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CNREC CHINA NATIONAL RENEWABLE ENERGY CENTRE

IRENA International Renewable Energy Agency

ZHANGJIAKOU

Energy Transformation Strategy 2050

Pathway to a low-carbon future

IRENA
International Renewable Energy Agency

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ABBREVIATIONS

oC	Degree Celsius
AC	Alternating current
BEV	Battery electric vehicle
BTM	Behind the meter
CHP	Combined heat and power
CNREC	China National Renewable Energy Centre
CO_2	Carbon dioxide
COP	Coefficient of performance
CSP	Concentrating solar power
DC	Direct current
DNI	Direct normal irradiance
EV	Electric vehicle
FCEV	Fuel cell electric vehicle
gce	Gram of coal equivalent
GDP	Gross domestic product
GIS	Geographic information system
GW	Gigawatt
GWh	Gigawatt-hour
HVDC	High-voltage direct current
ICE	Internal combustion engine
IRENA	International Renewable Energy Agency
kg	Kilogram
kgce	Kilogram of coal equivalent
km	Kilometre
km^2	Square kilometre
kV	Kilovolt
kVA	Kilovolt-ampere
kW	Kilowatt
kWh	Kilowatt-hour
LPG	Liquefied petroleum gas
m	Metre
m^2	Square metre
m^3	Cubic metre
MW	Megawatt
MWh	Megawatt-hour
MSW	Municipal solid waste
NDRC	National Development and Reform Commission
PV	Photovoltaic
R&D	Research and development
SGCC	State Grid Corporation of China
tce	Tonne of coal equivalent
TFEC	Total final energy consumption
TPEC	Total primary energy consumption
TWh	Terawatt-hour
UK	United Kingdom
UN DESA	United Nations Department of Economic and Social Affairs
US	United States
USD	United States dollar
V	Volt
V1G	Unidirectional charging
V2G	Vehicle-to-grid
V2H/B	Vehicle-to-home/building
VRE	Variable renewable energy

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EXECUTIVE SUMMARY

Zhangjiakou is a medium-sized Chinese city of 4.4 million people located in north-west Hebei Province, adjacent to Beijing. With its abundant renewable energy resources and excellent skiing conditions, the city was selected to support Beijing in hosting the low-carbon 2022 Winter Olympic Games. This has provided Zhangjiakou with an opportunity to showcase the impressive renewable energy development that it has achieved over the past few years.

Looking at the longer term, the State Council of China has designated Zhangjiakou to become the country's first-ever National Renewable Energy Demonstration Zone. This has offered the city both political and policy support in developing its abundant renewable energy resources to meet local energy demand. More profoundly, it provides an opportunity for Zhangjiakou to serve as the test bed for applications of advanced and innovative renewable energy technologies, as well as for power sector reforms in favour of accelerating the nationwide scale-up of renewable electricity generation and use.

Institutionally, the steering committee overseeing the development of the Demonstration Zone has been established under the co-leadership of the vice-chairman of the National Development and Reform Commission (NDRC), the provincial vice-governor and the deputy administrator of the National Energy Administration. This guarantees effective cross-ministerial co-ordination on the approval of innovative policies and regulations to be proposed by the local government to scale up renewables in the Zone.

Another advantage that Zhangjiakou could leverage in designing innovative policies to spur the development and deployment of new technologies and applications is its long-standing partnership with the Chinese Academy of Sciences in advancing the city's scale-up of renewable energy.

In addition, policy and market innovations can play a significant role in creating a healthy ecosystem for the development and application of advanced technologies and systems and for the creation of novel business models to achieve a high share of renewables, which would enable Zhangjiakou to become a low-carbon city by 2050. The experience gained, and lessons learned, can and should be shared nationwide, an important mandate that the National Renewable Energy Demonstration Zone was given.

This is important for China as it seeks a way to sustainably fuel its continued urbanisation over the next three decades, with an estimated 255 million people set to be added to Chinese cities by 2050. How China chooses today to power its cities will have a far-reaching impact on future energy and environmental sustainability.

In this context, a new paradigm is needed for many of the Chinese cities that are eager to wean their energy systems off coal and to take advantage of the uptake of renewable energy technologies and other enabling technologies such as electric vehicles, hydrogen production and applications, battery storage systems and smart grids. Given the increased nationwide impetus for advancing the energy transformation, this study can be expected to contribute to a rising tide of urban strategic energy development planning across China.

Zhangjiakou is abundant in renewable energy resources, including an estimated technical resource potential of 30 gigawatts (GW) for solar photovoltaics (PV) and 40 GW for wind, a large amount of biomass and geothermal potential for heat, as well as excellent geological conditions for pumped storage hydropower facilities.

Over the past decade, the city has stepped up its efforts to deploy renewable energy systems. In 2017, renewables accounted for 73% of the total installed capacity in Zhangjiakou and for around 45% of the total electricity output. Nevertheless, much of the potential has yet to be exploited. In terms of future energy demand, uncertainty remains regarding the shaping and implementation of Zhangjiakou's industrial restructuring strategy, the electrification of some end-use sectors, energy efficiency improvements, and the enhancement and expansion of local and regional power grids. Overall, increasing local use of renewables requires greater application of innovative end-use technologies in concert with renewable energy generation.

This study has shown that because Zhangjiakou has undertaken an initiative to upgrade its current industrial sectors – a transformative move to a new generation of industrial development for the city – urban energy system planning must be strategically harmonised with industrial sector development to ensure that the new energy demand can be met as much as possible by renewables.

For example, with the planned shutdown of Xuan Steel or the potential upgrading from blast furnaces to electric arc furnaces, the energy demand from industry would be greatly reduced. By the same token, as big data centres are established in some counties of Zhangjiakou, the distribution of electricity consumption will change.

Based on the city's big data development plan, 1.5 million servers are to be put into operation in Zhangbei County in the coming years, adding around 14 terawatt-hours (TWh) of annual electricity consumption, which would double the current level. As advanced information technologies such as the Internet of Things, cloud computing and big data develop, electricity consumption by the industries producing them will also continue to grow rapidly, with the resulting addition expected to exceed 20 TWh annually during 2020-2030.

The demand for electricity needed to produce hydrogen from renewables will increase as well. In addition, smart manufacturing will substitute for conventional production facilities, offering better energy and environmental performance. For energy production, including of electricity and heat, generation should be as close as possible to the loads to reduce transmission losses. In this regard, distributed generation could prevail. With sufficiently forward-looking strategic planning, Zhangjiakou can offer unique opportunities for businesses to reduce their environmental impact through scaled-up use of renewable energy sources.

The EnergyPLAN model analysis in this report indicates the extent to which local renewable energy resources would be exploited, in terms of generation capacity and the contribution to both the overall energy supply and different sectors. Electricity and hydrogen have been identified as the two key energy carriers to scale up the local use of renewables. Along with the anticipated greater electrification of end-use sectors, electricity is clearly an important energy carrier in all scenarios. However, if the electricity is mostly generated by variable renewable energy (VRE) sources, the enabling technologies, particularly energy storage, would be a key determinant. Regional exchange of electricity is recognised as an important element but will be discussed in a separate study. Hydrogen is assumed to play an important role in the future energy landscape, as both the power density and the scale of storage of electricity are not anticipated to experience revolutionary technological breakthroughs.

Electricity and hydrogen are the key energy carriers to scale up the local use of renewables

This study has identified the key areas where specific actions, if designed well and implemented effectively, could facilitate the transformation of Zhangjiakou's current energy system along specified strategic pathways.

