local governments, but can be set between producers and consumers after consultation
2010	MEP	Opinions on air quality	Ban construction of coal boilers if not co-generation in urban areas; promote expansion of surface area supplied with central heating; air quality measures for boilers
2010	Central Government	Renewable energy law	Open heat networks to biomass heat
2012	NDRC	12th FYP on energy development	Development of gas co-generation; heat network rehabilitation
2012	NDRC	Notice on coal-fired plant rehabilitation	Standards for coal boiler rehabilitation (minimum heat load of 70 tonnes/hour and covering at least 2.4 million m²)
2012	MOHURD	12th FYP on building energy saving	Focus on heat metering and network renovation

2012	SC	12th FYP on energy saving and emission reduction	Use of industrial excess heat for DHC; heat metering for at least 400 million m² in NUH
2013	NEA, MOHURD, MoF, MLR	Opinion on geothermal energy development	Where resources available, geothermal energy promoted for urban energy and heating
2013	SC	Action plan on fighting air pollution	Development of centralised heating as part of small boilers decommissioning
2014	NDRC	Action plan on upgrading and reforming energy saving and emission reduction of coal-fired electricity generation (2014-20)	Emissions standards for coal-fired units above 300 MW; distributed boilers replacement by centralised heating; excess heat utilisation
2015	NDRC	Notification on waste heat utilisation	Using low-grade excess heat to replace 2 billion m² equivalent of coal boilers (or 50 Mtce)
2016	NDRC	Administrative measure for co-generation plants	Specifications on co-generation plants according to city size
2016	NEA	13th FYP on energy development	Promotion of tri-generation and biomass co-generation; geothermal heat; low-grade excess heat
2016	NDRC, MLR, NEA	13th FYP on geothermal energy	Open heat market access to geothermal companies; target on geothermal heating/cooling development
2016	NDRC	Energy supply and consumption revolution strategy (2016-2030)	Development of district energy networks and biomass heating
2017	MoF	Notification on support to pilot clean heat projects in NUH	500 M to 1 billion CNY subsidies for pilot projects in clean heating in NUH, depending on city type
2017	MOHURD	13th FYP on buildings energy saving and green buildings	Energy intensity per m² in NUH decrease 15% by 2020; 200 million m² newly built and supplied with shallow geothermal
2017	NDRC, MEP, MORHUD, NEA	Plan on clean heating in NHU (2017-2022)	Cut coal consumption for heating by 74 million tons in three years and 150 million tons in 5 years

Key message • Measures and regulations cover a significant portion of district energy supply in China.

Opportunities for cleaner district energy systems in China

In China there are vast differences between climatic zones, building types and resource availability. These differences all have a strong influence on the technology options for improving energy efficiency and reducing CO_2 emissions and local air pollution in China's massive district energy network. To ensure this network delivers thermal comfort at affordable prices using clean energy technologies, policies should take into consideration not only energy, air pollution and climate strategies but also other equally important development goals.

For older systems in the NUH district heating network, strategies to replace or improve existing assets will need to take into consideration implications for building energy demand and performance, for instance for older, inefficient buildings without thermostatic control of heat. This may require, in the short term especially, supply-side investments (e.g. hydronic balancing and excess heat recovery from local industry) that can drastically improve the overall energy intensity and effectiveness of the district heat network. More recent systems, or those being considered for expansion or addition, may offer an opportunity to choose high-performance, low-carbon and renewable technology for modern, advanced DHC (Box 2). This could include demonstration projects, such as fourth-generation low-temperature district heating systems (e.g. 50-55°C, or lower, if using booster heat pumps) and modern tri-generation district energy networks.

Box 2 • Advanced district heating solutions for energy-efficient, low-carbon communities

Modern district energy networks can play a key role in enabling energy-efficient, low-carbon energy communities. They can accept heat from a wide range of sources, including excess heat from industry and variable renewables, using both short- and long-term storage and advanced district energy solutions, such as low-temperature heat. Advanced district energy systems can also take advantage of synergies in energy networks, such as heat exchanges between cooling services and hot water supply across multiple buildings, to improve net efficiency and reliability.

The IEA Technology Collaboration Programme for DHC including CHP (DHC TCP) is a co-operative platform involving ten countries in Europe, North America and Asia. The DHC TCP aims to advance innovation in, and improve the economics for, district energy solutions and technologies, including research, development and demonstration programmes (called annexes) that explore how DHC and co-generation can help to build sustainable energy communities.

Much of the DHC TCP's work has focused on achieving an optimal match between energy supply and demand. Annex X looked at economic and design optimisation to integrate renewable energy and excess heat into district energy systems. Annex TS1, on low-temperature district heating for future energy systems, continued this work. It identified comprehensive, innovative approaches that treat energy-efficient buildings and their related supply streams as one integrated system that maximises synergies at the community scale. Annex XI has an initiative for a transformation roadmap to similarly improve existing district energy systems through lower-temperature operation.

The DHC TCP work programme to 2020 considers advanced district energy solutions, including work on system operation and asset management, as well as on cooling technologies. Further information on the TCP can be found at www.iea-dhc.org.

This section considers how energy efficiency, excess heat, renewables and natural gas can improve district energy networks in China. These clean energy measures can enable China to continue its transition away from energy-intensive heating and power systems that are causing local air pollution and significant carbon emissions.

The role of energy efficiency

The cleanest and often least expensive energy is the energy that is saved through energy efficiency. Three types of energy efficiency can improve district energy systems: (1) energy demand efficiency, (2) energy distribution efficiency and (3) energy supply efficiency.

Energy demand efficiency

In a district energy system, reducing the energy demand for heating and cooling (potentially including sanitary hot water) through energy efficiency measures can have a significant impact on the scale of district energy distribution and supply systems and the overall investments needed.

At the building level, demand for space heating can be reduced through measures that improve the energy efficiency of building envelopes (e.g. insulation, low-u-value windows, reduced air infiltration) and of heating distribution systems (e.g. duct insulation, duct sealing and pipe insulation) and through heating management measures (e.g. sensors, indoor temperature control, dynamic balancing and metered energy paid by the building occupant or operator).

Onsite heating systems, such as small gas-fired engines, can also influence the type and efficiency of heat that can be used in the building. For instance, steam radiant heating systems require high-temperature heat while in-slab radiant systems or onsite heat exchangers can use low-temperature district heat.

Demand for space cooling can be reduced similarly through measures that improve the energy efficiency of building envelopes (e.g. insulation, low solar heat gain co-efficient windows, overhangs and other building shading) and of cooling systems (e.g. ventilation fans, duct insulation and sealing, and pipe insulation), as well as cooling management measures (e.g. sensors, controls and metered energy). Humidity control can also influence cooling energy demand. Simultaneous treatment of humidity (latent) and sensible heat can dramatically decrease the operational performance of cooling equipment.

Onsite cooling systems affect the efficiency of cooling that can be used in the building. Low-temperature cooling with reheat to reduce humidity requires high-grade cooling, while in-slab radiant systems or onsite heat exchangers can enable the use of high-temperature district cooling. This can also enable the use of free (i.e. natural) cooling sources. Cooling system efficiency can also be greatly improved by using systems with high delta T values (a high temperature difference between supply and return) that efficiently transfer energy from the system into the building. To make high-temperature district cooling possible in humid climates, in-building systems need dehumidification and/or energy recovery ventilation.

While district heat for sanitary hot water is not common in China, it can also be improved through building efficiency measures. Hot water demand can be reduced by using more efficient faucet and shower heads, and more efficient equipment (e.g. low-water, high-efficiency clothes washing and dishwashing machines) and through energy management measures (e.g. sensors, controls and metered energy paid by the building occupant or operator).

Energy distribution efficiency

Energy distribution refers to the physical district energy network that typically includes pipes, controls and resource management (e.g. network operators). Energy distribution efficiency is increased primarily by using insulation, sensors and controls, as well as improved energy management. Two critical factors that affect the overall energy distribution efficiency are the length of the distribution pipes and the temperature of the energy distributed. In China, network losses currently represent 3% to 5% of heat production (BERC, 2017).

The length of distribution pipes can increase the energy consumption of the district energy network due to thermal losses and the energy needed for pumping. Pumping energy can be decreased markedly through careful pipe design, proper balancing and using variable speed pumps to minimise pressure drops.

Distributional temperatures also influence network energy losses. High-temperature heat (or low-temperature chilled water) has higher thermal losses than low-temperature heat (or high-temperature chilled water) because of the temperature difference between the thermal distribution and the exterior of the pipes. Thermal distribution losses can be reduced by increasing the insulation on the pipes, using low-temperature heat and high-temperature chilled water, and by increasing the delta T value.

Energy supply efficiency

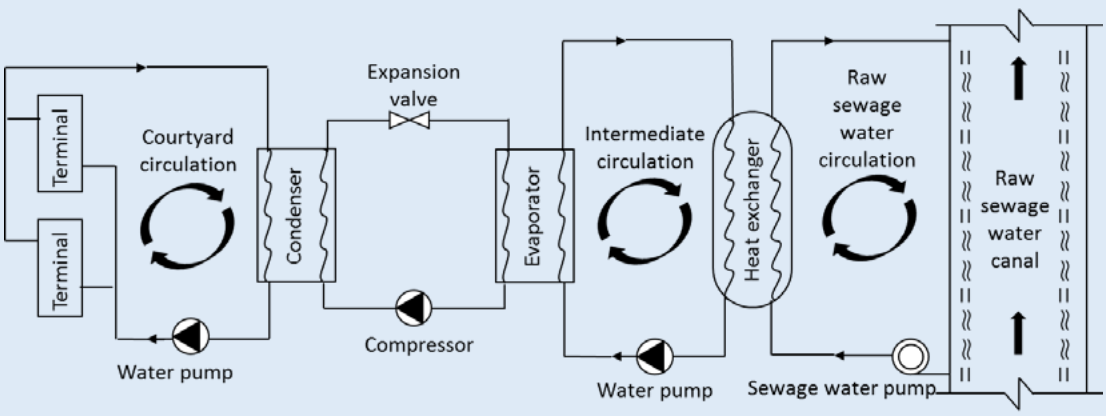
Energy supply efficiency is improved primarily by selecting better technologies or fuel types, by increasing technical efficiency (e.g. by optimising operational conditions), and by efficiently capturing "free" heating or cooling when possible. "Free" heating and cooling can include several energy sources that are typically not feasible at the building scale, such as excess heat recovery from industry or even from sewage (Box 3). It can also include better use of onsite heat, for instance using co-generation technologies to recover heat in electricity production.

The overall cost-effectiveness of a district energy system depends very much on whether energy supply is more efficient that individual building heating and cooling systems. Typically, district energy systems are only more cost-effective than individual heating and cooling systems when they can benefit from system scale, from co- or tri-generation for increased efficiency, from mixed energy sources that are not feasible at the building level (e.g. waste incineration or excess heat recovery), and from the capture of free heat or free cooling.

Box 3 • Case study: Sewage heat use in Shenyang, Liaoning province

In the city of Shenyang, heat recovered from waste water sewage supplies a block of residential buildings of around 280 000 m². The heating period in Shenyang typically runs from October to April, with an average outdoor temperature of around -11°C. Waste water is considered as a competitive heat source as its average temperature is around 16°C, even higher than that of underground water.

In the Shenyang central network, sewage waste water is pumped to the heating station from a canal 600 metres from the heating area. An intermediate water loop is used between the waste water circulation and heat pumps to protect the evaporators from blocking and prevent corrosion from contact with the waste water (see diagram).



Radiant in-floor heating systems have been used to improve the efficiency of the heating system, enabling the use of low-temperature supply water and raising the COPs of the heat pumps. Monitoring data shows that the supply water temperature ranges from 25°C to 40°C during the heating period (relative to the heat demand), while the waste water is typically between 12°C and 15°C.

The systematic COP (considering the entire electricity consumption of the heat pumps, water pumps and waste water pumps) reached a high value of 4 at the beginning and end of the 2016 heating period, with the lowest COP of 2 on the coldest days. The average COP was 3.2. During the entire 2016 heating period (151 days), the electricity consumption of the system was around 25 kWh/m², with an energy cost of CNY 17.3 (USD 2.50) per m² at an electricity price of CNY 0.69 (USD 0.10) per kWh. The waste water heating system saved more than 6000 tce in primary energy consumption as well as 17 800 tonnes of CO_2 emissions, 58 tonnes of sulphur dioxide (SO_2) and 50 tonnes of nitrogen oxides (NO_x) per heating season.

The waste water heating system has safely worked for four years, proving the stability of the heat source and the reliability of sewage heating technology. Waste water heating could be promoted further in NUH China as most cities have public infrastructure for sewage treatment. The heating capacity of waste water is much lower than most cities' needs, but waste water could enrich the diversity of heat sources for urban district heat.

Source: Building Energy Research Centre of Tsinghua University.

Technology selection, fuel choice and operational efficiency play key roles

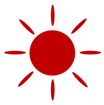
Technology selection and fuel choice can have a significant influence on district energy networks' impact on site energy (final energy), source energy (primary energy) and related emissions. Cost tends to be the main criterion in choosing technologies and fuels, although such choices are also influenced by policies (e.g. minimum energy performance standards or local pollutant controls) and market frameworks (e.g. contractual obligations or market exchange mechanisms). Within the selected technology and fuel, individual systems and components can also improve efficiency through optimisation of operations, regular maintenance and other technical improvements (e.g. hydronic balancing, more efficient pumps and motors, and sensors and software to manage the network).

In any determination of technology efficiency for the heating and cooling systems, the impact of efficiency on the size of the systems should be analysed. In large buildings that would otherwise already use large-scale systems, a district system may not offer much benefit of scale, and any savings may be lost in the distribution if not properly managed. Smaller buildings with smaller heating and cooling systems naturally can benefit from the scale of a district energy system, while also taking advantage of other efficiency opportunities such as the use of variable renewable energy and IEH.

Efficient capture of "free" heating or cooling

The efficient capture of "free" heating or cooling – the third critical way of making a district energy system cost effective (along with technology and fuel choice and technical efficiency) – is highly dependent on location (Figure 7). This can include natural sources, such as rivers, lakes and geothermal heat, as well as "free" heat from locally available resources (e.g. IEH) that otherwise would be lost. While capture of these heating and cooling sources (e.g. equipment, transport and pumping) is not "free", their use can significantly increase the overall efficiency of the district energy network. Further, sources of "free" heating and cooling can transition to priced energy with the right business model (see Business Model section), increasing the attractiveness and viability of the district energy network.

Figure 7 • Sources of "free" heat and cooling energy



- air temperature (N)
- water temperature (N)
- ground temperature (N)
- geothermal (N)
- solar (N)

- industrial excess heat (W)
- agricultural waste (W)
- sewage or other waste (W)

- air temperature (N)
- water temperature (N)
- ground temperature (N)
- solar (N)

- geothermal (N)*
- industrial excess heat (W)*
- agricultural waste (W)*
- sewage or other waste (W)*

Notes: (N) indicates a source of natural energy that can be captured for heating or cooling. (W) indicates a source of otherwise wasted or excess energy that can be captured for heating or cooling. (*) indicates less common sources can also be used for district cooling, using absorption chillers.

Key message • Natural and waste sources for heating and cooling are highly dependent on location but can significantly improve overall efficiency of district energy networks.

Natural energy: Air, water and ground-source temperatures can all be used with heat exchangers or heat pumps to move thermal energy from the air, water or ground into district energy. Geothermal and solar energy (see Renewable Energy section) can be used directly by the district energy system, but may require pumping or other transport of energy.

Waste energy: Excess heat (see Excess Heat section) is typically available at different temperatures from various other processes, most commonly industrial or power generation excess heat. Excess wood/biomass (see Renewable Energy section) and other waste can be used for conversion to heat at the district energy plant and can often be a low-cost source of energy. However, the efficiency of excess biomass (e.g. agricultural waste) and other waste depends on the transport and efficient conversion of those materials to heat.

Several factors influence how efficiently natural or waste energy can be captured. Temperature and access to the "free" heating and cooling source are major issues, as can be environmental concerns such as the impact on local fish and wildlife of releasing heat into bodies of water. Cost can also be a major factor, where the energy may be available but costly to access (e.g. deep drilling for geothermal heat).

Capture of free heating and cooling may also require changes within the operations or distribution of the district energy network. For instance, solar heat often has lower temperatures, which may require heat pumps to augment the temperatures for high-temperature distribution networks. If solar heat is used at lower temperatures, better building performance is required (e.g. improved insulation to reduce heating demand). Likewise, for cooling, the end-user could switch to higher temperature cooling to increase the ability to capture free cooling from the air, water or ground.