Engaging in long-term energy system planning

Long-term energy planning is an essential component of the energy sector as well as of energy policy-making processes at the national and municipal levels. Long-term energy plans feature quantitative scenarios and targets for the energy mix that meet overall policy goals, which can help establish a stable and predictable investment environment and provide a framework to inform recommendations on where to direct investment. Urban energy system modelling behind long-term energy scenarios can take into account such factors, allowing for system-wide and strategic policy assessments for a city.

The city context also requires an appropriate level of temporal granularities and spatial boundaries when applying an energy system planning tool or model, given the unique geographic and production patterns of renewables such as wind and solar.

Adopting GIS-based spatial planning tools and methods

Energy planning tools based on geographic information systems (GIS) can help with the optimisation of the generation, distribution and allocation of the renewable energy potential with both demand and urban development. Various trade-offs have to be assessed spatially and temporally. The development of a city model, including different layers of GIS-based data, can facilitate implementation of the energy transformation by providing a visual quantification of all the aspects for urban planners to consider.

The GIS analysis can be further enhanced by combining it with advanced statistical software, allowing in-depth analysis of energy demand patterns as well as forecasting, which is particularly of use in the case of Zhangjiakou, requesting advanced methods for the optimal control of an energy system including a high share of VRE.

Developing stronger and flexible power grids for regional electricity exchange will help to gain a better understanding of regional balancing of renewable energy generation and consumption. The flexibility of different parts of the overall grid system would provide useful insight regarding how much and where variable renewables could be accommodated without jeopardising grid stability and reliability if no grid enhancement measures are taken. However, understanding the regional grid stability deserves a separate study.

Diversifying end-use applications of renewables through hydrogen

To enhance the flexibility of the grid to accommodate greater shares of variable renewables, the end-use sectors need to be more engaged in grid operation. Electrification of the end-use sectors is widely acknowledged as an effective approach to have more players on the demand side that grid operators could possibly engage with in maintaining grid stability. Also, renewable-derived hydrogen has been viewed as a promising solution to increase the demand-side flexibility of the power system, as variable renewables could be converted into an energy carrier through electrolysers, which can be used whenever needed.

Strengthening institutional capacities

Strengthening local energy planning is critical for the long-term development of renewables. However, such urban energy plans are often developed by a contracted firm that may use proprietary tools or methods that cannot be transferred. This can result in published plans, but without a process for updating them as they are dependent on the availability of outside support. An urban energy system should be planned by the users of such a plan, and their capacity to develop plans or at least to understand planning should be cultivated to allow for independence and timely updates when necessary. The capacity can be created within government institutions to develop scenarios through the use of modelling results in urban energy system planning. To do this, however, the institutional and human capacities for urban energy system planning are just as important to establish in Zhangjiakou.

Establishing a demonstration and training facility for advanced renewable energy systems

Given that Zhangjiakou is mandated to establish the National Renewable Energy Demonstration Zone, a strong facility equipped with advanced renewable energy systems for the purposes of demonstration and training is crucial to enable the city to assume its important role as demonstrator to the rest of China in scaling up the use of renewables at the local level.

Such a facility could also benefit from existing similar facilities, such as the State Grid Corporation of China’s training centre with an integrated energy system of solar, wind and energy storage, and from the real-world renewable energy projects installed in Zhangjiakou through collaborative agreements with project owners or developers. In addition, the facility can serve as a platform for Zhangjiakou to communicate with the rest of the world on knowledge exchange, technical collaboration, training for officials from other developing countries, and co-operation in technological innovation.

Engaging with international communities

Cities are waking up to the need to address climate change through energy transformation. But they are not doing this in isolation. Promoting efforts to achieve a low-carbon future for cities involves many active partners, including civil society groups such as ICLEI, C40 and the Global Covenant of Mayors, as well as global and regional platforms such as UN-Habitat's World Cities Day, the IRENA Assembly and the Asian Development Bank's Asia Clean Energy Forum.

Zhangjiakou could benefit tremendously from engaging with these partners in exchanging knowledge and sharing experience and lessons. More importantly, joining such groups and participating in these activities could help Zhangjiakou speed its renewable energy development and deployment and explore more opportunities to forge joint research and development programmes at various scales.

1. INTRODUCTION

Key points:

- In recent years, Zhangjiakou – a medium-sized Chinese city of 4.4 million people that is adjacent to Beijing – has responded positively to the green, low-carbon and sustainable development concept advocated by the state government. The Chinese national policy direction is very clear: diversifying the energy mix with an increasing share of non-fossil sources, particularly renewables, is a means to enhance energy and environmental security.
- How China chooses today to power its cities will have a far-reaching impact on future energy and environmental sustainability.
- With its abundant renewable energy resources and excellent skiing conditions, the city was selected to support Beijing in hosting the low-carbon 2022 Winter Olympic Games.

Figure 1 Geographic location of Zhangjiakou

Source: Google

Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

- In 2015, the State Council of China approved Zhangjiakou City as the country's first-ever National Renewable Energy Demonstration Zone, serving as the test bed for applications of advanced and innovative renewable energy technologies, as well as for power sector reform in favour of accelerating the nationwide scale-up of renewable electricity generation and use.
- As the first of its kind in China, the *Zhangjiakou Energy Transformation Strategy 2050* will set a new paradigm for many other Chinese cities that are eager to wean their energy systems off coal and to take advantage of the uptake of renewable energy technologies and other enabling technologies.

This section of the report describes the profile of Zhangjiakou City and provides general background on how the city's energy system was analysed and contextualised with regard to both geographic and time-scale aspects. This is followed by a description of the methodologies that were applied.

1.1 City profile

Zhangjiakou is a medium-sized Chinese city located in north-west Hebei Province, adjacent to Beijing (Figure 1). For several decades, the city has sought to prioritise ecological preservation above economic development, with a mandate to supply and protect the natural resources needed for economic growth in the region (Li *et al.*, 2017). In May 1995, Zhangjiakou was granted permission to benefit from China's "reform and opening up" policies, first adopted in 1978.[1] Before then, the city's economy had been sluggish, with more people living in poverty in Zhangjiakou than in other cities in the province (Zhang *et al.*, 2011).

1 *This was a key milestone in China's economic reform process, transforming the country from a planned economy towards a market economy.*

Why Zhangjiakou?

Zhangjiakou is a resource-rich city with an abundance of not only minerals, such as coal, but also of renewable resources such as solar, wind, geothermal and biomass. As China has increased its uptake of renewable energy over the past decade, Zhangjiakou has also rapidly scaled up its development of renewables, driving the city's economic expansion. Annual growth in the city's gross domestic product (GDP) hit double digits during 2010-2013 and has since remained above the national average.

The year 2015 marked an important milestone for Zhangjiakou. Several events that occurred around this time presented unique opportunities for the city and arguably have changed the trajectory of its future development.

1. **Co-ordinated Development of the Beijing-Tianjin-Hebei Region:** After decades of rapid economic development, China's top policy makers realised that the benefits of polarised development, centred in big cities such as Beijing and Tianjin, were not being effectively distributed in the region, resulting in widening inequity and deteriorating ecological systems in the Beijing-Tianjin areas and challenging the sustainability of social and economic development.[2] For example, although Beijing and Tianjin are home to around one-third of the region's population, these two megacities accounted for more than half of the regional population growth during 2012-2016 (Zhou, 2018), posing increasing challenges to their carrying capacities.

   Against this backdrop, in 2014 Chinese President XI Jinping put forth the concept of the "Co-ordinated Development of the Beijing-Tianjin-Hebei Region". The following year, the Central Politburo of the Communist Party of China – representing the highest level of decision-making in the country – approved the guideline for developing the plan, and in 2016 the 13th Five-Year Plan for the region was issued, with clear targets set for 2020. This was the first Five-Year Plan of this type in China, as conventionally the Five-Year Plans have been developed at a national and provincial level, and no cross-provincial development plan had ever been created.