The role of excess heat

Excess heat delivered through thermal energy networks can be a valuable source of district energy that does not involve additional generation of heat (e.g. use of coal boilers). The extent to which excess heat can be technically and economically recovered depends on the characteristics of sources (such as cleanliness, temperature level and intermittency of supply) as well as the availability of the particular end use.

Several studies have estimated national and regional IEH inventories, using diverse methodologies. Results vary widely, with IEH inventories ranging from 20% to 70% of the country's final industrial energy consumption. These ranges are wide even though the contribution of energy-intensive industries to total national industrial energy use does not vary so greatly across countries, reinforcing the importance of the approach taken.

Excess heat from co-generation: potential and options for heating

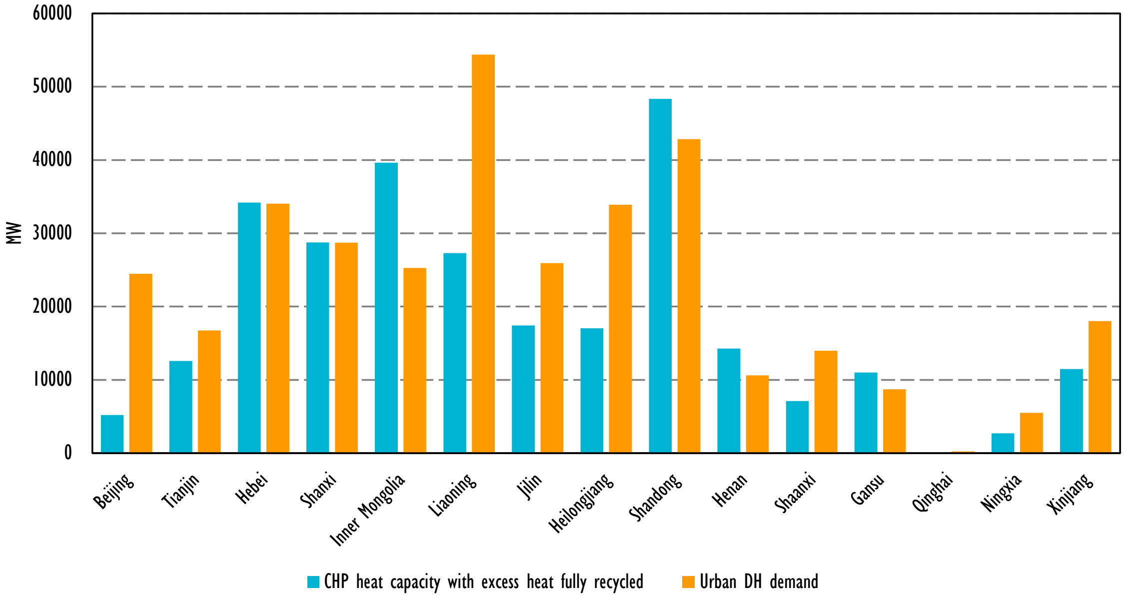
Co-generation has gone through rapid development in China, as the demands for space heating and industrial heat have expanded. The electric capacity of CHP in NUH units reached 211 GW in 2014, accounting for around 30% of the total national thermal power capacity and 43% of capacity in NUH China (CEC, 2015). CHP dominated about half of the heat market in 2015 and it continues to increase as coal boiler capacity is reduced.

Total installed co-generation capacity increased by 96% between 2009 and 2014; by contrast, heat production by CHP only grew by 23%. This contrast in capacity and production is due to multiple reasons, such as high priority given to electricity generation to support increasing electricity demand and issues of long transport distances for heat, caused by outward migration of power plants from urban centres. Recently, however, electricity surpluses have drawn attention to heat production, and technical developments have improved the capacity to lengthen the economical heat transfer distances to 100 km or more. As a result, greater attention is being paid to opportunities to increase heat generation and capture from co-generation plants (BERC, 2015).

Electricity generation can achieve as much as 45% efficiency by using advanced coal-powered technologies, with the remaining 55% of energy released as excess heat. This provides an opportunity to use excess heat to meet district heat demand, for instance using co-generation technologies. The most commonly used technology for co-generation units is to extract steam before going to the low-pressure turbine and transfer heat to district heat with steam-to-water heat exchangers. The extraction technology using steam heating can recycle approximately 70% of the excess heat from the steam turbine, where the remaining 30% of excess heat can be utilised by boosting back pressure or by using heat pumps. In either case, making full use of excess heat not only expands the heat capacity but also increases the energy efficiency of the co-generation units. Coal consumption using co-generation heat production can be reduced to less than 20 kilograms (KG) of coal equivalent per GJ, showing significant advantage compared to stand-alone coal boilers (BERC, 2015).

Based on the existing co-generation units already installed and connected to the NUH district heat networks, the heat capacity from excess heat capture is estimated at 277 GW_{th} if the excess heat were fully recovered (Figure 8). This capacity is equivalent to around 80% of the 2015 heat demand in the NUH district heat networks. Furthermore, if conventional (non-co-generation) coal power units and nuclear power plants that could be feasibly converted into co-generation units were taken into consideration, the potential excess heat would be large enough that in principal no new installation of co-generation capacity would be necessary, even as district heat demand grows.

Figure 8 • CHP heat capacity and urban DH demand



Notes: Co-generation heat capacities are estimated by absorption heat pump technology according to the installed electric capacity; urban district heat demands are estimated by district heating network floor area coverage.
Source: China electricity statistical yearbook, China Electricity Council, 2015; China urban-rural construction statistic yearbook, MOHURD, 2015.

Key message • Heat capacity from co-generation excess heat is equivalent to around 80% of the 2015 heat demand in NUH district energy networks.

Industrial excess heat potential and options for heating and cooling

Industry in China continues to play a disproportionately large role in energy use, accounting for more than half of the energy consumed by the end-use sectors, or 1 700 Mtce (50 EJ), with transport, residential and services lagging far behind (IEA, 2017a). Industrial energy demand in China has made up nearly 60% of the growth in final energy consumption since 2000, largely because of the rapid rise of energy demand for steel, cement and chemicals production, among other energy-intensive processes.

Energy-intensive industrial sectors[3] tend to be more intensive in excess heat, provided the processes involved have greater specific energy requirements and operating temperature levels. Tapping into its abundant excess heat, either by improving industrial efficiencies or for other uses, such as district energy, offers China a real opportunity to reduce the overall intensity of its energy sector and reap the consequent economic and environmental advantages.

In *Energy Technology Perspectives 2017* the IEA estimated the potential for excess heat recovery in the iron and steel sector globally at 71.7 Mtce (2.1 EJ),[4] which is 7% of global final energy consumption in the sector (Figure 9).[5] Around 74% of this potential lies in non-OECD economies,

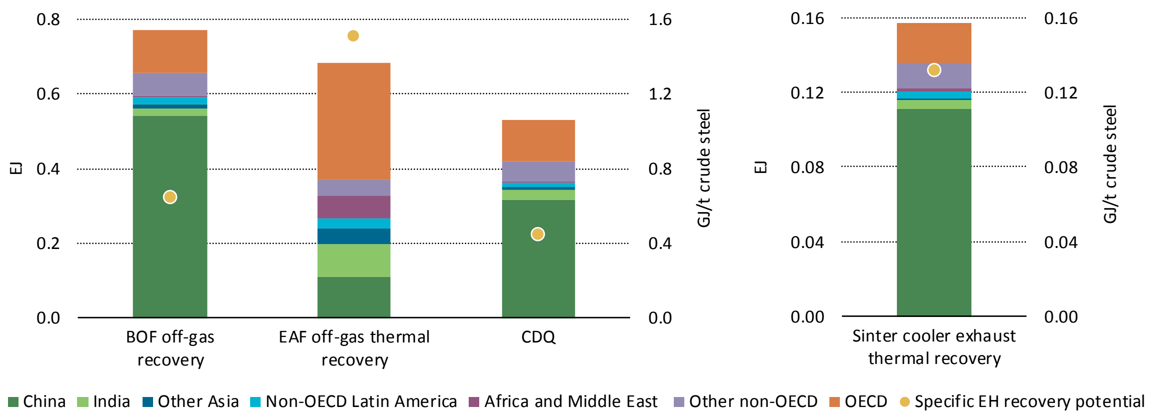
[3]Energy-intensive sectors refer to iron and steel, non-metallic minerals, chemicals and petrochemicals, pulp and paper, and non-ferrous metals.

[4] Sensible heat recovery from hot stoves exhaust is not included. The basic oxygen furnace (BOF) off-gas recovery potential covers both the sensible and chemical energy from the off-gases.

[5] Final energy consumption of the iron and steel sector was 1122.6 Mtce (32.9 EJ) in 2013, including blast furnaces (BF) and coke ovens (CO).

which are also responsible for about 70% of global crude steel production. China represents half of that identified global technical energy savings potential (IEA, 2017a).

Figure 9 • Global technical IEH recovery potential from selected applications in the iron and steel sector



Notes: CDQ = coke dry quenching, EAF = electric arc furnace, EH = excess heat. Technical IEH recovery potentials refer to 2013 industrial stock. Specific energy savings in GJ/t crude steel refer to the relevant share of global crude steel production: crude steel production via BF and BOF for CDQ, BOF off-gas recovery and sinter cooler exhaust thermal recovery, and crude steel via EAF for thermal recovery from off-gas generated in this process. Thermal energy recovery from hot stove exhaust gas is not included in the global technical recovery potential assessment due to lack of regional implementation information.

Source: IEA analysis (IEA, 2017a) based on IEH recovery technologies regional implementation levels from: Lu, H. (2015), *Capturing the Invisible Resource: Analysis of Waste Heat Potential in Chinese Industry and Policy Options for Waste Heat to Power Generation*; Rock, M. and M. Taman, (2015), *China´s Technological Catch-up Strategy: Industrial Development, Energy Efficiency and CO_2 Emissions*; and IEA estimates.

Key message • More than 34.1 Mtce (1 EJ) of excess heat, or 1.3 GJ per tonne, of crude steel could be technically recovered in the iron and steel industry in China.

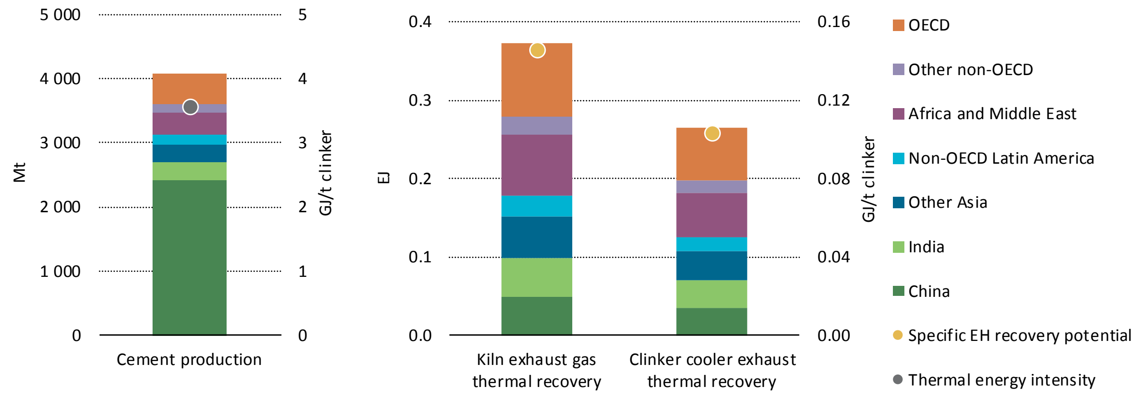
In the cement industry, the calcination of limestone to lime for clinker-making in a kiln is the most energy-intensive process and offers substantial IEH recovery potential. The differing moisture content of raw materials leads to contrasting energy requirements for clinker-making: almost 5.9-6.7 gigajoule per tonne of clinker (GJ/t clinker) for the wet process and 2.9-4.6 GJ/t clinker[6] for the dry process (IEA, 2007).

State-of-the-art dry-process kiln systems already include IEH recovery techniques to make use of part of the thermal energy of kiln flue gases to preheat raw material[7] and of the air to cool the clinker down as secondary combustion air. Depending on the moisture content of raw materials, opportunities for further thermal energy recovery can be found in the dry clinker-making process. For instance, 20.5 Mtce (0.6 EJ) globally could be technically recovered from kiln and clinker cooler exhaust gases when the process involves raw materials with low-moisture content of 2-6% and a five-stage preheater cyclone and pre-calciner kiln configuration. Nearly 15% of the identified global technical potential could be saved in China, or 0.06 GJ/t dry-process-based clinker, which accounts for 60% of global cement production (Figure 10).

[6] The range of thermal energy intensity related to the dry-process clinker-making covers from a long-dry process to a six-stage preheater and pre-calciner rotary kiln.

[7] The number of cyclones of a dry rotary kiln is determined by the moisture content of the raw materials. Each additional preheating stage increases the level of thermal recovery.

Figure 10 • Global technical IEH recovery potential from selected applications in the cement sector



Note: Technical IEH recovery potentials refer to 2013 industrial stock. Specific energy savings in GJ/t cement refer to global dry-process-based clinker production.

Source: IEA analysis (IEA, 2017a) based on IEH recovery technologies regional implementation levels from: Lu, H. (2015), *Capturing the Invisible Resource: Analysis of Waste Heat Potential in Chinese Industry and Policy Options for Waste Heat to Power Generation*; BCS Incorporated (2008), *Industrial Waste Heat Recovery: Technology and Opportunities in U. S. Industry*; IIP (Institute for Industrial Productivity) and IFC (Internal Finance Corporation) (2014), *Waste Heat Recovery for the Cement Sector: Market and Supplier Analysis*; Izumi, Y. (2014), *Role of the Japanese Cement Industry in the Establishment of a Sustainable Society*; Italcementi (2015), *Solar Power and New Concrete Applications: A Pilot Plant in Morocco*; and IEA estimates.

Key message • 2.7 Mtce (0.08 EJ) of IEH, or 0.2 GJ/t dry-process-based clinker, could be technically recovered in the cement industry in China, which represents 60% of global cement production.

Additional opportunities exist for recovering IEH for heating and cooling purposes. The aluminium sector, for example, presents considerable opportunities for medium- and high-temperature IEH recovery (IEA, 2017a). Recovering low-temperature excess heat is also possible, although it typically poses additional challenges because greater heat transfer surface area is required, which translates to higher capital investment costs and a greater chance of reaching space constraints in the industrial site. Finding a compatible end use for low-temperature recovered excess heat can also be limiting in some industrial activities. In these cases, external end uses or the implementation of upgrading technologies (e.g. heat pumps) need to be explored (Kumar and Karimi, 2014).

Assessing the potential for low-temperature IEH recovery is especially complex given the larger number of possible sources and the greater impact of site-specific characteristics and ambient conditions. Site-level process integration becomes even more relevant to identify additional energy savings from low-temperature sources. For instance, process integration techniques, including pinch[8] analysis, could deliver 5% additional energy savings compared with best-practice energy performance in the petrochemical and chemical sector (Saygin et al., 2011).

While it is difficult to assess the total recoverable heat potential from IEH in China, the opportunity for excess heat recovery for supplying district heat is significant. A study of IEH by Tsinghua BERC in 2016 found that as much as 100 Mtce (nearly 3 EJ) of potential excess heat recovery was possible during the heating season in the NUH region using low-grade industrial heat (Luo et al., 2017). That excess heat would also carry additional benefits, including more than 3 billion cubic metres (bcm) in water savings from thermal generation for district heat production.

[8] Pinch analysis consists of generating composite curves by aggregating *hot streams* to represent the total heating demand of a system and *cold streams* to represent the total cooling demand. The point at which the curves are closest is called the *pinch*, and the area in between both curves represents the maximum heat recovery as a function of temperature.

IEH can also satisfy cooling demands using absorption chillers. As with centralised operations for district cooling, the net energy and emissions gains from adopting such technology for district cooling should be compared with those obtained from high-performance cooling equipment in buildings. Combinations of various technology solutions (e.g. IEH with absorption chillers, ice storage and augmenting network efficiency with natural cooling using locally available resources) can provide high-performance packages for district cooling, but can also require high upfront investment costs.

An additional option for excess heat recovery in district energy systems is nuclear co-generation, which has not been fully explored in China. Heat (steam) from nuclear power generation can be used for district heating, production of hydrogen and synthetic fuels, and even desalination. The feasibility of these non-electric applications for nuclear energy has been demonstrated through decades of experiences with about 74 reactors around the world (about 17% of the world's current fleet) (IAEA, 2009). However, non-electric applications of nuclear energy will only develop if nuclear co-generation is more economical than the technical solutions it replaces. Transmission distances for heat can also be barrier to tapping into this technology potential, as nuclear generation facilities are often far from cities. Chinese think tanks and companies are investigating the potential for nuclear heating in small cities, however, which are currently supplied only by coal-fired heating (Box 4).

Box 4 • Potential for nuclear heating in China

Small-scale nuclear reactors ranging from 100 MW to 400 MW could in theory replace coal boilers in cities with fewer than 300 000 inhabitants as they can produce heat below 100°C and are safer because they are not pressurised. Such reactors could supply heat for 2 to 10 million m^2.

Nuclear co-generation can be found in Western Europe and Russia, but dedicated reactors can be developed solely for district heating. The reactors are immersed in deep water pools that prevent the reactor core from melting. The circulating water transfers the heat from the reactor to the district heating system, heating the water for the urban network by 60°C to 90°C. Two internal closed water loops prevent exposure to radioactivity.

The cost of the reactor can be divided into initial investment and operational cost. The construction of a 400 MW heating system is around CNY 1.4 billion (USD 200 million), with a 50-year lifetime. Currently, nearly half of the investment is dedicated to R&D expenditure, so the cost is expected to drop when the commercialisation stage is reached. The operational cost is mainly for nuclear fuel. A batch of nuclear fuel costs nearly CNY 304 million (USD 44 million). It can supply a five-month heating period for six years, so the energy cost per GJ is just CNY 8 (USD 1.21), even lower than that of coal-fired boilers.

Barriers and market frameworks for excess heat options

Excess heat offers valuable potential to meet China's large district energy demand. Notable demonstration projects for IEH are already in place in Qianxi county, for example, where total heating capacity from excess heat recovery is projected to reach 225 MW for an investment of around CNY 276.4 million (USD 40 million) (Li et al., 2016).

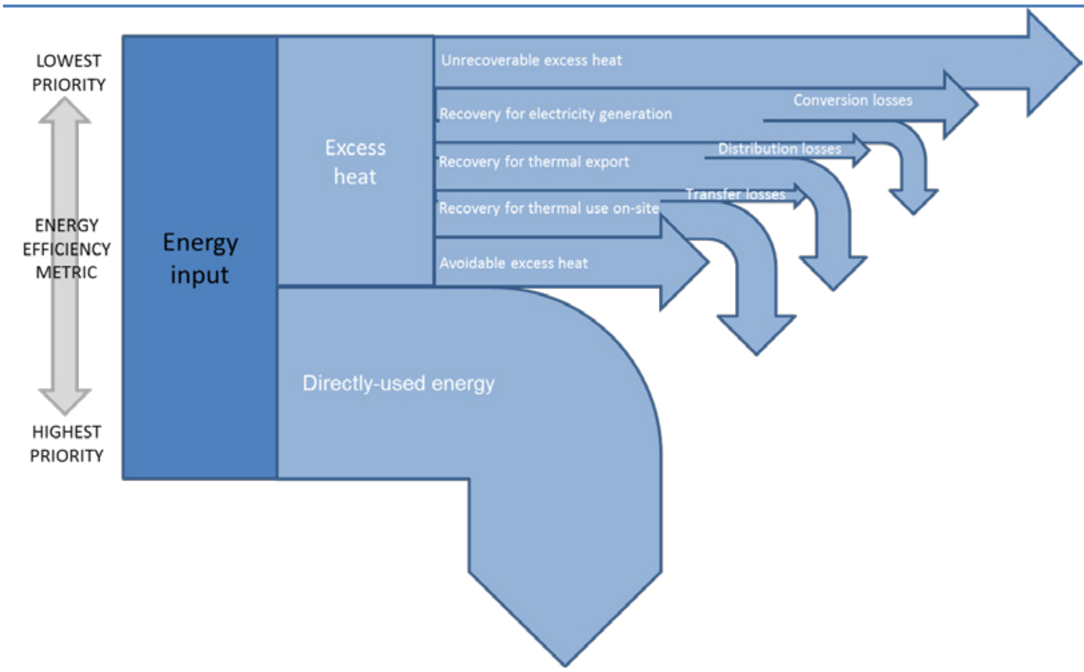
In practice, deployment of IEH recovery technologies is often limited by non-technical factors. These include site-specific characteristics, such as local availability of a compatible end use for the recovered heat, and local or regional economic aspects, such as capital investment requirements, energy prices, and existence of financial and fiscal supportive mechanisms for energy efficiency projects. All these factors are typically put in contrast with investor (e.g. IEH provider) expectation of short payback times compared with long-living industrial infrastructure to determine the economic viability of an IEH recovery project.

Other issues can limit use of IEH for district heating and cooling. For instance, feasibility studies in Qianxi county found that the excess heat did not necessarily distribute to district heating demand (Luo et al., 2017).

Such barriers require IEH recovery for district energy to be planned within a broader, integrated energy systems perspective in order to guarantee energy supply and thermal comfort in buildings. IEH providers also need to be assured that IEH recovery for DHC will not constrain their normal industrial processes.

From an energy efficiency perspective, IEH generation should be minimised in the first place by limiting process temperatures, improving process control and maintenance, and enhancing equipment insulation. After reaching the economically effective level of process optimisation (i.e. energy efficiency first in the industrial process), diverse applications of recovered IEH can be considered: direct use on site, export to local DHC networks that supply urban areas or neighbouring industrial facilities, or electricity generation (Figure 11).

Figure 11 • Excess heat management and possible uses in the industrial energy chain



Notes: Illustrative sketch of an industrial process not at scale. Levels of directly used energy vary depending on the type of process and site-specific practices and constraints. Unrecoverable excess heat refers to excess heat whose recovery cannot be economically justified. Thermal transfer losses are typically negligible compared with distribution or conversion losses.
Source: Developed from Forni, D., D. Di Santo F. and Campana (2015), *Innovative System for Electricity Generation from Waste Heat Recovery*.

Key message • Policies to maximise energy efficiency would improve management of excess heat, including its use for district energy networks in China.

The distance between end users and suppliers is a key factor determining the viability of transporting recovered thermal energy, because it directly increases distribution thermal losses and required capital investment. A recent study found that thermal losses through 10 km of heat pipes between the locations of IEH recovery and end-user demand were 50% (Hammond and Norman, 2013). However, thermal distribution losses can vary greatly depending on transportation distance, delivery and return temperatures and system physical configuration (e.g. heat pipe diameter, insulation characteristics and maintenance protocols).

Another barrier to the use of IEH in thermal distribution networks is the risk of security of supply. Unforeseen or planned disruptions in industrial activity may affect heat delivery if IEH is making a significant contribution to network energy and the thermal storage capacity was not designed for this circumstance. Industrial sites may not see value in providing excess heat to district energy networks if they have to guarantee a certain level of heat supply.

A long-term perspective can broaden the range of opportunities when assessing compatible end uses for recovered IEH, including district energy networks. Policy strategies to support the cost-effective implementation of IEH can also improve the business case of thermal recovery projects. This can include policies that ensure market conditions are transparent for heat suppliers and buyers, while ensuring market prices reflect the real costs of electricity and heat generation (IEA, 2014). Policies can provide additional incentives to local industries to make available their excess heat for DHC networks by acknowledging the co-benefits of efficient use of IEH recovery for district energy, for example by awarding pollution credits.

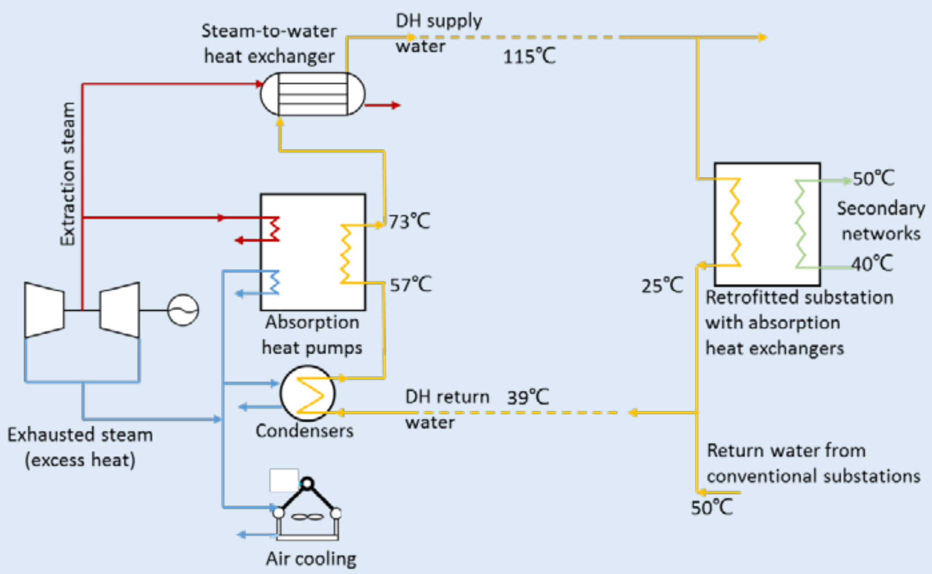
Additional effort is necessary to map the IEH potential in China, relative to district energy demand and DHC network planning (Box 5). Local, regional and even national heating and cooling planning strategies can use such mapping information to identify cost-effective opportunities for IEH recovery, while identifying additional barriers or specific market conditions that need to be addressed to achieve that potential (see Business Models section).

Box 5 • Case study: Excess heat from a CHP plant in Datong, Shanxi province

Most conventional CHP plants use extraction steam from turbines as a heat source for district heating but release the heat carried by exhausted steam in cooling towers. If the excess heat is recovered, the heating capacity can be raised by more than 30%. Massive excess heat of CHP in North China has significant potential to meet the rapid growth of urban heating demand and the urgent requirement for clean heat sources.

The Yungang CHP plant, a demonstration project in Datong city, is composed of two 220 MW and two 300 MW coal-fired co-generation unit. The plant originally supplied space heating for 16 million m², but demand reached 25 million m² in 2015, so the plant is aiming to bridge this gap by recovering its excess heat.

The retrofitting of the two 300 MW units started in 2012. Absorption heat pumps were installed in the main plant and in district network substations, and the district heating network was supplied at a temperature of 115°C. In the main plant, DH water was cascade-heated by condensers, absorption heat pumps, and steam-to-water heat exchangers. At the substation level, 42% of substations with enough space were retrofitted with absorption heat exchangers. Almost all the excess heat is now recycled except for the minimum required to freeze-proof air cooling equipment. The heating capacity has reached 885.7 MW, of which more than 40% is excess heat. The new system also improved electricity generation by reducing the exergy loss in heat transfer processes. As more excess heat could be recovered to supply the district heating system, less extraction steam was needed, contributing to approximately 7% more electricity generation than before (see diagram).



The co-generation company invested CNY 148 million (USD 21.4 million) to retrofit the co-generation plant units and CNY 180 million (USD 26 million) for the substations. Ideally, the heating company would have invested in absorption heat exchangers in substations, but this was not profitable as long as heat prices remained unchanged. Even though the co-generation company took over retrofitting of the substations, the heating company that operates the equipment had no desire to reduce the return water temperature. Efficiency of the system could be improved with an appropriate business model.

In view of the economic benefit, the recovered excess heat was recorded at 3.1 petajoules (PJ) per year, and heat was sold to the heating company at CNY 21 (USD 3) per gigajoule (GJ). With revenues from recovered excess heat of CNY 2.8 billion (USD 410 million) per year, the return on investment was only five years.

Source: Building Energy Research Centre of Tsinghua University.

The role of renewables

Renewable sources for heating and cooling can provide benefits such as reducing CO_2 emissions and air pollutants, and dealing with organic wastes, such as agricultural residues and a proportion of municipal solid wastes. Renewables still play a small role globally in the heat sector, however, accounting for just 9% of global heat consumption in 2015. This section explores the options for renewables in district energy, how competitive they are, and provides examples of international best practice for achieving high shares of renewable heat.

District energy networks can facilitate the deployment of renewables, because their economies of scale can give them a cost advantage over building-scale renewable heat installations. Additionally, connection to a network is often easier than deploying renewable technologies in individual buildings. However, most district energy continues to be supplied from fossil fuels. Of the 385.6 Mtce (11.3 EJ) of energy for district heat provided globally in 2015, only 27.3 Mtce (0.8 EJ) (7%) came from renewables. The share of renewables in district heating in 2015 was 28% in the European Union but only 1% in China. There is significant potential for increasing this share – both in China and globally. It may be feasible to increase renewables' share in district heat generation in China to 24% by 2030 (IRENA, 2017).

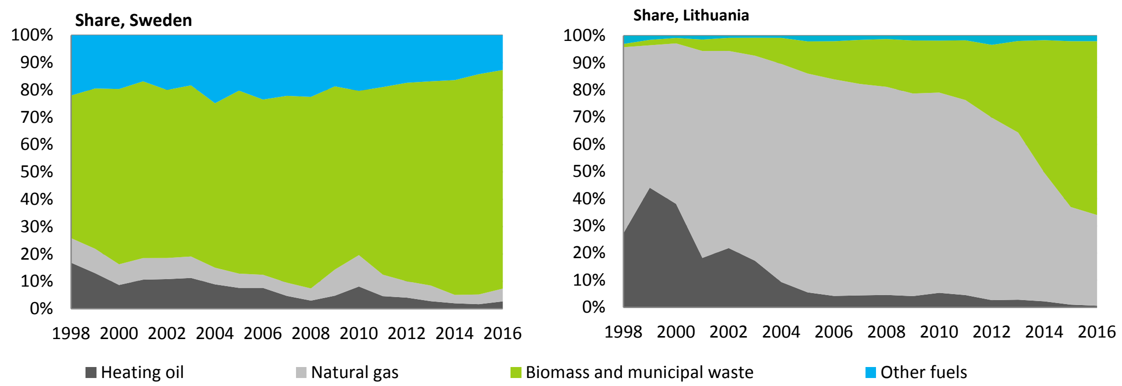
Renewable heat solutions for district energy depend to a large extent on local resource availability. The largest penetration of renewable heat has been achieved in countries that have excellent resources of geothermal heat (e.g. Iceland) or biomass (e.g. Nordic and Baltic countries). While district energy developments in these countries are generally much smaller than those in China, some of their incentives, policies and business models can still provide relevant insights, especially for certain localities.

Sweden, for example, has undergone a long-term shift in district heating systems from coal and oil to renewable fuels, particularly biomass from forestry residues and municipal waste (Figure 12). This gradual transition over several decades has been motivated initially by energy security concerns and later by decarbonisation policies. While oil accounted for 90% of fuel use in district heating plants at the end of the 1970s, by 2015 its share had dropped to just 2%, with biomass and municipal waste accounting for 70%. The financial case for this switch was strengthened by carbon taxation, for example the 2016 carbon tax of USD 131 (CNY 905) per tonne of CO_2 effectively doubled the price of heating oil.

The switch has been much quicker in Lithuania, where the contribution of biomass to district heating more than tripled between 2010 and 2016 to reach 64% (Figure 12). The key stimulus for this transition was the need to diversify heating fuels and reduce reliance on imported natural gas.

In Denmark, incentives like biomass subsidies and taxes on fossil fuels have steadily increased the share of renewables to over 50% in district heating. Denmark is also notable for using domestic agricultural residues such as straw for district heating. In other countries, overall deployment of renewables in district energy has been less widespread. At the local level, however, in cities such as Paris and Munich, moves are under way to switch to renewables (Box 6).

Figure 12 • Share of fuels in Swedish (left) and Lithuanian (right) district heating plants (1998-2015)



Source: Statistics Sweden (2017) and Lithuanian District Heating Association (2017).

Key message • Strong policy frameworks and the availability of domestic biomass resources have spurred major shifts from fossil fuels to renewable energy in Sweden and Lithuania.

Box 6 • Case study: Geothermal district heating in Paris and Munich

The European Union has the most dynamic market globally for geothermal energy in district networks. Between 2012 and 2016, 51 new geothermal plants began operating and a further 200 projects are planned. Installed capacity is expected to grow from 1.7 GWth to 6.5 GWth by 2020, with the main markets in France, Germany, Hungary and the Netherlands (European Geothermal Energy Council, 2017).

Greater Paris has the world's largest concentration of deep geothermal wells linked to district heating networks. Most of these exploit the warm waters of the Dogger aquifer (55˚C to 85°C) at a depth of 1 500 to 2 000 metres. First exploited in the Paris region in the 1960s, geothermal heat expanded during the 1970s as a response to the oil price shocks. A more recent boom in geothermal heat includes plants that access water at lower temperatures. The latest plant was put into operation in early 2017 in the Clichy-Batignolles area, supplying 83% of the heat needs of a new 54-hectare highly energy efficient housing development for 7 500 people. This plant extracts water at 30°C from the shallower Albien aquifer from a depth of 650 metres and then uses heat pumps to increase the temperature (Engie, 2017).