   The specific role assigned to Zhangjiakou City in this context was to ensure the secure supply of clean water and ecological benefits to the capital city of Beijing as well as to the Beijing-Tianjin-Hebei region. However, this overall recognition of Zhangjiakou's contribution to the regional sustainability of development could also provide the city with a strategic opportunity for economic growth with lesser impact on the environment.

2. **Low-carbon 2022 Winter Olympic Games:** In 2015, Beijing was selected to host the 2022 Winter Olympics, and Chongli District of Zhangjiakou was tasked with hosting most of the Olympic skiing events. Beijing has set an ambitious low-carbon goal for the 2022 Winter Olympics. Zhangjiakou, benefiting from its abundant renewable energy resources, will play an important role in supporting Beijing in achieving this goal.

3. **Zhangjiakou National Renewable Energy Demonstration Zone:** Also in 2015, the State Council of China approved Zhangjiakou City as the country's first-ever National Renewable Energy Demonstration Zone[3]. The city has subsequently set near- and mid-term renewable energy targets.

   Importantly, the Demonstration Zone is to serve as the test bed for applications of advanced and innovative renewable energy technologies, as well as for power sector reform in favour of accelerating the nationwide scale-up of renewable electricity generation and use.

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2 The region is home to 111 million people, or 8% of the national population (Zhou, 2018). The region is home to 111 million people, or 8% of the national population (Zhou, 2018).

3 Previously, the Chinese government approved similar renewable energy development zones at the provincial or municipal levels.

Because the Zone was approved at the national level, the city is entitled to financial and policy support from the central government. The benefits also could be shared, and the model replicated, nationwide. From a regional perspective, Zhangjiakou has secured political and policy support in developing its abundant renewable energy resources to meet local energy demand with cleaner energy sources, and potentially to provide clean energy to Beijing as well as other cities in the region. These efforts would also support Beijing's hosting of the 2022 Winter Olympics.

Capitalising on the above opportunities requires strategic thinking and planning as well as innovative action. Zhangjiakou needs to develop a clear, long-term and plausible energy transformation strategy that also is reconciled with the transformation of the city's industrial and economic sectors towards sustainability.

Once developed, this strategy could serve as an interesting model for other cities, existing or planned, to follow.

Population distribution and GDP by area

In 1993, Zhangjiakou was elevated to the level of a prefecture and its administrative boundary was expanded to nearly 38 000 square kilometres (km²), similar in area to the Netherlands. By the end of 2017, the city's population was 4.43 million, reflecting a modest 2% increase from 2010 (Zhangjiakou Municipal Statistics Agency, 2018). As shown in Figure 2, most of the city's 16 districts and counties have populations between 100 000 and 200 000, while five (located in the southern part of the city) have populations over 300 000, together accounting for half of the total population of Zhangjiakou.

On average, Zhangjiakou has a population density at around 120 people per km², slightly below the national average of 144 people per km². However, within Zhangjiakou, the population density varies widely by county and district, as shown in Figure 3. Xuanhua, QiaoXi and Jingkai districts have the greatest population densities, while the rest have much lower densities. The population densities of most counties and districts correlate closely with their GDPs. This suggests that the economic activities in these areas are labour intensive. One exception is Jingkai District, which is a high-tech-oriented district.

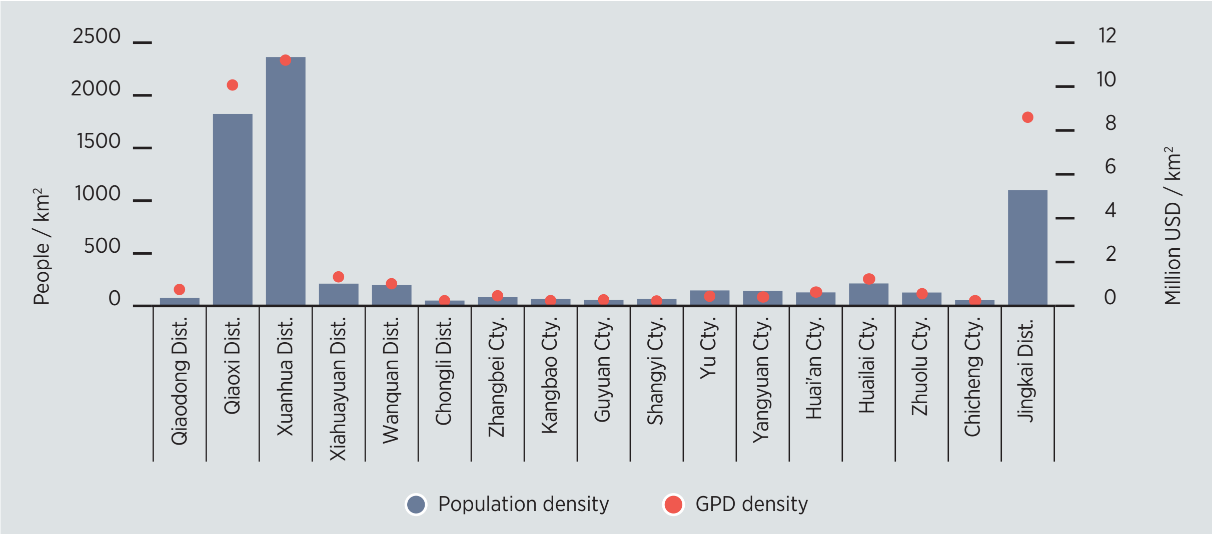
Figure 2 Zhangjiakou administrative divisions and population distribution

Source: Based on data from Zhangjiakou Municipal Statistics Agency
(Note: Jingkai district is integrated into its neighbouring districts and counties.)
Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

The regional distribution of urban versus rural populations should also be taken into consideration. The average urbanisation rate[4] in Zhangjiakou has grown from 48% in 2011 to 56% in 2017 (Figure 4). As with many cities in China, the rural population, especially the labour force, has been migrating to the centres of economic activity for better job opportunities, a trend that has left rural areas with large elderly populations and fewer people actually living there than are registered. This demographic shift has implications for energy use in both rural and urban areas, as discussed later in the report.

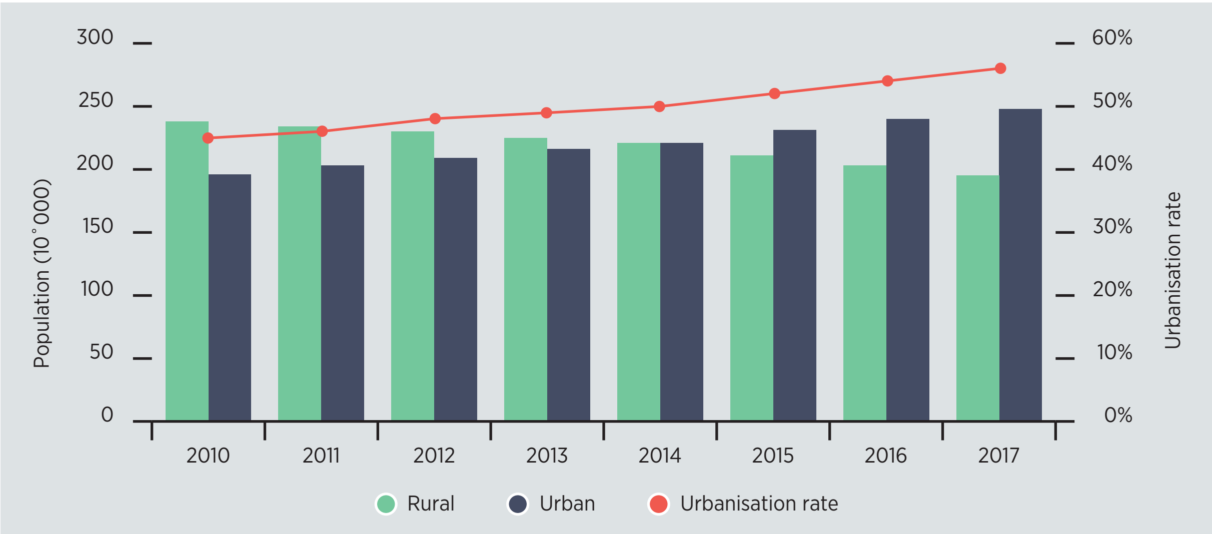
The present demographics will likely change following the completion of a high-speed railway line by the end of 2019, which will reduce the travel time for the 200 kilometres between Beijing and Zhangjiakou from 3 hours to only 45 minutes. This would help Zhangjiakou attract more talent from Beijing for its workforce. The scale of demographic change, however, will depend on Zhangjiakou's current progress in economic catch-up and on its potential for leapfrogging its industrial sectors, including transformation of the energy sector.