The district heating network in Paris is owned by the city and run as a public service concession by the *Compagnie Parisienne de Chauffage Urbain* (CPCU), which is owned jointly by the city authority and the energy company Engie. Renewable energy targets have been written into the concession contract; the current aim is to achieve 75% of renewable or recovered energy by 2020. A new concession contract will be awarded in 2024 which could include even more ambitious targets.

The geothermal heat developments benefit from a reduction in the value added tax rate for the heat sold from 20% to 5.5%. In addition, financial support has been available under the French government's heat funds (*Fonds chaleur*) programme. For example, the Clichy-Batignolles plant received more than USD 2.5 million (CNY 16.6 million) from the programme and other public funds to support a total investment of USD 13.3 million (CNY 88.4 million). Furthermore, investing in renewable heat earns exemptions from the carbon tax, which the French government is planning to increase progressively from USD 24.3 (CNY 161) per tonne of carbon in 2017 to USD 61.2 (CNY 407) in 2022.

In Germany, *Stadtwerke München* (SWM), the local utility of Munich, has committed itself to using renewables to supply 100% of its growing district heating demand by 2040. Currently, the majority of Munich's district heat is supplied by coal and gas co-generation plants. SWM sees geothermal heat as the main option for reaching its renewables goal, as the southern Bavarian Molasse basin offers good potential. SWM opened its first geothermal plant in 2004 and now has five plants in operation. In the pursuit of its ambitious 2040 target, SWM is working on a feasibility study for a further 400 MWth of deep geothermal heat supply and expects to open another four plants by 2025. The switch to geothermal heat will also require changes to Munich's district heating network, for example switching from steam supply to hot water in the inner-city area (Stadtwerke München, 2016).

SWM is a limited company, fully owned by the City of Munich. As such it operates on a commercial basis and still considers geothermal heat as a cost-effective technology. However, it does take a longer-term planning horizon and can accept longer payback periods than private sector companies. SWM received financial support of USD 3.6 million (CNY 24 million) from the federal government to support the mapping of geothermal resources in the city area but otherwise builds and operates the geothermal plants without subsidies. SWM is one of the largest utilities in Germany and can raise capital cheaply. Smaller utilities can apply for subsidised loans from the state-owned KfW Bank.

Both Paris and Munich also use municipal waste and biomass in their district heating schemes. For example, CPCU converted its boiler at Saint-Ouen in the Paris region from coal to biomass in 2016, and around 8% of CPCU's energy came from solid biomass and bioliquids in 2016. In addition, 43% came from municipal solid waste (CPCU, 2017).

Renewable energy options for heating and cooling

Biomass dominates renewable heat supply globally, and accounted for 95% of renewable district heat supplied in 2015, but several other renewable options are suitable. A key benefit of district energy networks is that they can integrate a variety of renewable options. The selection of renewable fuels tends to depend on available local resources. Options include:

Biomass: heat-only boilers or co-generation plants fuelled by woodchips, wood pellets, agricultural residue briquettes, the organic fraction of municipal solid waste or other solid biomass.[9] Biogas produced through anaerobic digestion of high moisture content organic wastes and liquid biofuels can also be used at smaller scales.

[9] Typically, around half of the energy content of municipal solid waste is attributable to biomass.

Solar thermal: large-scale solar thermal installations, either on roofs or freestanding. They are often combined with seasonal storage to extend availability to the peak heating season.

Geothermal: depending on resource availability, shallow or deeper geothermal wells (e.g. drawing hot water from aquifers). Lower temperature resources may need to be combined with heat pumps.

Heat pumps: electricity is used to extract renewable ambient heat from air, ground or water sources. Heat pumps, which can also utilise IEH heat sources, represent both an energy-efficient and a renewable option.

Most district energy networks with a high share of renewable energy integrate several different heat sources, including some excess heat and some fossil fuels (e.g. for periods of peak heat demand). In addition, heat pumps and electric boilers can play a useful role in helping to balance electricity networks that have high shares of variable renewable electricity.

Renewable cooling solutions include electricity from renewable sources, especially solar photovoltaic (PV) systems – as high insolation levels coincide with peak cooling demand – as well as heat pumps and absorption chillers using solar thermal or other renewable heat sources. Many district energy systems combine heating, cooling and electricity generation, often using tri-generation plants. Some of these use renewable fuels such as biogas.

These options are all available in China but the most appropriate mix differs from city to city. Geothermal district heating is already well advanced in some cities. Xiong county in Hebei province (which has 390 000 residents, part of the recently declared Xiong'an New Area) generates all its heat from geothermal sources. With several renewable heat targets in the 13th FYP, renewable deployment is set to expand significantly, especially for geothermal and biomass.

Scaling up solid biomass district heating in China

China possesses abundant biomass resources and has established a market for solid biomass heating fuels in forms such as pellets and briquettes. However, current demand is primarily from the industrial sector. The feedstock choice for biomass fuels differs by geographic location (Map 2), with pellets produced domestically from forestry residues, peanut shells and straw feedstocks. Briquettes are produced mainly from a variety of agricultural residues. Substituting coal consumption with biomass has the ability to reduce CO_2, SO_2 and NO_X emissions, while exploiting these resources can also support rural development.

Higher availability of agricultural residues within NUH provinces means these are likely to be more widely used for district heating than forestry residues. China possesses large quantities of agricultural residues, with an energy potential of over 409 Mtce (12 EJ) (Gao et al., 2016). These are underutilised, however, mainly because it is difficult to establish fuel supply chains to transport these dispersed resources to where they can be used. In some cases, this leads to burning in the field, which results in significant emissions of particulate matter (PM) without obtaining value from these resources. Agricultural residues are also generally more challenging to use for district heating than forestry residues because their composition is more variable and they sometimes contain contaminants, although these barriers can be overcome through adequate plant design and fuel pre-treatment.

Map 2 • Biomass resources in China and key coal phase-out areas

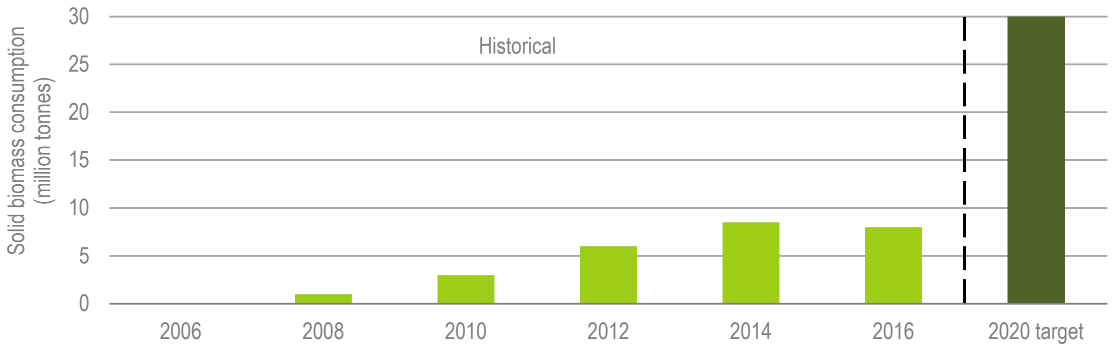
This map is without prejudice to the status of or sovereignty over any territory, to the delimitation of international frontiers and boundaries and to the name of any territory, city or area.

Key message • There is large potential for biomass resource use in district energy in China, which remains underutilised, due to the need to build fuel supply chains from these dispersed resources.

China's 13th FYP includes an ambitious target to scale up solid biomass consumption within the heating sector from around 8 million tonnes (Mt) in 2016 to 30 Mt by 2020 (Figure 13). Within the target, the technology required to use this fuel (e.g. heat-only boilers or co-generation systems) is not specified. The target also does not specify consumption by end use, for instance how much biomass should be used in district heating as opposed to industry. While there are sufficient agricultural and forestry residue resources to support such an increase, it remains an ambitious target given that global wood pellet consumption in 2016 was around 28.5 Mt.

Even if the 30 Mt biomass target was met and all this solid biomass was used in district heating, it would still only make a minor contribution to the substantial energy demand within the NUH: from around 5% to 8% in 2020, depending on the energy content of the biomass fuels used and how well energy efficiency targets are delivered. At the same time, solid biomass fuels will continue to be used within the industrial sector. As such, biomass should be viewed as one of a portfolio of low-carbon fuels for coal substitution in district heating.

Figure 13 • Solid biomass consumption for heating in China (2006-16) and 2020 target



Note: China does not report the use of bioenergy for heat in industry. Given China's significant pulp and paper industry, it is likely that biomass residues are used for heat but not reported in official statistics submitted to the IEA. As a result, the consumption reflected in the figure above is not reflected in IEA statistics.

Source: China National Renewable Energy Centre (CNREC) (March 2017), email to author.

Key message • Meeting the biomass targets in the 13th FYP would see a significant rise in biomass's contribution to heat demand, although use for district energy is not specifically mentioned.

The best opportunities for solid biomass use for heating in China are initially expected in industry and the district energy networks of towns and villages with nearby biomass resources. Deployment potential is further increased where local supplies of either coal or natural gas are limited. Among provinces and municipalities in the NUH with biomass resources and the strongest requirements to phase out coal, the highest potential to scale up biomass use in district heating is in Beijing, Tianjin, Hebei, Shandong and Henan. Other provinces where heat demand overlaps with biomass resources could use more biomass, depending on the relative economic case for biomass compared to other district heating fuels, such as natural gas (Box 7).

Box 7 • An economic assessment of solid biomass and natural gas heating fuels in China

Policies to limit coal consumption in China's heating sector open the door to alternative fuels for district heating provinces in the NUH. Solid biomass and natural gas are feasible substitutes for coal under the right heat pricing structure.

Currently, city gate[10] natural gas prices are determined by the NDRC and vary by province. In 2015, they ranged from CNY 78 (USD 11.3) per GJ in Shanghai and Guangdong to CNY 57 (USD 8.3) per GJ in Xinjiang. Local governments set natural gas prices for residential and non-residential consumers and district heating companies. Generally, residential gas prices are the lowest, followed by district heating company prices, with non-residential users subject to the highest gas charges. Conversely, solid biomass prices are determined by the market according to the calorific value of the fuel, which is in turn linked to the feedstock used.

Coal is the cheapest heating fuel if external costs such as environmental and health impacts are excluded (Table 4). Where air quality and decarbonisation concerns result in policies requiring diversification of heating fuels, biomass is cheaper than natural gas in many Chinese provinces. If energy demand necessitates imports of alternative fuels to coal, wood pellets at market rates of USD 86 (CNY 595) to USD 124 (CNY 860) per tonne would cost less on an energy basis than LNG, based on 2015-16 import prices. Both wood pellets and LNG imports require initial investment in logistics infrastructure, which is outside the scope of this analysis. Imported wood pellets are not anticipated to play a role in the Chinese heating market, however, as it is anticipated that domestic biomass will be prioritised.

[10] City gate refers to the location or measuring station where a natural gas distributor connects to the transmission system.

Table 4 • End user heating fuel price comparison in China

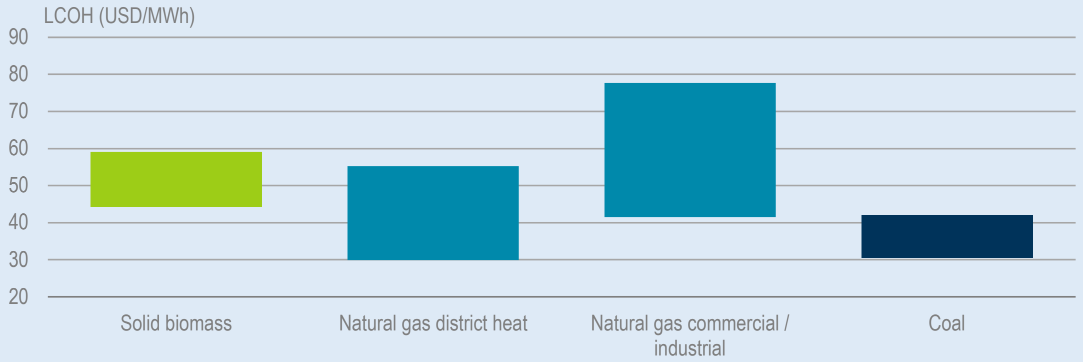
Fuel	Calorific value (GJ/tonne)	Fuel cost (USD/GJ)	Assumed boiler efficiency (%)	Delivered heat fuel cost (USD/GJ)
Natural gas (non-residential)	0.036*	8.4–19.2	92%	9.1 – 20.9
Natural gas (DH company)	0.036*	6.7–13.4	92%	7.3 – 14.5
Heating oil	41.9	16.5	88%	18.8
Coal	20.9	3.6–5.0	65%	5.5 – 7.8
Biomass briquettes	12.6	7.2	80%	9.0
Wood pellets	18.0	9.2	85%	10.8

Notes: *Calorific values for natural gas on a GJ/M^3 basis. DH = district heating. Non-residential natural gas price ranges based on minimum and maximum values across twenty-four provinces, DH company price range from minimum and maximum values across seven provinces. To convert gas prices to MBtu divide per GJ price by 0.947.

Sources: IEA analysis based on CNREC (April 2017), email to author; Hong, H. (2017).

Energy pricing is not the only consideration; a wider set of parameters need to be taken into account in a full cost comparison. For instance, investment costs per kW capacity for megawatt-scale natural gas heating boilers in China of about USD 86 (CNY 660) are less than global cost estimates for biomass boilers, which begin at around USD 318 (CNY 2 200). However, an assessment of the levelised cost of heat (LCOH) reveals that solid biomass can deliver heat similar to the lower-end cost of natural gas for commercial and industrial users. Compared with natural gas for district heating, the LCOH from biomass is competitive only where natural gas fuel prices are greater than USD 12 (CNY 80) per GJ. In 2015, city gate natural gas prices in 12 provinces fell into this category, including Henan, Beijing, Tianjin, Hebei, Liaoning and Shandong in the NUH area. Given the cost assumptions in Table 4, the LCOH from biomass fuel would not be competitive with coal. The LCOH for natural gas for district heating only reaches cost competiveness where fuel costs are below USD 10 (CNY 70) per GJ (Figure 14).

Figure 14 • LCOH comparison for solid biomass, natural gas and coal



Notes: LCOH ranges have been calculated based on the data shown in Table 4 alongside other assumptions. Investment cost assumptions are USD 300-500/kWth capacity for biomass, USD 100/kWth capacity for natural gas and USD 75/kWth for coal. Cost ranges shown are for heat-only boilers not co-generation systems.

Fuel costs are the largest overall contributor to LCOH for solid biomass, natural gas and coal. For solid biomass, however, initial investment costs are a far more significant part of the overall cost of delivered heat than for the other two fuels. This suggests that biomass could be more cost-competitive if domestic manufacturers were able to reduce solid biomass boiler investment costs. Carbon taxation of fossil heating fuels – natural gas and coal – would also make biomass more attractive.

The availability of biomass resources in the vicinity of heat demand needs to be taken into account – procurement is only permitted within a 100 km radius – as well as the consequent possibility of scaling up fuel production and supply chains. While scaling up fuel production from biomass resources can be challenging, it can also offer an opportunity for rural economic development (e.g. biomass pelletisation and fuel supply industry). For natural gas, too, location of available resources is a key consideration, including gas fields, LNG import terminals, pipelines and storage facilities.

City governments set the heat prices per square metre that district heating companies are able to charge for domestic and public buildings. Buildings that meet new efficiency standards pay more per unit of heat supplied than older building stock. In the cities of Beijing, Taiyuan and Xi'an, an assessment showed that at current heat prices, district heating companies would not make a profit using biomass or natural gas to supply heat to the current building stock. In more efficient new buildings, both alternative fuels could deliver a profit based on allowable heat charges in Beijing and Xi'an, but not in Taiyuan.

Current heat prices are based on lower fuel costs for coal and industrial waste heat. Therefore, switching from coal to natural gas and biomass will require a re-evaluation of heat charges and a continuation of efforts to improve building energy efficiency. In certain cities, environmental regulations need to be modified to allow the use of biomass technologies fitted with emissions control, to decarbonise energy production and improve air quality.

To justify replacing coal with solid biomass fuels on air quality grounds, biomass systems must offer efficient combustion and possess emissions-control equipment to significantly mitigate PM emissions. This will require increased manufacturing capacity for dedicated biomass heat and co-generation systems as well as fuel production technologies (e.g. pelletisation plants). It is anticipated that growth in biomass heating will initially come from heat-only boilers, with a gradual shift to incorporate co-generation systems. Action will be needed in the following areas:

- developing and implementing biomass fuel standards to ensure consistent fuel quality
- increasing the availability of more sophisticated small and medium-sized biomass boilers that offer higher degrees of automation[11]
- establishing and enforcing emissions standards from biomass boilers.

In addition, more robust policy support will be required. The NEA five-year plan for biomass development released in 2016 allocated USD 2.5 billion to fostering solid biomass fuel consumption and outlined support to increase private sector investment in the industry. How this funding will be used is not specified, however. A subsidy for the production of solid biomass heating fuels has been discontinued but could be re-established. Alternatively, a financial incentive for replacing coal with biomass could be introduced, as has been done for natural gas. Policy interventions may also be required to help develop supply chains for agricultural residues in order to increase fuel production from these resources.

Solid biomass and air quality

Policies that aim to phase out coal consumption in China's heating sector open the door to alternative fuels such as solid biomass. Biomass fuels have lower sulphur and generally less nitrogen than coal, and therefore emit less SO_2 and NO_X. Incomplete combustion of solid biomass can result in significant PM emissions, however (PM emissions are not significant for biogas or liquid biofuel). To reduce these emissions and deliver air quality benefits, biomass systems must

[11] Many biomass systems currently in use in China are adapted from coal boilers.

offer efficient combustion and possess emissions-control equipment. Modern emissions-control equipment can reduce PM emissions by over 99% (Biomass Energy Resource Centre, 2011), and is installed as standard in most sophisticated biomass stoves and boilers in Europe. This increases boiler investment costs so it is more cost-effective in larger systems for use in district heating systems than smaller scale boilers for individual buildings.

The economics of renewable options

The costs of renewable heat options span a wide range, even for applications in the same sector and the same country. They depend on many factors such as investment costs, local climatic factors, building conditions (e.g. levels of insulation), local resource availability (e.g. biomass) and energy taxation. Generally, applications in district heating are significantly cheaper than applications in individual buildings. International benchmark figures for some key renewable heat sources are as follows:

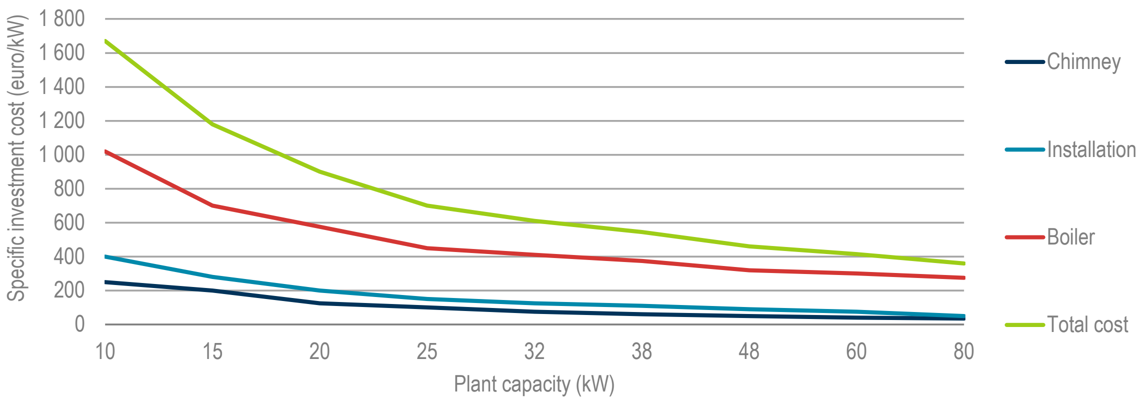
Geothermal district heating systems are often very competitive with fossil fuels, with costs ranging from USD 43 (CNY 295) per thermal megawatt hour (MWh_{th}) to USD 81 (CNY 560) per MWh_{th} (IEA, 2011). Even lower costs have been found in China for recent projects (Box 8).

Large-scale solar thermal systems for district heating are much cheaper than small rooftop systems. In Denmark, which is the world leader in solar thermal district heating with more than 900 MW_{th} installed, the average cost for large-scale systems (>10 000 m²) with seasonal storage is USD 51 (CNY 355) per MWh_{th}, but USD 128 (CNY 885) to USD 195 (CNY 1 350) per MWh_{th} for typical small domestic applications. However, the cheapest systems depend on the availability of cheap urban land, as can be found in some smaller Danish towns.

For the larger-scale biomass boilers used for district heating, delivered heat costs of USD 29 (CNY 200) to USD 77 (CNY 530) per MWh_{th} are achievable. Biomass fuel costs influence these results. For instance, wood pellet prices of USD 96 (CNY 660) to USD 139 (CNY 960) per tonne would result in fuel costs of USD 22 (CNY 150) to USD 30 (CNY 205) per MWh_{th}. The cost of biomass residues is generally lower and in some cases zero, if they are produced onsite through industrial processes.

Investment costs for biomass heating and co-generation plants for district heating benefit from economies of scale compared with lower-capacity installations in individual buildings (Figure 15). Typical investment costs for large (e.g. multi-megawatt) biomass district heating systems in Europe range from USD 506 (CNY 3 500) to USD 1085 (CNY 7 500) per kilowatt (kW) of capacity.

Figure 15 • Biomass boiler investment costs by capacity



Source: Reproduced from Rakos, C. (2017), "Pellet boiler markets – perspectives for the future", presentation at the 5th Central European Biomass Conferenced Nordic Baltic Bioenergy Conference, Graz, Austria, 18 January 2017.

Key message • Biomass boiler costs depend on plant capacity, as economies of scale can make costs in district energy systems relatively lower than those in smaller local (e.g. building) applications.

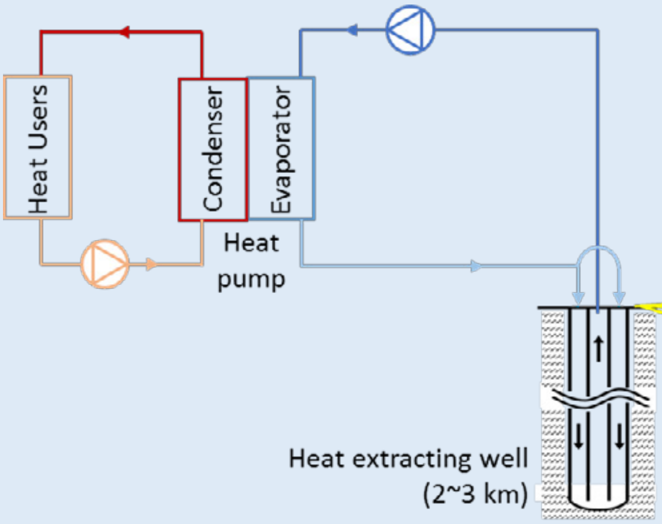
Despite competitive prices, especially at larger scales, it is still difficult for many renewable heat options to compete with fossil fuels, and particularly coal, in China. Existing heat pricing tariffs based on the cost of coal might be an obstacle to the development of renewable options (Box 7, Box 8). Policy frameworks should consider how heat pricing tariffs and market conditions either encourage or discourage integration of renewable energy sources. Renewables may not necessarily provide all of the required heat production but could nonetheless play a role in an integrated and diversified energy production portfolio (Box 9).

Box 8 • Case study: A deep geothermal heat system in Fengxi, Shaanxi province

Geothermal heating is seen by Chinese authorities as a way of avoiding air pollution. Important reserves and wide availability makes geothermal heat attractive. In Fengxi, a new town near Xi'an in Shaanxi province, four geothermal projects for commercial buildings provide heat for 70 260 m². Geothermal energy is extracted from an aquifer 2 000 metres deep at a temperature of around 70°C (see diagram). In contrast with traditional geothermal wells, from which water is pumped and then re-injected after heat extraction, heat transfers in Fengxi are done underground, without pumping water from the aquifers. Each well has a pipe inside a casing. The technology limits the geological and environmental risks of underground water use, although pipe length leads to some heat losses due to inefficiencies in heat transfer.

Water temperature from the wells is no more than 30°C. Heat pumps are required to raise the temperature high enough for space heating (45°C). According to test data during cold days in January, the average COP is 5*.

The major obstacle to exploiting geothermal heat, especially deep geothermal heat, is the initial cost. The wells in Fengxi cost nearly USD 145 (CNY 1 000) per metre, or around USD 289 436 (CNY 2 million) per well. The heating capacity of wells ranges from 250 kW to 400 kW, depending on the circulating water flow and the temperature difference between the inlet and outlet water. Assuming a 30-year lifetime, the cost of geothermal heat source is approximately USD 7.8 (CNY 54) per MWh_{th}. Considering the electricity consumption of the heating system of approximately 63 kWh/GJ,** the price of heat production is USD 34 (CNY 234) per MWh_{th}. Deep geothermal heat therefore could be competitive with natural gas boilers.



* Including electricity consumption of the heat pump unit and circulating water pumps, but excluding the DH circulating water pumps
** The price for industrial and commercial electricity is USD 0.1148 (CNY 0.7934)/kWh in Shaanxi.
Source: Building Energy Research Centre of Tsinghua University.

Box 9 • Case study: A multi-energy system in Suzhou Industrial Park, Jiangsu province

The Suzhou industrial park in Jiangsu province is a country-level administrative area of 288 km², with a population of around 810 000. Established as a Sino-Singaporean project in 1994, the zone hosts companies, as well as residential areas. It has also recently become a flagship for multi-energy distributed systems, providing power, heating and cooling. The area is supplied by two 360 MW gas power plants – which supply heat to 270 houses through a 62 km network – as well as 40.8 MW of distributed solar photovoltaic (PV) power, a 1.65 MW distributed gas engine and a cool production centre.

Further developments are planned, including an additional 3 MW of distributed gas turbines, 25.75 MW of distributed PV, 22.3 MWh of energy storage linked with the solar PV system, 5 MW of ground source heat pump, 150 kW of distributed wind power, as well as 200 electric vehicle charging points and demand-side management systems for 100 companies. By 2020, 20 km of heat network will be built. The different energy sources are integrated through a demand-side management and financial trading platform. A demonstration micro-grid of 100 000 m² is also planned, to integrate PV, gas-fired tri-generation co-generation, wind, excess heat and energy storage.

Policies to encourage renewable heat deployment

Generally, countries with high shares of renewable heat support renewable options in district heating with policy incentives or mandates. Such interventions are needed as in many countries the market does not price in externalities associated with fossil fuels, such as the emission of air pollutants and CO_2. Furthermore, renewable options can have higher capital costs than fossil fuel alternatives and, in some cases, entail risk. Costly drilling for geothermal heat, for example, may not always be successful in finding sufficient resources. Examples from five countries illustrate how key policy interventions can help to overcome those barriers (Table 5).

Table 5 • Major policy interventions that support renewables in district energy in selected countries

	Share of renewables in district heating	Key policy interventions
Denmark	51%	National target of 100% fossil free heating by 2035 No oil heating allowed in homes on district energy networks High energy taxes on fossil fuels, with an exemption for biomass Feed-in tariffs for biomass co-generation Investment subsidies for large-scale heat pumps in district heating systems through tenders Local heat plans
Finland	37%	Carbon tax with biomass exemption Local government requirements (e.g. Helsinki decision to shut down coal co-generation and replace with renewables) Heat “bonus” for biogas and biomass co-generation plants on top of their electricity feed-in tariff Investment grants for renewables
France	15%	*Fonds Chaleur* (Heat Funds): subsidies for renewable or waste-based district heating projects, aim is to bring the cost of renewable district heat at least 5% below that of heat from fossil-fuel sources Requirement by Paris city government for renewable share when issuing tender for running district heat network
Germany	12%	Investment grants under the KFW renewable energy programme for renewable heat plants (solid biomass boilers or co-generation, solar thermal, geothermal, heat pumps), as well as district heating networks, provided they have a minimum level of supply from renewable heat City-level targets, implemented by district energy companies that are often fully owned by municipalities (*Stadtwerke*)

Sweden	80%	Very high carbon tax with exemptions for biomass Electricity certificate scheme for some biomass co-generation Ban on landfilling combustible wastes

Key message • A range of policy interventions is necessary to overcome barriers that prevent greater deployment of renewables in district energy markets.

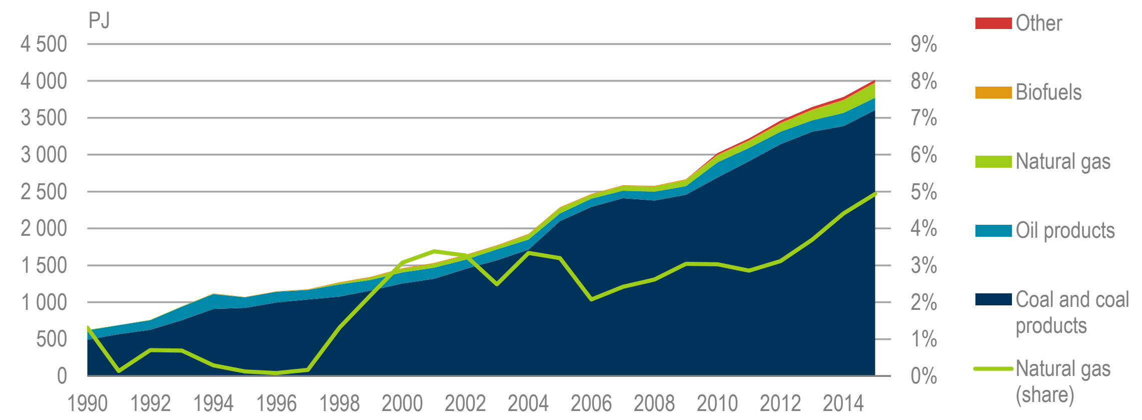
The role of natural gas

The use of natural gas as a fuel source for district energy is increasing in China and can play a stronger role in offsetting inefficient and polluting coal heat generation in China's NUH networks. Strong political support to improve air quality has already promoted increased production of heat from gas-fired boilers and co-generation.

The relatively low cost of coal continues to give it a dominant share of China's fuel mix for heat production, but recent government push for coal to gas switching has increased the share of gas-fired heating (Figure 16). In 2016, important efforts were made: the share of gas-fired applications reached 12% of surface covered by district heating, and 3% for gas co-generation (BERC, 2017). However, objectives set under the 13th FYP to improve air quality are expected to reduce the share of coal-fired heat production and increase the share of gas-fired heat generation.

The existing coal-based district heating systems in the NUH area are already gradually switching to natural gas and other alternative fuels. In 2015, roughly 11 bcm of natural gas was consumed for district heat production. Around 80% of the natural gas consumed for district heating was concentrated in six provinces, of which Beijing had the largest share with 35% (Map 3). Severe air pollution, particularly in the densely populated Beijing, Tianjin and Hebei regions, boosted the switch from coal to gas. Beijing urban areas are now entirely fuelled by four large gas co-generation plants.

Figure 16 • Share of natural gas in heat production in China, 1990-2015



Source: IEA (2017c), *Natural Gas Information* (database), www.iea.org/statistics.

Key message • The increase in gas-fired heat generation for district heat in recent years is likely to continue in the coming decade.

Alongside political and financial support, switching to natural gas requires efforts to accelerate the security of gas supplies. In the Beijing, Tianjin and Hebei areas, for instance, regasification terminals at Tangshan and Tianjin provide the opportunity to diversify the region's gas supply with liquefied natural gas (LNG), despite infrastructure challenges during winter. Other provinces, such as Xinjiang, produce natural gas or are located along the gas pipeline import route from the Caspian region, which provides access to several gas supply sources.