Figure 3 Population density and GDP density by county/district



Source: Based on data from Zhangjiakou Municipal Statistics Agency

Figure 4 Urban and rural populations in Zhangjiakou City area, 2010-2017



Source: Based on data from Zhangjiakou Municipal Statistics Agency

4 Defined as the ratio of urban residents that live in cities or towns for more than six months in a year to the total Chinese population, according to the Central People's Government of the People's Republic of China (2013).

Climate and weather patterns

Zhangjiakou City is divided by Yin Mountain into two main geographic areas: the plateau area with elevations exceeding 1 400 metres above sea level, covering four counties (Kangbo, Guyuan, Shangyi and Zhangbei), and the basin area covering the rest of the city at lower elevations (Figure 2). This division has formed two distinct climatic zones as well as different profiles for renewable energy potential, particularly for wind energy.

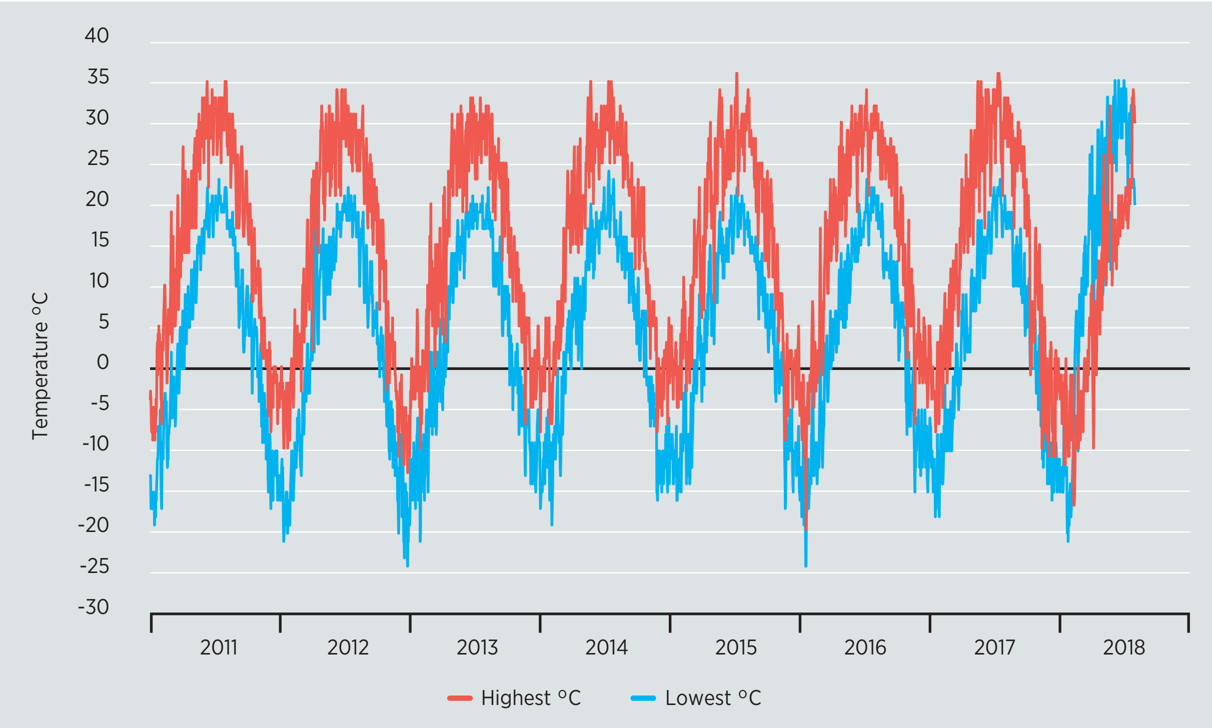
In general, the plateau area has a much colder winter than the basin area. The winter season is long and cold while the summer is short and mildly hot. The spring and autumn are dry. Figures 5 and 6 show the variation in temperatures at different time scales. Currently Zhangjiakou has greater heating demand than cooling demand, although this might change over time in part because of climate change.

1.2 National and regional contexts

After three decades of rapid economic growth and urbanisation, China has reached a crossroads in its energy and environmental security. At the national level, the policy direction is very clear: diversifying the energy mix with an increasing share of non-fossil sources, particularly renewables, is a means to enhance energy and environmental security. Ultimately, the country's future energy system could be based predominantly on renewable energy sources.

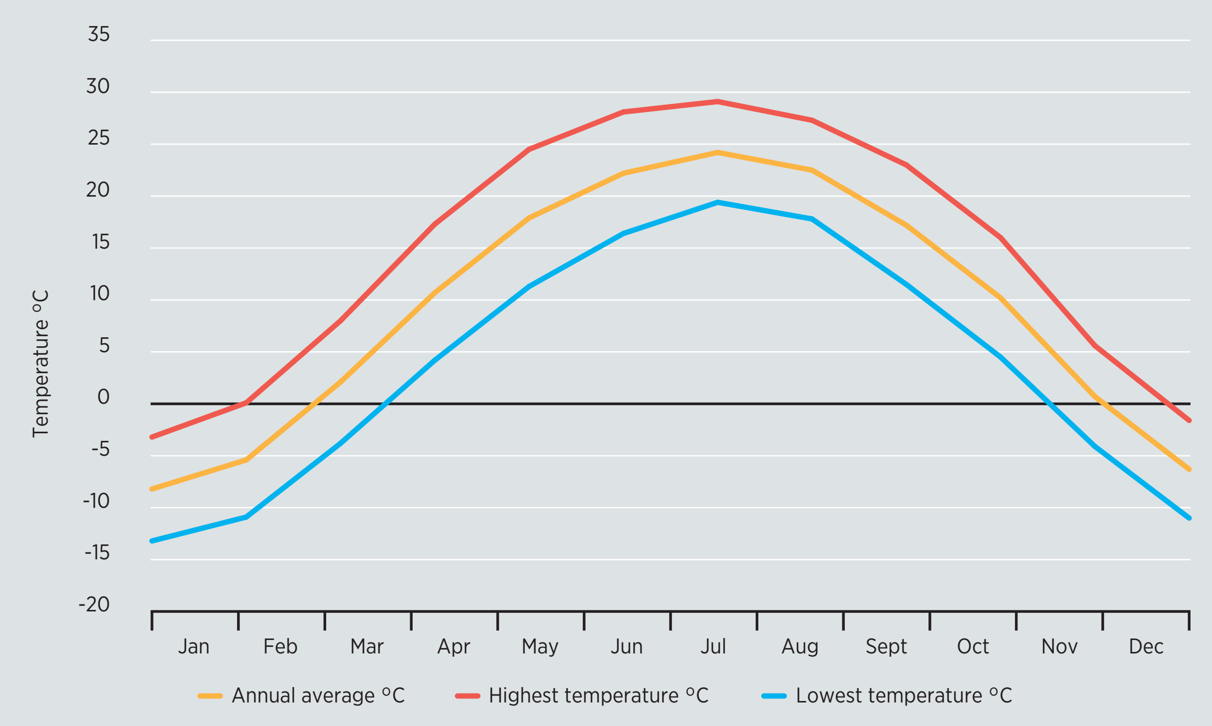
Over the next three decades, an estimated 255 million people are set to be added to Chinese cities, according to the United Nations Department of Economic and Social Affairs (DESA). The fastest growth would occur in medium-sized cities with populations between 300 000 and 1 million. UN DESA estimates that worldwide, nearly 100 such cities will grow at more than 4% annually – double the world average for this category – and just over half of those cities are located in China. Overall, the global urban population is expected to increase by 2.5 billion by 2050. China, along with India and Nigeria, are among the major countries projected

Figure 5 Daily temperatures between January 2011 and July 2018



Source: Zhangjiakou Municipal Meteorological Station, 2019

Figure 6 Temperatures in 2017



Source: Zhangjiakou Municipal Meteorological Station, 2018

to lead future urbanisation in Asia and Africa, where 90% of the urban growth is expected to occur (UN DESA, 2015).

These trends have implications for China's ongoing energy transformation, and particularly for the development of the country's urban energy infrastructure. How China chooses today to power its cities will have a far-reaching impact on future energy and environmental sustainability.

Renewable energy, in particular solar and wind power, has been driving the energy transformation in China. By 2017, renewables were contributing more than a quarter of the country's total electricity output. Although much of this was from hydropower, solar and wind have grown dramatically in the past decade, helping China achieve its 2020 target for reducing its carbon intensity[5] three years early. Geothermal and biomass for space heating are also gaining strong momentum. In the transport sector, the rise in electric vehicles (EVs) is easing the demand for petroleum and contributing to carbon emissions reduction.

Between 2005 and 2017, China's carbon intensity declined by 46%, exceeding the target of a 40-45% reduction by 2020 (NCSC, 2018). However, achieving China's mid-term carbon intensity reduction target of 60-65% by 2030 requires further effort, and renewables will remain crucial. By 2050, according to the *Chinese Renewable Energy Outlook 2018*, China could and should achieve high shares of renewables in its energy mix.

At a regional level, another key dimension is the need to address the serious smog and air pollution in Beijing and many cities in Hebei Province. Beijing shut down its last coal-fired thermal power plant in March 2017, meeting its target to become China's first no-coal city, which was set in the Beijing Clean Air Action Plan 2013-2017.

Four new local integrated gasification combined-cycle (IGCC) energy supply centres have filled the gap left by the coal phase-out, which has enabled the city to avoid the burning of around 10 million tonnes of coal annually (Chinanews, 2017).

5 Defined as the amount of carbon dioxide emission per unit of GDP.

Looking forward, Beijing has both the ambition and the potential to become a low-carbon city by 2050. Electrification will play an important role[6], as will imports of cleaner electricity from outside of Beijing (Zhangjiakou will likely be a key supplier, given its abundant renewable energy resources). According to a recent study, 81% of Beijing's electricity demand in 2050 will have to be provided by other regions, up from 57% today (He *et al.*, 2018). This effort is also part of the Co-ordinated Development of the Beijing-Tianjin-Hebei Region pilot planning initiative (Box 1).

In recent years, Zhangjiakou City has responded positively to the green, low-carbon and sustainable development concept advocated by the state. It has also willingly taken on the role of water conservation and ecological support area for Beijing. Together, Zhangjiakou and the Xiong'an New Area that was planned by the state in 2017 form the two "wings" for the future development of Hebei Province, co-operating in the effective implementation of the plan for Co-ordinated Development of the Beijing-Tianjin-Hebei Region.

Box 1 Co-ordinated Development of the Beijing-Tianjin-Hebei Region

The core of this State Council-approved initiative is the co-ordinated development of Beijing, Tianjin and Hebei Province as a whole, with the overall objectives being to address Beijing's challenges as a mega-city, to adjust and optimise the urban layout and spatial structure, to construct a modern transport network system and to expand the ecological space of environmental capacity. The Beijing-Tianjin-Hebei region has reached the following consensus on the development of synergies and regional governance:

- Adhere to the premise of ecological priority, promote industrial restructuring, and build a green and sustainable living environment.
- Adhere to the principle of regional integration and co-ordinated development and seek the co-ordinated development and layout of urban systems, regional spaces and major infrastructure.
- Remove institutional barriers to the free movement of populations and factors in the region and promote cross-regional co-operation in many forms.
- Establish a new system and mechanism for the preparation and implementation of cross-regional planning.

Source: ADB, 2015.

In 2015, the State Council of China approved Zhangjiakou City to become the country's first National Renewable Energy Demonstration Zone, based on the area's rich renewable energy potential and its geographical proximity to the Beijing-Tianjin-Hebei power load centre. The aim is to develop the area into a renewable energy production base, a pilot area for market-oriented renewable power reform, a pilot zone for international advanced technology application and leading industry development for renewables, and a green transformation and development demonstration zone. The intention is to provide a replicable experience with new renewable energy technologies, ideas and models that can be successfully promoted and transmitted nationally.

1.3 Purposes of this study

This study was part of the implementation for the workplan for co-operation under the Memorandum of Understanding (MoU) between the People's Government of Hebei Province of the People's Republic of China and the International Renewable Energy Agency (IRENA). The aim of this joint initiative is to develop a long-term vision for Zhangjiakou in 2050 and to explore strategic pathways for energy transformation that Zhangjiakou City can take not only to serve as the overarching framework for policy making, but also to guide the development of future action plans for advancing the transformation process towards a green, clean and low-carbon energy system for the city.

As the first of its kind in China, the *Zhangjiakou Energy Transformation Strategy 2050* will set a new paradigm for many other Chinese cities that are eager to wean their energy systems off coal and to

6 *More information can be found in IRENA and SGCC (2019).*

take advantage of the uptake of renewable energy technologies and other enabling technologies such as EVs, hydrogen production and applications, battery storage systems and smart grids. Given the increased nationwide impetus for advancing the energy transformation, this study can be expected to contribute to a rising tide of urban strategic energy development planning across China. The methodology of this study could in turn provide a replicable model for other cities in the country to follow, with reasonable modification to suit their local situations and conditions.

Last but not least, with this strategy at hand Zhangjiakou will be able to communicate effectively with the international community and with like-minded cities in the exchange of knowledge and experience related to urban energy transformation. Other cities around the world can learn valuable lessons from Zhangjiakou and from its vision to adopt renewables, become energy independent and explore the synergies that can be created in the process.

1.4 Methodology

This study was jointly conducted by IRENA, the China National Renewable Energy Centre (CNREC) and the People's Government of Zhangjiakou City. Energy transformation requires strategic thinking and vision as well as long-term planning. The Zhangjiakou government was looking to develop a strategy along these lines, and IRENA, in collaboration with CNREC, applied the methodology to develop several plausible scenarios to meet the city's future energy demand sustainably.

The methodology that was applied included expert group discussion, multi-stakeholder consultation and interviews to gain qualitative insights and form the narratives. The outlooks for 2022, 2035 and 2050 were built on quantitative analysis of all relevant forms of energy sources using the EnergyPLAN model.

The starting point for the analysis was to analyse the current energy system of Zhangjiakou. Subsequently, projections of renewable energy generation for wind and solar were calculated based on the measured weather conditions, wind speed and solar radiation for the year 2017. Other renewable energy potentials, such as biomass and geothermal, were directly provided by the municipality as yearly potentials.