Map 3 • Provincial share of central heating consumption in urban (county) areas, 2015

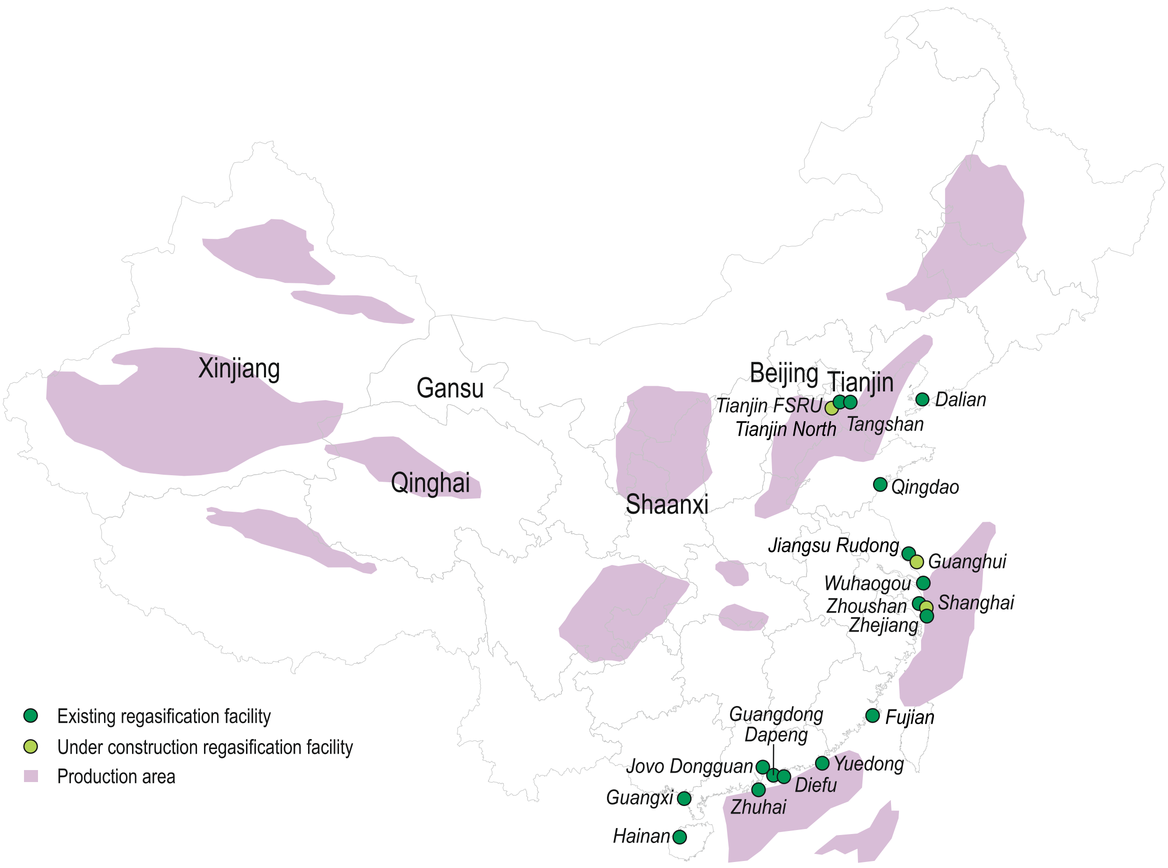
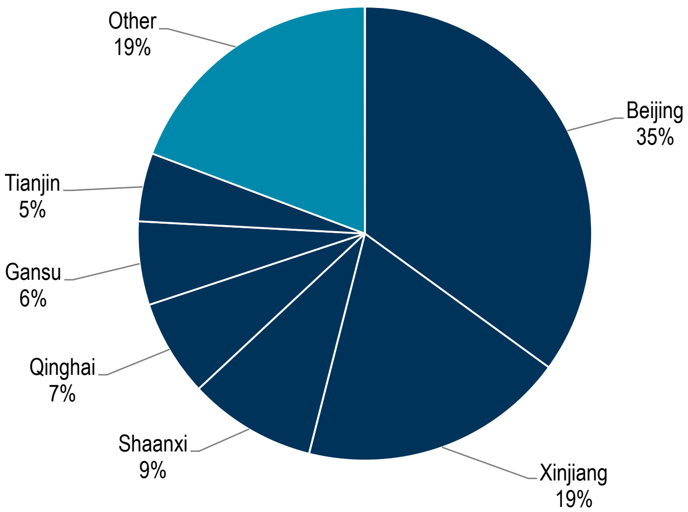


Figure 17 • Urban and county gas consumption for district heating (2015, 11 bcm)



Source: MOHURD (2015), *Statistical Yearbook of Urban and Rural Construction*.

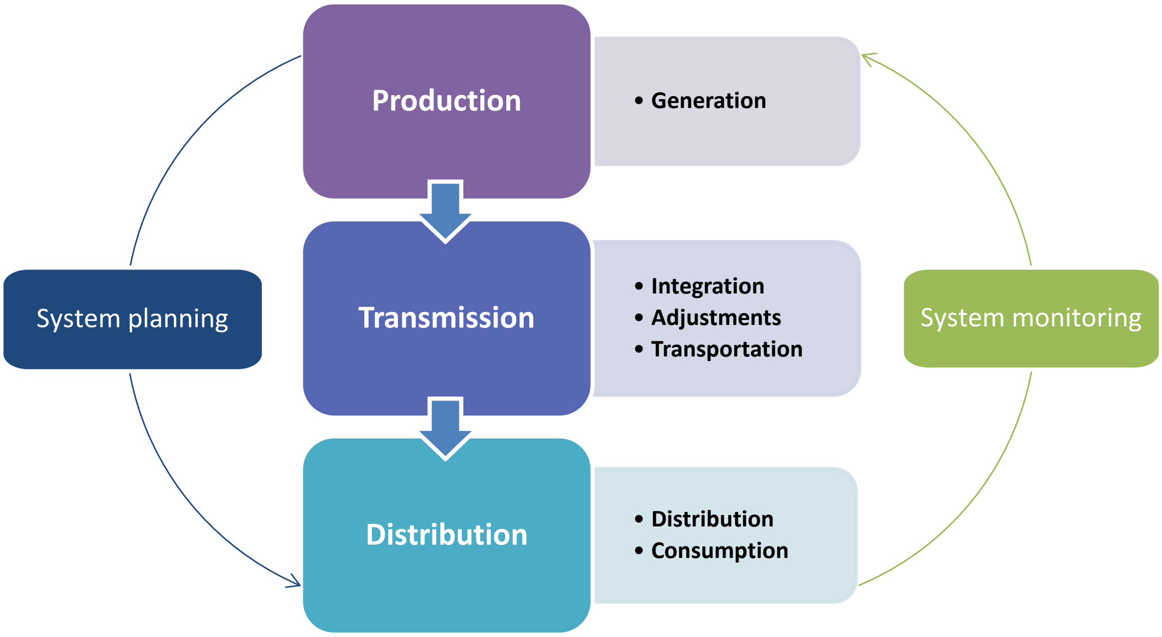
Key message • China's policy to increase air quality will provide growth potential for gas as a fuel in district energy production.

Natural gas (or LNG) can also be used in gas-fired absorption chillers and for waste cooling from regasification plants. This could be used in co-generation or tri-generation production in the HSCW zone, for instance, or in and around dense urban centres with large summer cooling demand.

Business models

A district energy system business model includes a range of ownership, financing and revenue options along the value chain of energy services, from generation to transmission, distribution and consumption (Figure 18). System monitoring and system planning are both key to ensuring effective business model decisions on pricing, investment and management. Innovations in district energy system business models are achieved by analysing the impact of changing products, services and pricing to meet customer needs.

Figure 18 • Placing district energy markets within the broader energy system framework



Key message • Business models and market frameworks should consider the role and viability of district energy systems as part of the broader energy market.

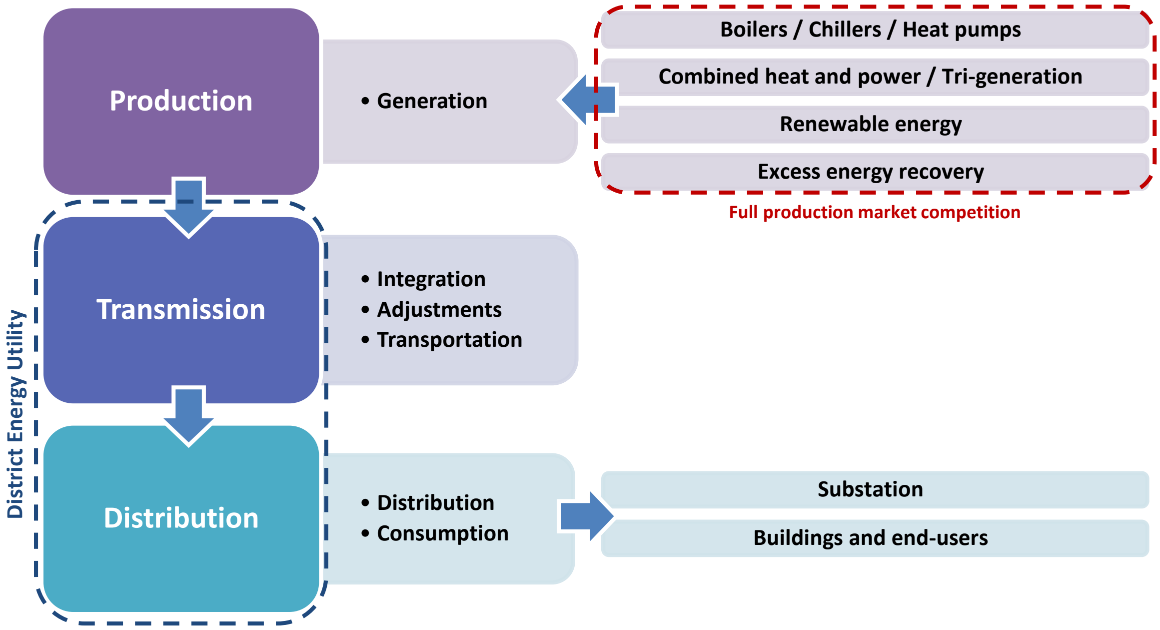
Applying district energy business models in China

Three business models with varying market structures are conceptualised in this section, including: (1) an energy production competition model; (2) a utility-led model with third party access; and (3) an energy service company (ESCO) integrated model.

Energy production competition business model

Energy production competition business models create full market competition for the generation of heating and cooling that supply district energy networks (Figure 19). One benefit of full competition with several energy suppliers is that innovation and efficiency can reduce market pricing for energy. Full competition can be hindered, however, by the typical monopoly that the energy utility has on full production, transmission and distribution of energy. In addition, appropriate system planning and monitoring is required to ensure that full market competition does not lead to unfavourable energy pricing (e.g. if short-term overproduction cuts into long-term capital costs for major district energy providers).

Figure 19 • Energy production competition business model



Key message • Full energy production competition removes production from the district energy utility while enabling several organisations and energy generation types to compete.

Establishing full market competition could help ensure a cost-effective transition to more sustainable and efficient district energy systems. Fortunately, China already has considerable experience in liberalising power markets. Lessons from this experience can be applied to competitive heat markets (Box 10). Improvements in China's district energy networks (e.g. heat metering with monitoring and controls) are also opening the way for market competition (Box 11).

Box 10 • The liberalisation process of China's power market

The restructuring of the Chinese electricity industry in 2002 unbundled one single state-owned company into seven large companies. State Grid and China Southern Grid, two of those companies, are "super grid" transmission companies that are not subject to competition. Like their peers in foreign markets, the Chinese grid operators are facing increasing pressure to liberalise the power market. The Chinese government has implemented regulations requiring grid companies to unbundle the accounting of transmission and distribution to provide market information on network system costs.

A vertically-integrated grid monopoly often has a financial incentive to discriminate against distributed-energy producers in favour of conventional generators. For instance, gas-fired co-generation and tri-generation market deployment are chronically constrained by gas supply infrastructure and high gas prices. Selling excess electricity to the grid raises the question of non-discriminatory third-party access to transmission networks, which would increase the cost-effectiveness of those co- and tri-generation technology investments. Regulated gas and power prices are slowly being overhauled, but successful pilot projects have already been established in some industrial parks, data centres and public facilities.

China is also developing a competitive wholesale market, including a pilot energy trading platform at the provincial level. Many electricity retailers are entering this emerging wholesale market. The Chinese government has planned to spend CNY 2 trillion (USD 315 billion) from 2015 to 2020 to improve its power grid infrastructure. The energy regulator recently ruled that only 75% of grid asset costs could be allocated to distribution, to limit overinvestment in transmission and distribution.

Box 11 • Case study: Customised heat utility

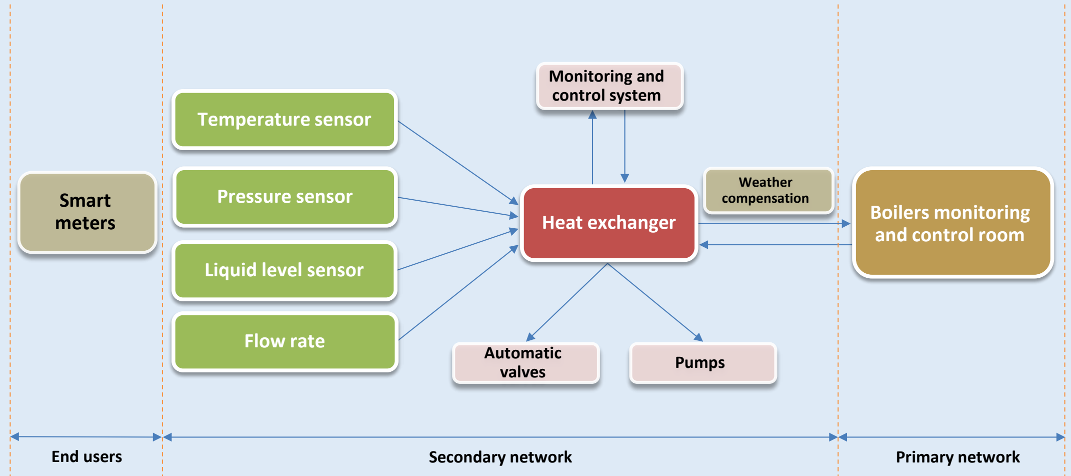
Heat supply in China commonly uses planned heat production to ensure a minimum indoor temperature in buildings. The prevailing centralised system in China connects different types of buildings at various distances from the heat substations. The heat companies typically rely on manual balancing valves, leaving heat consumers with limited or no control of the heat supply.

To increase the efficiency of the overall system, the supply temperature and flow need to be adapted to demand on a timely and variable basis. The constant flow and manually balanced network cannot customise end-user heat demand to optimise the system. To deliver the right amount of heat as cost-effectively as possible, the whole system needs to shift from a supply-driven to a demand-driven perspective. This means adapting the supply system to achieve variable demand while keeping the system hydraulically balanced.

The variable demand approach reinforces the competition from new entrants in the heat market. Dunan, a leading Chinese conglomerate, is one of the new challengers in this traditionally monopolised market. Dunan has piloted numerous technological innovations in a district heating project in Changyuan city (Henan province) to increase energy efficiency and improve thermal comfort for end users. For end users, the customised heat utility approach includes controls that adjust the temperature in the building based on occupant needs. The smart meter at the building is able to communicate the demand for heat to the heat supply network to optimise the temperature and flow of heat to the building from the secondary network's heat distribution (see diagram).

The secondary network enables the variable heat approach with the addition of a remote monitoring and control system that uses automatic valves and sensors to control the heat exchanger. A weather compensation unit is used to adjust the flow temperature based on the outdoor temperature in real time. The electronic sensors track changes in liquid levels, flow rates, pipe temperature and pressure so the system can react to variable demand. This approach allows data to be captured and analysed to understand heat production, transmission, distribution and consumption across the network.

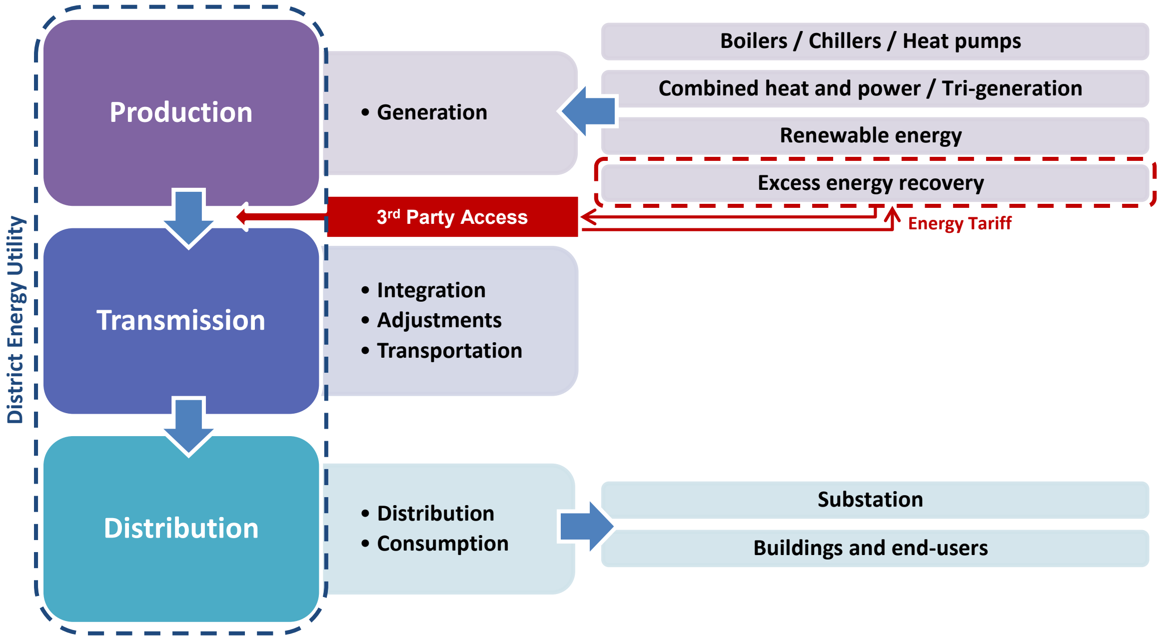
Altogether, this allows the primary network to operate at lower flows and higher temperature differences. This significantly reduces heat losses and pumping energy consumption, and saves money for both the district heating provider and consumers. With the help of these measures, the project in Changyuan has achieved energy efficiency of 0.26 GJ/m2 – a 19% improvement compared with current levels in the sector.



Utility-led business model with third-party access

The utility-led business model with third-party access enables the district energy utility to purchase energy from third parties with energy (Figure 20). This approach can allow utilities to integrate the most cost-effective energy sources into the network, while commoditising otherwise wasted energy, like excess heat from industry. This approach can also enable the selection of energy sources based on their environmental impacts (e.g. with appropriate incentives, price signals or tax schemes) to encourage third-party energy providers to help the utility meet broader sustainability goals.

Figure 20 • Utility-led business model with third-party access energy for excess heat recovery



Key message • Third party access enables energy production competition from third parties paid through an energy tariff while the main production is within the district energy utility.

Several examples of utility-led third-party access business models exist in district energy markets, including in China (Box 12). As with full market competition, policy frameworks and market conditions need to ensure attractive energy prices to encourage third-party energy providers to participate in the market. This also includes ensuring the right conditions and market stability (e.g. through contractual agreements and pricing tariffs) to address concerns of third-party participants such as IEH providers, who may not be interested in providing minimum energy services (i.e. heat) if varying energy demand and production affect their operations.

Box 12 • Case study: Heat market integrated business model in Qingdao, Shandong province

The city of Qingdao aims to adopt a non-coal based energy system with a low-temperature heat distribution network. Instead of coal, Qingdao will use natural gas, solar thermal, shallow ground geothermal and excess heat recovered from industrial plants to power its district heating, cooling and power production and distribution systems.

To achieve this transition, Qingdao has imposed a zero purchase price by allowing the use of excess heat for district heating services. With the support of this policy, the overall project indicates a financial internal rate of return of 10% because of savings in fuel costs. In the absence of free-cost excess heat, the project would not have been economically viable (Table 6).

The project will install small natural gas boilers, an excess heat recovery system from sewage plants and industry, heat pump systems, a solar heating system, a heat storage system and low-temperature pipelines in eight locations. These measures will help the city sharply reduce emissions of carbon and pollutants, directly benefiting 420 000 people by improving air quality and reducing household spending on heating.

The project is being implemented by Qingdao Energy Group, wholly owned by the Qingdao municipal government. The local government has requested a loan of USD 124 million (CNY 860 million) from the Asian Development Bank's ordinary capital resources to help finance the project. The loan has a

25-year term, including a grace period of 5 years. Qingdao Energy Group is financing USD 128 million (CNY 885 million) through an equity contribution.

Table 6 • Financial internal rate of return with various fuels as heat sources in Qingdao

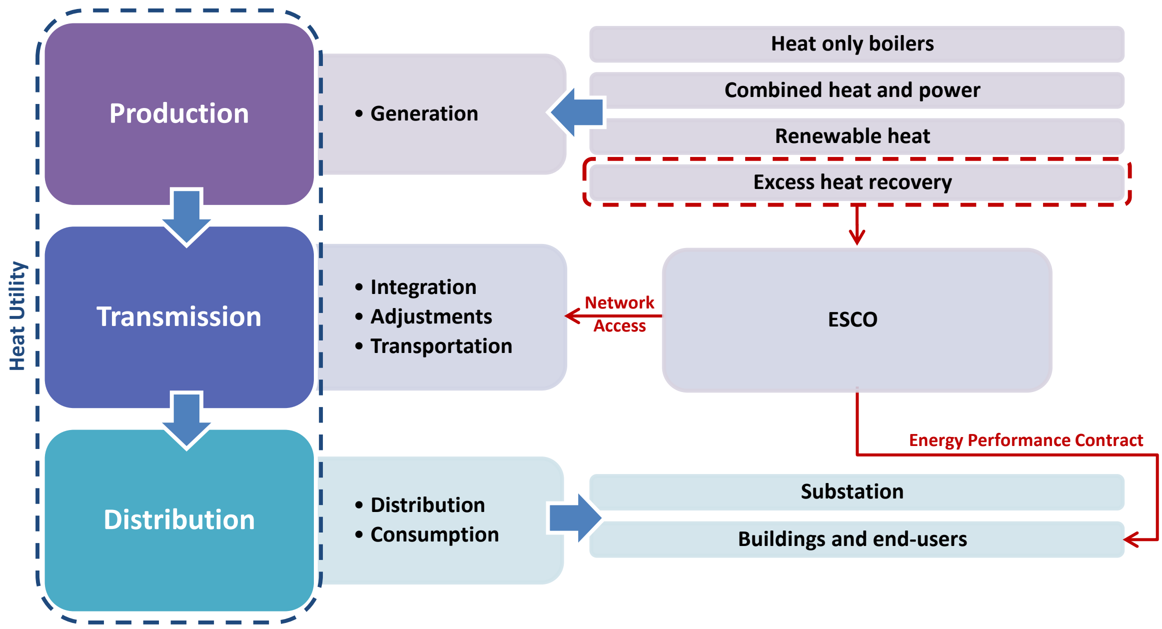
Heat source	Financial internal rate of return
1. Natural gas	- 1.5%
2. Shallow geothermal	Negative
3. Solar thermal	Negative
4. Excess heat utilisation	24%
Overall	**10%**

Source: Asian Development Bank (2017).

ESCO-integrated business model

Integration with an energy services company (ESCO) can result in simplified agreements between the utility and third parties to enable energy to enter the district energy network and to improve demand-side management. ESCOs can affect both energy supply (production) and consumption. In terms of energy supply, an ESCO can be an intermediary between energy producers and the wholesale market as it can trade energy on behalf of small-scale energy providers that are not able to participate in the electricity market (Figure 21).

Figure 21 • ESCO-integrated business model



Key message • Under ESCO integration, a single agreement with an ESCO can enable several smaller agreements that allow excess energy recovery (or other energy types) to enter the district energy system.

In terms of consumption, an ESCO typically creates an agreement with consumers either through shared savings or guaranteed savings contracts. Under a shared savings contract, the costs of savings are split with a predefined percentage, while under a guaranteed savings contract, the ESCO guarantees a certain level of energy savings.

With the help of advanced information and communication technologies, such as virtual power plants (VPPs), ESCOs can act as comprehensive energy services providers by pooling and managing various energy resources. This approach can allow ESCOs to become an integral part of smart grids, combining distributed energy, energy storage, and energy demand (commercial, industrial, residential and electrical vehicles) to optimise the district energy network.

China's ESCO market is the largest in the world and already has the capability to play a key role in district energy systems (Box 13). In 2015, China's ESCO market had annual revenues of USD 54 billion (CNY 371 billion) and helped achieve annual energy savings 3 600 PJ (124 Mtce). The number of ESCOs has increased six times since 2010 to more than 5 400 in 2015, cumulatively creating 607 000 jobs. Managing energy supply and consumption in the district energy system will be important for ESCO market growth.

Box 13 • Case study: An ESCO-integrated business model in Tangshan, Hebei province

Qianxi county is an administrative district of roughly 390 000 people in the eastern part of Tangshan city. District heat fuelled by coal-fired boilers has historically been the main source of space heating. Rapid growth of building floor area and district heat demand, along with restrictions on coal consumption, pose challenges to meeting energy and environment objectives in Qianxi.

A demonstration project was developed in 2014 to recover excess heat from two new nearby steel plants, with the aim of using three types of industrial excess heat for the district heat network: cooling water from the blast furnace, flushing water from blast furnace slag and mixed steam from basic oxygen furnaces and rolling heating furnaces. Using this heat recovery, the heating potential was estimated at 217.5 MW, which could serve the district's basic heat load through to 2030.

The ESCO, Qianxi Heran Energy Conservation Company, has created a joint venture district heating company with the local government. The district heating company concluded a concession agreement with the local government and a long-term contract of using excess heat with local steel plants. The ESCO then signed an engineering, procurement and construction contract with the ad-hoc district heating company under the shared savings approach. The ESCO was in charge of providing third-party finance for project investment.

The district heating company rents the franchise rights to service the district heat network from the local government, and the excess heat recovered from the steel mill is purchased at CNY 4.8 (USD 0.69) per GJ. Local buildings then pay a heat price of CNY 24 (USD 3.53) per m2.

The project has three phases. The total investment for the first phase of the project was approximately CNY 297 million (USD 43 million), which included transport pipelines, pipelines inside the plants, heat recovery devices, and a new heating station. The second phase is expected to cost an additional CNY 53 million (USD 7.7 million) and the third phase CNY 117 million (USD 17 million). When complete, the project is expected to reduce the annual district heat production cost by nearly CNY 31 million (USD 4.5 million) in 2016 and CNY 66 million (USD 9.5 million) in 2030. The whole project's payback period is roughly seven years across the three phases (Table 7).

Table 7 • Cumulative investment and benefit over three phases of the Qianxi excess heat project

CNY million	2016	2020	2030
Long-distance transport pipeline	170	170	170
Devices and pipelines in plants	113	113	128
Heat station	*20*	*20*	*20*

Pipes inside steel plant	*45*	*45*	*55*
Heat exchangers	*30*	*30*	*35*
Absorption heat pumps	*18*	*18*	*18*
Advanced heating substations	-	46	146
Total investment	**283**	**334**	**444**
Annual cost reductions	**28**	**41**	**63**
Payback (years)	**10.1**	**8.1**	**7.0**

Source: IEA (2016b), *Energy Technology Perspectives 2016*, OECD/IEA, Paris.

Impact of sector coupling on business models

Coupling of electricity, heat and cooling markets creates challenges and opportunities for district energy system business models that affect demand management and network optimisation.

District energy networks need to manage increasingly variable electricity supply sources, such as solar PV or wind power, and fluctuating energy demand. With a greater proportion of variable supply sources, enhanced capacity to manage the intermittency of the electricity grid becomes more important to maintain power quality in real time.

Sharing energy resources or surplus energy with neighbours can help monetise energy that is not managed within the district energy utility. By connecting peers with one another, this collaborative economy business model can value under-utilised assets. The rise of the sharing economy is jump-starting business innovations for energy demand and storage management. Building owners can share electricity through a distributed solar PV market with rooftop leasing, which can also translate to business models for district thermal energy sharing.

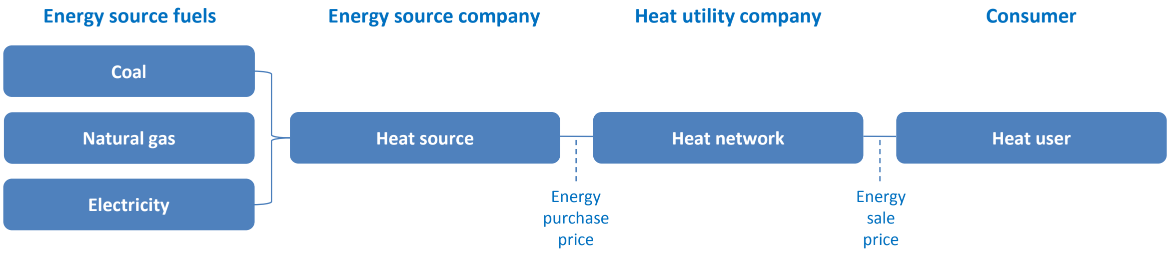
Demand management can be improved by allowing energy consumers to purchase energy from or sell energy savings to retailers that serve as an aggregator. This business approach can reduce peak loads in the district energy network by using energy stored from less expensive off-peak generation. With almost 70% of China's power demand coming from large industrial consumers, there could be considerable potential for electricity trading among these consumers, with or without an aggregator.

Pricing options

District energy prices are regulated by provincial or city administrations. In 2006, the State Council ordered the implementation of progressive marketisation in order to promote heat as a commercial product, with prices based on heat quantity (SC, 2006). This principle was incorporated in the revised energy saving law in 2007 (Central Government, 1998), and in an administrative measure that allows non-public capital to invest in heating facilities. While prices are set by local governments, they can be determined directly between producers and consumers after consultation. Prices are divided into three components: heat produced, transmission costs and end-user price (categorised by end-user type). The final price consists of heat costs (in terms of fuel cost, capital, operational and related maintenance costs), taxes and profits not exceeding 3% of total cost (NDRC, MOHURD, 2007). Further market-oriented prices for some areas were recently suggested by NDRC (NDRC, 2017a).

In theory, this three-part pricing structure can reconcile heat production efficiency and network investment return. In reality, however, heat billing is largely based on a flat energy cost per m^2 regardless of heat consumption (Figure 22). Heat tariffs are highly regulated as part of social welfare, to ensure that low-income consumers have access to heating. The large majority of employers pay heat bills for their employees. While the Chinese government does encourage consumption-based billing, consumers do not face pricing incentives as long as heat is not fully commoditised.

Figure 22 • Heat pricing structure in China



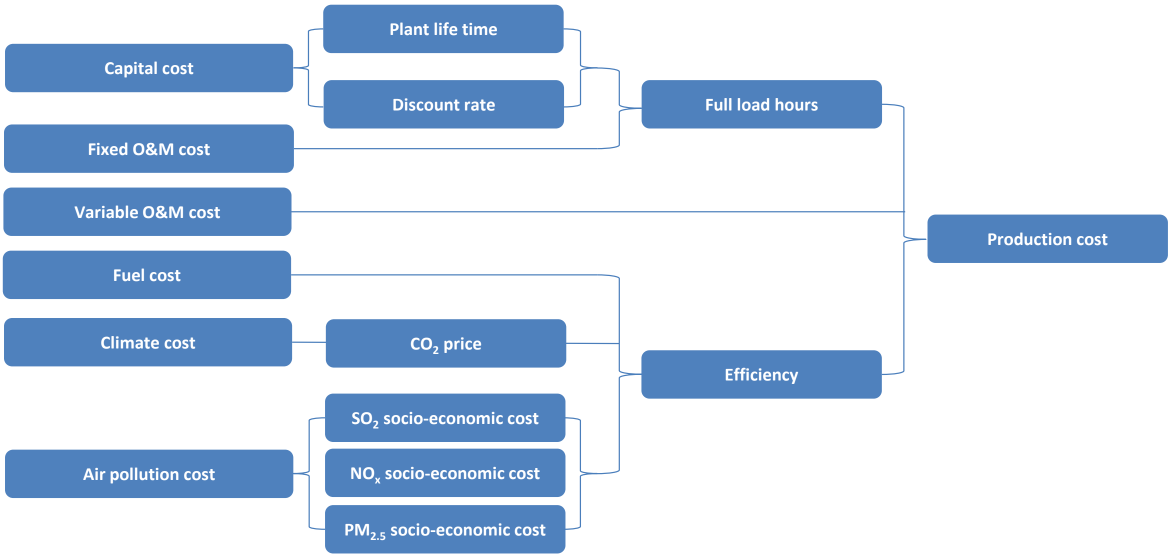
Key message • A three-part pricing structure reflect the real costs of heat generation, distribution and consumption, to improve efficiency and allow a wider mix of energy inputs, but requires strategic shifts away from the current flat-fee pricing structure in China.

While the coal market in China is subject to liberalisation, heating companies cannot pass variations of fuel costs on to the regulated heat tariff. Rising coal prices have resulted in claims from companies that current heating revenue does not allow them to sustain and improve heating services. With the heat market traditionally subject to limited market competition, the large monopoly heating companies have a strong incentive to exaggerate the business loss due to the regulatory policy in order to cross-subsidise their production and distribution activities. In cases where a third party can supply excess or renewable heat to the district energy network, the incentive for energy utilities may be further exaggerated due to less utilisation of the existing assets.