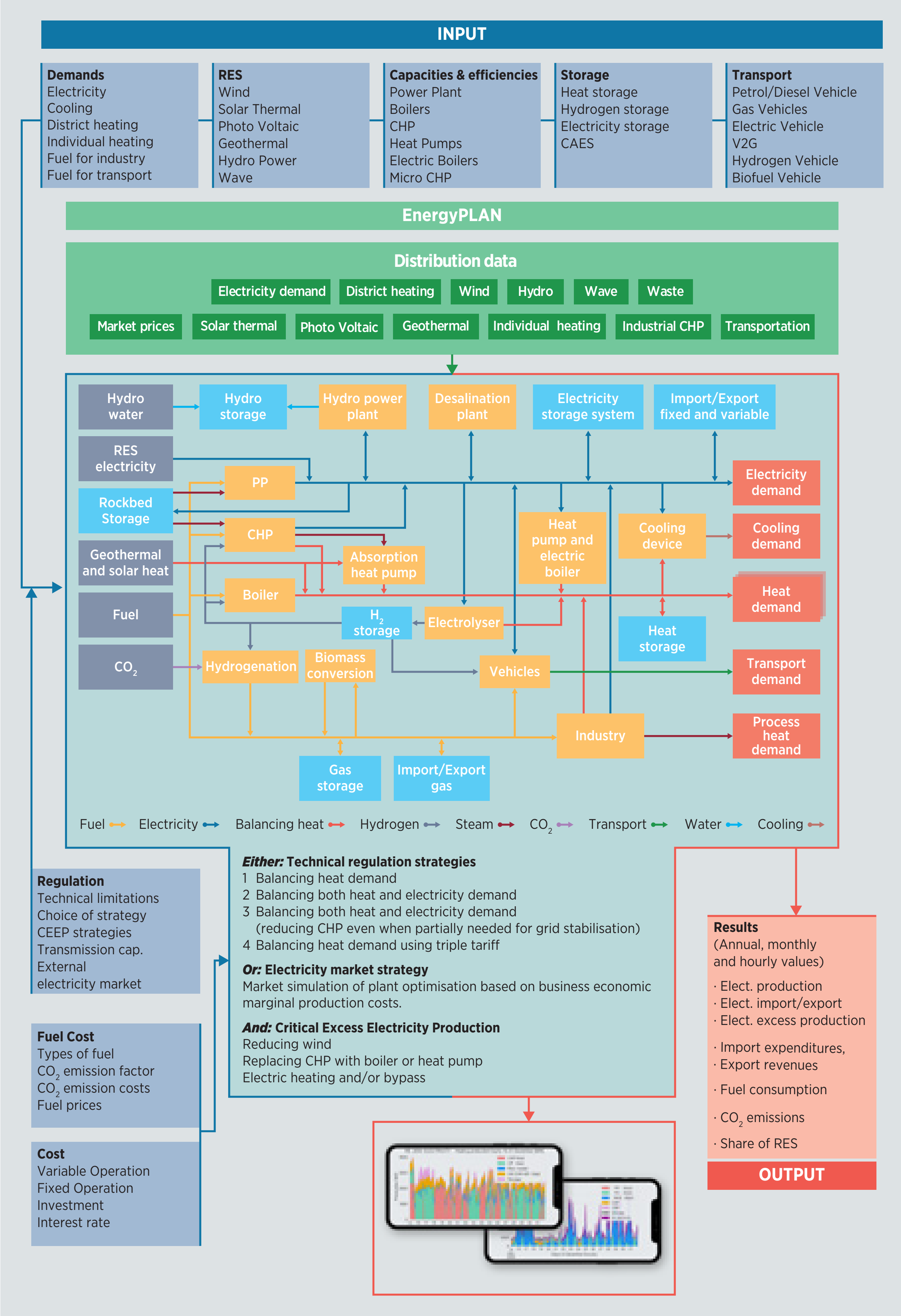
The heating requirements were determined based on a method of calculating heating degree days, derived from the Zhangjiakou temperature profile. The hourly time series providing the heating requirements for Zhangjiakou was calibrated with the actual yearly heating demand provided by Zhangjiakou municipality. Further details are provided in section 4, which presents the core analysis of the different energy transformation pathways and concludes with optimal scenarios for the short- and long-term horizons (2022, 2035 and 2050).

Identification of the energy transformation pathways is based on modelling results from EnergyPLAN, which was developed by Aalborg University, Denmark in 1999 and has since been steadily improved. EnergyPLAN is an advanced long-term energy system analysis tool with a focus on clean energy and the integration of power and thermal energy. The tool has been peer-reviewed in more than 100 publications (Østergaard, 2015) and is widely used for studies at different geographical scopes, including at the regional and municipal levels (for example, for analysis of the energy systems of cities including Aalborg, Denmark (Ma *et al*, 2014), Altavilla Silentina, Italy (De Luca *et al*., 2018), Ebino, Japan (Noorollahi, 2017) and Hong Kong, China.

EnergyPLAN provides a manual heuristics platform for finding optimal energy transformation paths based on different system configurations. The deterministic input-output computer modelling tool provides a fast computing set-up to perform scenario analysis, by applying rule-based simulation to solve a temporally high-resolution problem.

The technical analysis provides a set of regulations-based simulations, facilitating the analysis of different energy strategies towards higher efficiency, higher shares of renewables produced and/or stability of the system, while allowing for consideration of the advantages of sector coupling and the deployment of storage or other strategies, such as vehicle-to-grid, heat excess management and the operation of co-generation systems (Figure 7).

Figure 7 The EnergyPLAN model for system transformation



Source: Lund, 2018, combined with IRENA charts for the analysis of output results

2. THE ENERGY SYSTEM OF ZHANGJIAKOU CITY

Key points

- The energy system of Zhangjiakou City is closely connected to regional and national energy systems. Therefore, discussion of the city's energy transformation should be contextualised within the overall industrial and economic restructuring of China and the integrated development of the Beijing-Tianjin-Hebei region.
- Zhangjiakou has abundant renewable energy resources, including an estimated technical resource potential of 30 gigawatts (GW) for solar PV and 40 GW for wind, a large amount of biomass and geothermal potential for heat, as well as excellent geological conditions for pumped storage hydropower facilities.
- Over the past decade, the city has stepped up its efforts to deploy renewable energy systems. In 2017, renewables accounted for 73% of the total installed capacity in Zhangjiakou and for around 45% of the total electricity output. Nevertheless, much of the potential has yet to be exploited.
- Currently, local electricity consumption is relatively low, while heat demand accounts for the lion's share of energy use due to the city's long and cold winter. In terms of future energy demand, uncertainty remains regarding the shaping and implementation of Zhangjiakou's industrial restructuring strategy, the electrification of some end-use sectors, energy efficiency improvements, and the enhancement and expansion of local and regional power grids. Overall, increasing the local use of renewables requires greater application of innovative end-use technologies in concert with renewable energy generation.
- Transmission constraints have emerged as a challenge to the sustained deployment of wind and solar photovoltaic (PV) electricity generation capacities. In 2013, the amount of curtailed electricity reached 1 terawatt-hour (TWh) in Zhangbei alone, one of the 13 counties in Zhangjiakou's jurisdiction. Curtailment issues have since been put on the agenda to address.
- The city has set ambitious renewable energy targets in relation to development of the National Renewable Energy Demonstration Zone. The progress has been impressive. However, the next step for the city is to set a longer-term objective for urban energy transformation in concert with other strategic goals that the city has established for other economic and industrial sectors.

2.1 Energy consumption

Zhangjiakou's total primary energy consumption (TPEC) increased during 2008-2011, following the city's rapid growth in GDP, and reached a peak in 2011 at 16.6 million tonnes of standard coal equivalent[7] (tce)[8]. It then dropped substantially and has since remained relatively flat at around 14 million tce (Figure 8).