System analysis of excess heat pricing

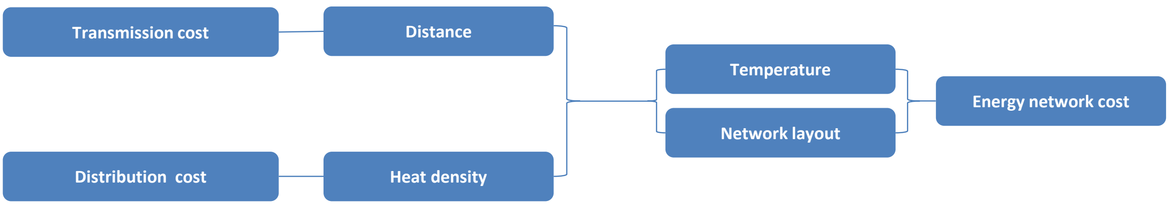
A systemic pricing approach aims to allocate the total system costs and benefits to corresponding market actors. Ideally, the regulator needs to investigate the "socially cost-effective" potential of each heating solution, based on cost and benefits for society as a whole. In particular, the production cost would reflect investment costs, fuel costs, operation and maintenance costs, and indirect costs and taxes associated with environmental externalities, including air quality damage costs (SO_2, NO_X and PM 2.5) and costs of CO_2 emissions. Typically, this systemic approach would consider integrated options of demand and supply, construct a baseline to provide a reference scenario, identify and evaluate high-efficiency alternatives to the baseline, and compare long-term costs and benefits of the options (Figure 23, Figure 24, Figure 25).

Figure 23 • The production cost structure for district energy systems



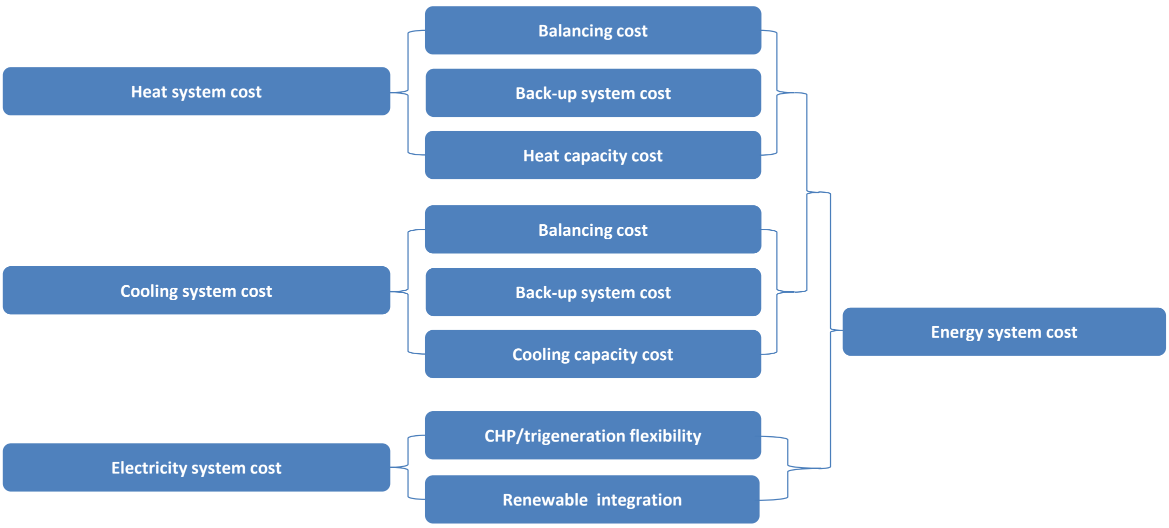
Key message • Energy production cost is the sum of costs for systems, fuel and environmental impacts.

Figure 24 • The district energy network cost structure



Key message • Energy network cost is the sum of transmission and distribution costs.

Figure 25 • The integrated district energy system cost structure



Key message • An integrated district energy system is the sum of heat, cooling and electricity costs.

Zero-cost excess heat

If the government is not ready or able to quantify costs and benefits from the system and societal perspective, it can implement a free excess heat policy by encouraging heat companies to use excess heat. Given the high capital costs of the distribution infrastructure, district heating utilities can take advantage of zero-cost excess heat sources to integrate more clean heat into the whole system. The government needs to play an important role by establishing an energy efficiency obligation, or a clean energy or emissions reduction target. With a no-profit objective, this option allows sharing of the financial gains of providing low-cost excess heat to customers.

Setting clean heat targets and obligations

The government can create a market by establishing a clean energy obligation that requires heating companies to diversify heat sources. This will encourage companies to look for the most cost-effective sources, and enable direct pricing of renewable and excess heat in comparison with the alternatives. Targets are already being set in China, with 23 cities and provinces committed to ensuring that emissions peak around 2020 or 2025, five or ten years ahead of China's national aim to ensure emissions peak by 2030. These cities have formed an Alliance of Peaking Pioneer Cities, which represents one-quarter of China's urban carbon emissions. Improving district energy efficiency is a major policy requirement of meeting their climate change commitment. In such a context, the government can place energy-efficiency or emissions-reduction obligations on district energy companies. Environmental and emissions taxation can assist the transition to cleaner fuels, with heat companies using financial analysis to optimise their fuel mix.

Indexing against the next-best alternative

Clean heat can be valued in relation to the alternative for district heating production. A new heat source is usually used to replace a more expensive fuel. The heat price of this alternative fuel can provide a good price metric against which clean heat is benchmarked. To apply this pricing model, the heat market will need to regularly monitor the prices of various heat sources in order to establish the benchmark.

As an alternative approach, the regulator can also price clean heat at a certain percentage discount of the least expensive heat production prices. If indexing methods pose risks of excessive fluctuation in clean heat prices, the regulator can set price caps, below which the price-setting tends to be more market-driven and less reliant on regulatory oversight.

Recommendations in the Chinese context

Policies and planning: Prioritise flexible, local solutions

- Locally based and tailored solutions are required to optimise and diversify district energy.
- Local, regional and national heating and cooling strategies are needed that map heat demand and potential heat supply to identify cost-effective opportunities for co-generation, renewables, excess heat and other options.
- A flexible approach that takes into account local conditions – including heat demand and heat sources – is preferable to an exclusively top-down approach.
- Local governments could be required to carry out heat mapping and assessments of demand and resources in order to choose the most suitable options.
- District heating networks could be dramatically improved through urban planning that increases densities and distributed (i.e. decentralised) energy potential.
- Long-term planning should be systematised, in parallel with industrial development planning for waste heat.
- Improving heating statistics would contribute to better policies.

Policies and market: Gradually promote fair prices with government support

- A clear policy framework and predictable market context are needed to support cost-effective diversification of heat sources, including renewables and IEH.
- Policy needs to ensure that market conditions promote transparent, fair prices that reflect the real costs of electricity and heat production, levelling the playing field for excess heat and other fuel inputs.
- Business models need to become more service-oriented and demand-driven.
- Clean energy sources need positive price signals, such as taxes on heat from coal for new districts, to become competitive with coal.
- Financial or fiscal incentives may be necessary to mitigate market failures (e.g. unfair pricing of electricity and heat), including integration of environmental benefits to reflect the "true" costs of heat generation for district energy.
- Policy interventions may be required to support the mobilisation of supply chains for biomass or waste fuels, and the introduction of fuel quality standards; this is especially relevant to agricultural residues, given their significant availability inside the NUH area.
- Including district heating in the national emissions trading system could help reduce CO_2 emissions from the sector.

Demand side: Develop adequate solutions based on assessed demand

- Demand-side analysis is essential in order to choose energy pathways that better match supply and demand.
- Development of new district energy should be demand-based (assessing demand first) and enable system balancing.
- To ensure district heating and cooling are sustainable, it is critical to reduce heat demand by improving building envelopes, including through retrofitting, and by limiting overheating in buildings (e.g. by using meters, sensors and controls).

- Heat mapping should also consider building energy performance, to identify where energy efficiency measures (e.g. building envelope improvements) will be most effective in improving heat demand and district energy network performance.
- Improving the intensity of building heat demand, alongside improved and cleaner heat generation, will require more flexible market structures (e.g. ESCOs) and policy frameworks that reward energy efficiency.
- Education on behaviour and energy conservation can support better demand-side management.

Supply side: progressively develop cleaner sources

- Heat supply should be based on locally-available heat sources and the scale of the district energy network.
- To limit air pollution, coal boilers should be avoided in larger cities, and reduced to a minimum or switched to cleaner coal in medium-sized cities.
- Excess heat and renewable sources, including geothermal and biomass, should be promoted according to locally available resources.
- Heat sources can be diversified with co-generation, heat recovery from gas boilers, IEH, excess heat from data centres, and renewable energy, but will require appropriate pricing signals and market frameworks.
- Geothermal should be considered an option only if environmental impact assessment allows.
- Excess heat recovery should be considered given its enormous potential in China, but policy and market frameworks that support appropriate business models are key to achieving that potential.
- Excess electricity generated by gas co-generation in comparison with coal co-generation should be anticipated and managed effectively, including pricing structures that encourage reasonable heat to power ratio.
- To integrate a higher share of renewables, a variety of sources are needed, often requiring business models (e.g. third-party access) that allow for variable heat generation.
- Where local resources are available, biomass represents an option to substitute coal in district heating.
  - The best opportunities for solid biomass use are initially expected in industry and the district heating networks of towns and villages with nearby biomass resources.
  - Biomass can offer lower fuel costs than other alternatives such as natural gas in many provinces.
  - Although solid biomass fuels generally emit less SO2 and NOX than coal, to justify their use on air quality grounds biomass boilers must offer efficient combustion and possess emissions-control equipment to significantly mitigate PM emissions.

The IEA CHP and DHC Collaborative and the Technology Collaboration Programme

The IEA CHP and DHC Collaborative was initiated in 2007 to accelerate global deployment of cost-effective, clean co-generation and district energy technologies. Its broad aims are to increase use of renewable energy, reduce GHG emissions and increase overall efficiency of the energy system. The Collaborative also aims to provide a platform for stakeholders to share best practices, policies, experiences and applied solutions for these technologies. Collaborators include governments, international organisations, regional industrial associations and the private sector, including equipment suppliers and utility companies.

The IEA CHP and DHC Collaborative has completed several publications that provide a vision of co-generation and district energy potential, along with an overview of policy best practices and recommendations to consider when implementing these policies. The Collaborative's 2014 report *Linking Heat and Electricity Systems: Co-generation and District Heating and Cooling Solutions for a Clean Energy Future* developed a compendium of case studies on both industrial co-generation and integrated approaches to co-generation with DHC. The report distilled lessons from the case studies to inform analysis of barriers to increased penetration of co-generation and efficient DHC technologies, while identifying opportunities to demonstrate the applied value of co-generation and DHC to achieve sustainable energy systems.

The IEA *Energy Technology Perspectives 2016* (*ETP 2016*) (IEA, 2016b) looks at the technology and policy opportunities, including co-generation and efficient DHC, available for accelerating the transition to sustainable urban energy systems. This includes in-depth case studies of integrated and advanced district energy solutions to achieve affordable, energy-efficient and low-carbon local communities.

The IEA CHP and DHC Collaborative's Country Scorecards, including recent reports on the United States (2014) and Sweden (2016), review the status of co-generation and DHC in the national policy context. They outline recent policy efforts and identify strengths and weaknesses in programmes and markets; evaluate potential for additional deployment; and identify country-specific challenges to co-generation and DHC. Each report provides a set of policy strategies to overcome market and policy barriers.

The IEA CHP and DHC Collaborative has benefited from expertise of the IEA Technology Collaboration Programme (TCP) on District Heating and Cooling (DHC TCP). Since 1983 the DHC TCP has been carrying out applied research on design, performance and operation of distribution systems and consumer installations, including co-generation. With more than 80 research projects completed, the DHC TCP is dedicated to helping make DHC and co-generation powerful tools for energy conservation and the reduction of environmental impacts of supplying heat. The research addresses both technical and policy-related issues. Current projects include a transformation roadmap from high- to low-temperature systems, optimising urban form for district networks, a user-centred approach to system operation and management, governance models and processes for deploying thermal grids, and a joint project with other TCPs on low-temperature district heating for future energy systems.

Acronyms, abbreviations and units of measure

Acronyms and abbreviations

BERC	Building Energy Research Centre (Tsinghua University)
BF	blast furnace
BOF	basic oxygen furnace
CDQ	coke dry quenching
CHP	combined heat and power
CNREC	China National Renewable Energy Centre
CNY	Yuan renminbi
CO_2	carbon dioxide
COP	co-efficient of performance
CPCU	*Compagnie Parisienne de Chauffage Urbain*
DEA	Danish Energy Agency
DES	district energy system
DH	district heating
DHAT	District Heating Assessment Tool
DHC	district heating and cooling
EAF	electric arc furnace
EE	energy efficiency
EH	excess heat
ESCO	energy service company
ETS	Emissions Trading Scheme
FYP	Five-Year Plan
GHG	greenhouse gases
GNI	gross national income
HDD	heating-degree days
HSCW	hot summer and cold winter zone
IEA	International Energy Agency
IEH	industrial excess heat
IFC	Internal Finance Corporation
IIP	Institute for Industrial Productivity
IRENA	International Renewable Energy Agency
LCOH	levelised cost of heat
LNG	liquefied natural gas

m^2	square metre
MEP	Ministry of Environmental Protection
MLR	Ministry of Land and Resources
MoF	Ministry of Finance
MOHURD	Ministry of Housing and Urban-Rural Development
NBS	National Bureau of Statistics
NDRC	National Development and Reform Commission
NEA	National Energy Administration
NO_x	nitrogen oxide
NUH	Northern Urban (district) Heat area
ORC	organic Rankine cycle
PM	particulate matter
PV	photovoltaic
R&D	research and development
RTS	Reference Technology Scenario
SC	State Council
SWN	*Stadtwerke München*
TCP	Technology Collaboration Programme
UNEP	United Nations Environment Programme

Units of measure

bcm	billion cubic metres
°C	degree Celsius
EJ	exajoule
GJ	gigajoule
GW	gigawatt
Mtce	million tonnes of coal-equivalent
t	tonne

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Glossary

Biofuels	Fuels derived from biomass or waste feedstocks; includes ethanol and biodiesel.
Biomass	Renewable energy from living (or recently living) plants and animals; e.g. wood chips, crops and manure..
Co-efficient of performance (COP)	Co-efficient of performance represents the energy efficiency ratio (watts in cooling equivalent per watt of electricity consumption): the higher the COP, the greater the energy efficiency.
Co-generation (or combined heat and power)	The simultaneous generation of both electricity and heat from the same fuel, for useful purposes. The fuel varies greatly and can include coal, biomass, natural gas, nuclear material, the sun or the heat stored in the earth. Trigeneration is the simultaneous generation of electricity, heat and cooling.
Energy efficiency	Something is more energy efficient if it delivers more services for the same energy input, or the same services for less energy input.
Energy intensity	Measure of total primary energy use per unit of gross domestic product.
Excess heat	The heat content of all streams leaving an industrial process at a given moment in time. The extent to which heat can be technically and economically recovered depends on the characteristics of the heat sources and the availability of a compatible end use.
Geothermal	Energy available as heat emitted from within the earth's crust, usually in the form of hot water or steam.
Heat	In IEA energy statistics, heat refers to heat produced for sale only. Most heat included in this category comes from the combustion of fuels, although small amounts are produced from geothermal sources, electrically powered heat pumps and boilers.
Low-carbon technologies	Technologies that produce no or low GHG emissions while operating. In the power sector this, includes fossil-fuel plants fitted with carbon capture and storage, nuclear plants and renewable-based generation technologies.
Lower heating value	The heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as a vapour and the heat is not recovered.
Mini-split	Split air-conditioning systems are typically characterised by an indoor unit that distributes cooled (or heated) air with an outdoor unit that houses a heat pump compressor with heat exchanger

	and fan. Mini-split systems are similar to normal split systems but have smaller capacities, with the advantage that they are ductless and typically only cool the desired space (or room).
Power generation	Fuel use in electricity plants, heat plants and combined heat and power (CHP) plants, including main activity producer plants and small plants that produce fuel for their own use (auto producers).
Shallow geothermal	The energy stored in the form of heat from the soil surface down to a depth of 400-500 m, in areas without specific geothermal anomalies. Low- to moderate-temperature heat found in the upper geological layers can be harnessed by shallow geothermal systems and serve as a source of heat for heat pump applications. It may also be directly used for comfort and process cooling, especially in colder climate zones.
Smart grid	An electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimising costs and environmental impacts while maximising system reliability, resilience and stability.
Subsidy	As monitored by the IEA, any government action directed primarily at the energy sector that lowers the cost of energy production, raises the price received by energy producers or lowers the price paid by energy consumers.
Traditional biomass	The use of fuelwood, charcoal, animal dung and agricultural residues in stoves with very low efficiencies.
Underground/ground source heat pump	A central heating and/or cooling system that extracts heat from the ground in winter and transfers the heat into buildings. Equally it can be used to provide an efficient mechanism for heat to escape from buildings down into the ground in summer. Ground source heat pumps are suitable for a wide variety of buildings and are particularly appropriate for projects with a low environmental impact.

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