The decline in energy consumption resulted mostly from the implementation of national air pollution abatement policies in the Beijing-Tianjin-Hebei region and from a scaling down in the manufacturing capacity of energy-intensive industrial sectors such as iron and steel.

7 Standard coal refers to "coal" with a low heat value at 7 000 calories per kilogram (kg), or 29307.6 kilojoules/kg, or 29.3 gigajoules/tce.

8 For comparison, 1 tce is equivalent to 8 141 gigawatt-hours (GWh).

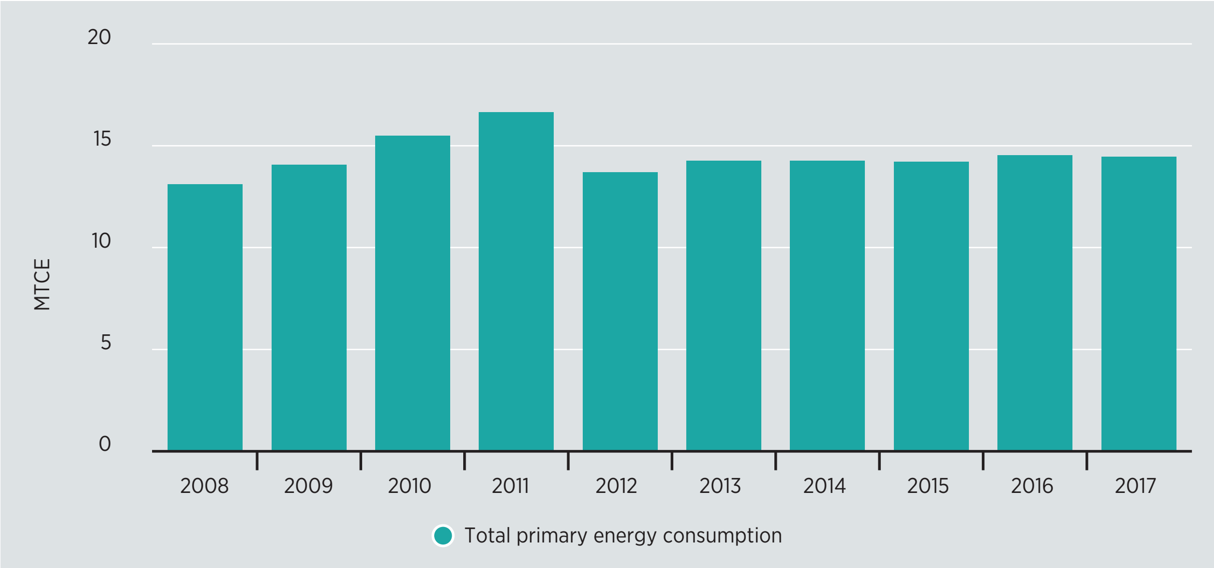
Figure 9 presents a breakdown of Zhangjiakou's total final energy consumption by end-use sector. Over the past decade, the **industry** sector has consistently consumed the largest share because most industries in Zhangjiakou are in energy-intensive sectors such as mining, coal mining and coke production; iron and steel; and cement and petrochemical industries.

According to the Zhangjiakou Municipal Statistics Agency, 57 such companies that consumed more than 5,000 tce annually by each of them, accounting for 67% of the city's total final energy consumption in 2016.

Among those, just two companies – Xuan Iron and Steel Mill and Datang Zhangjiakou Power Plant – accounted for a combined 64% of the total energy use (42% and 22% respectively). The city's top 10 industrial energy consumers (Table 1) accounted for 91% of the total energy consumption by industry in 2016.

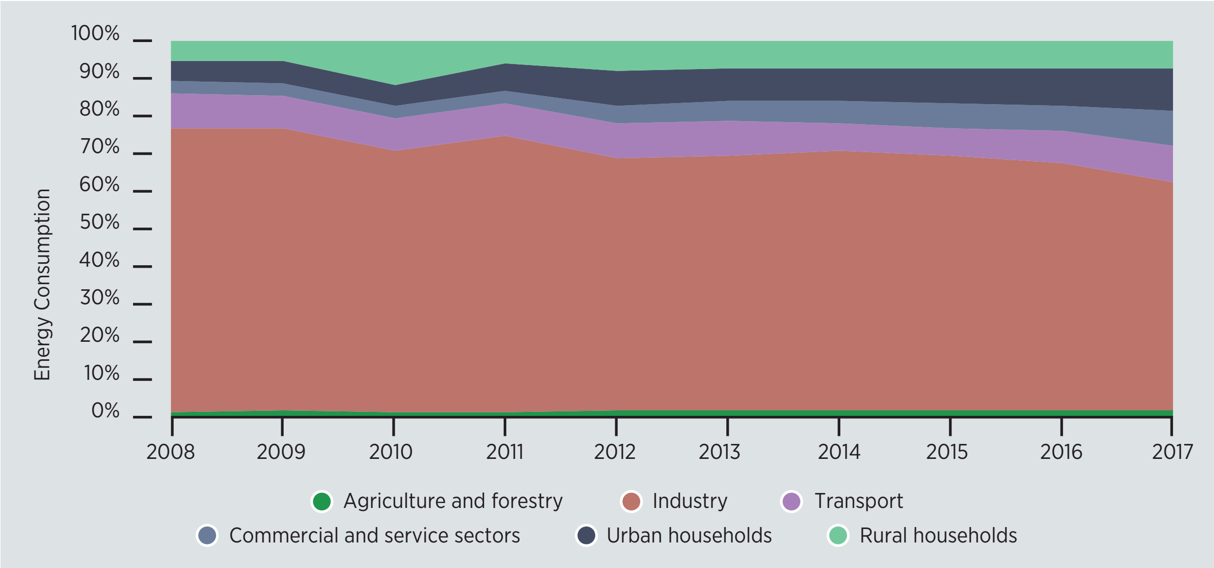
As indicated in Figure 9, the industry share has been trending down, whereas the shares from urban households and the commercial and service sectors have been growing, due to the increase in electricity consumption of these sectors.

Figure 8 Total primary energy consumption, 2008-2017



Source: Zhangjiakou Municipal Statistics Agency, 2018

Figure 9 Final energy consumption by sector, 2008-2017



Source: Zhangjiakou Municipal Statistics Agency, 2018

Table 1 Zhangjiakou's top 10 industrial energy consumers, 2016

Name	Total energy consumption (tce)	Comprehensive energy intensity
Xuan Iron and Steel Mill	4 034 549	534 kgce/tonne
Datang International Zhangjiakou Power Plant	2 125 508	300.65 gce/kWh
Huai'an CHP (subsidiary of China Guodian Corporation)	606 748	202 gce/kWh
Xuanhua (Hebei CHP)	571 923	190 gce/kWh
Datang International Zhangjiakou CHP	497 868	250 gce/kWh
Hebei Shenghua Chemicals Factory	222 074	n/a
Zhuolu Jinyu Cement Factory	201 768	n/a
Datang International Xiahuayuan Power Plant	144 767	156 gce/kWh
SGCC Yibei Power Zhangjiakou branch	134 486	n/a
Yangyuan Lime Factory	117 600	n/a

Note: CHP = combined heat and power; kgce = kilograms of coal equivalent; gce = grams of coal equivalent; kWh = kilowatt-hour; n/a = not available

Source: Based on data from People's Government of Zhangjiakou City and interviews

The **residential sector** (urban and rural households) has the second highest final energy consumption, accounting for about one-fifth of the total. The three main categories for household energy consumption are space heating[9], electrical appliances and cooking.

By source, coal accounts for the lion's share of residential energy use, mostly for heating due to the long and cold winter, although coal's share declined during 2008-2015 (Figure 10). Liquefied petroleum gas (LPG), used mainly for cooking, remained relatively constant over the period but is increasingly slightly.

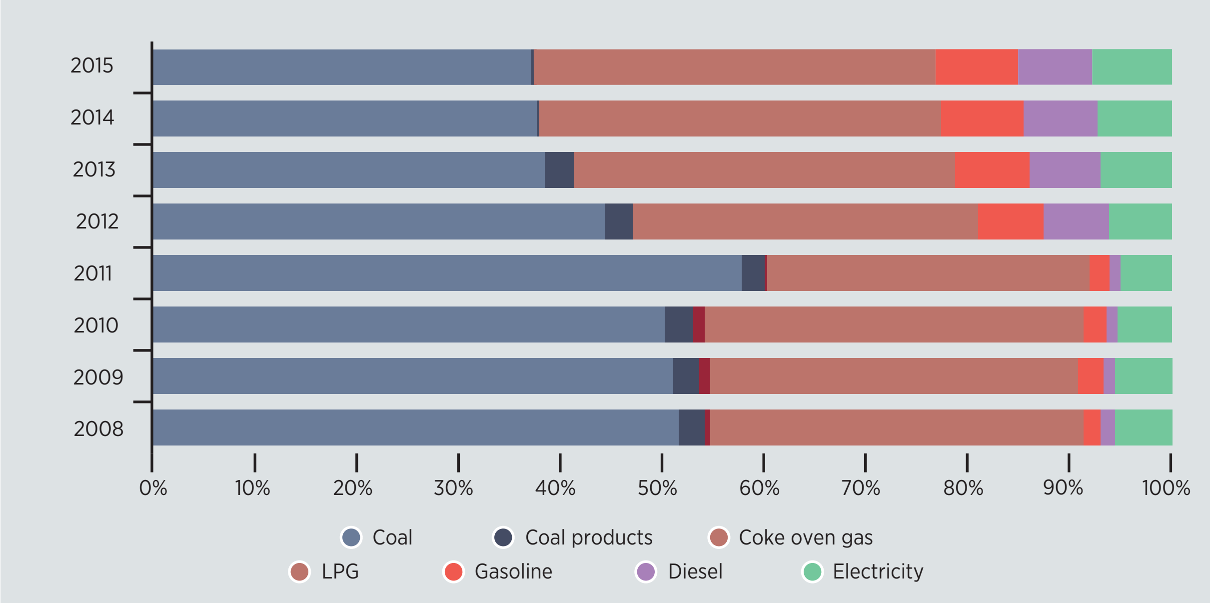
The **transport sector's** share of total final energy consumption remained below 10% during 2008-2015. By the end of 2017, the total number of vehicles on Zhangjiakou's roads neared 800 000, most of them conventional internal combustion engine (ICE) vehicles. The share of alternative energy vehicles such as hydrogen fuel cell and battery-powered vehicles is very low, but the potential, particularly for hydrogen-based fuel cell electric vehicles (FCEVs), is huge. By 2017, the city had installed nearly 3 000 charging posts, 355 charging stations and 1 hydrogen filling station to power around 2 600 new energy vehicles.

Zhangjiakou has already put 174 FCEV buses on the road, the largest number in China thus far, thanks to the government's support. To put this in perspective, the total number of FCEVs worldwide in 2018 was 11 200, and China as a whole accounted for nearly 20% (although only around a quarter of these are working due to a lack of the necessary infrastructure), according to the International Energy Agency (IEA, 2018). Because both FCEVs and battery electric vehicles (BEVs) are much more energy efficient than ICE vehicles, if Zhangjiakou steadily replaces its ICE vehicles with these alternative vehicle types, the final energy consumption of the transport sector would decrease even though the number of vehicles might go up.

Overall, **electricity consumption** in the region has increased by nearly 40% over the past decade (Figure 11), although the demand for electricity

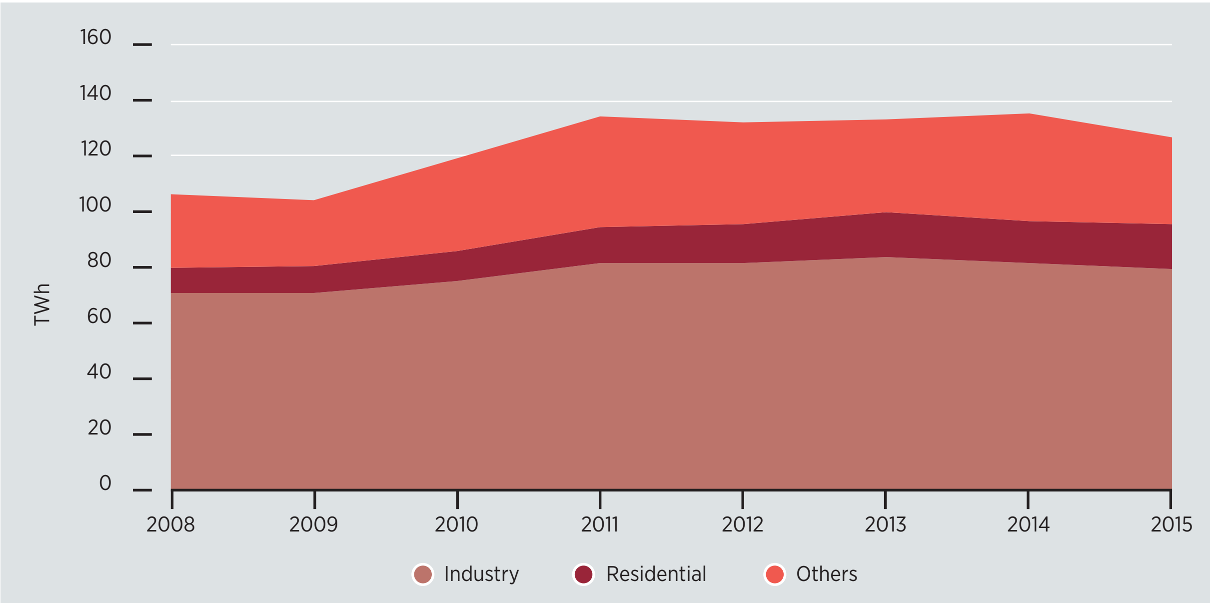
9 Most of the buildings in Zhangjiakou do not need cooling during the summer and hot water supply to households.

Figure 10 Final energy consumption for residential sector by energy source/carrier, 2008-2015



Source: Zhangjiakou Municipal Statistics Agency, 2018

Figure 11 Electricity consumption by sector, 2008-2015



Source: Zhangjiakou Municipal Statistics Agency, 2018

in Zhangjiakou is still relatively low. In 2017, the city consumed only a third of the electricity that it generated, with the remaining two-thirds transmitted to neighbouring cities, primarily Beijing.

Electricity consumption during the period 2008-2015 was largely correlated with TPEC up until 2017. In 2017, however, TPEC remained nearly unchanged, whereas electricity consumption increased by nearly 13%. This was largely because of implementation of the wind power-to-heat scheme in Zhangjiakou, which was designed to address the long-standing challenge of wind power curtailment in the area, which has outstanding wind resources by the national standard.

In 2017 alone, more than 5 million m^2 of space heating was met by wind power through either electric heaters or heat pumps.

This accommodates 708 GWh of electricity generated from wind that would otherwise be curtailed. The resulting environmental benefit was significant, resulting in the avoidance of more than half a million tonnes of carbon dioxide (CO_2) emissions and 1 600 tonnes of nitrogen oxide emissions, according to estimates from Zhangjiakou Municipal Energy Agency. (This scheme is discussed in detail later in the report.)

Industry consumed more than half of the total electricity output during 2008-2015, while the residential sector accounted for only about 10-13%, with the rest going mainly to the commercial and service sectors.

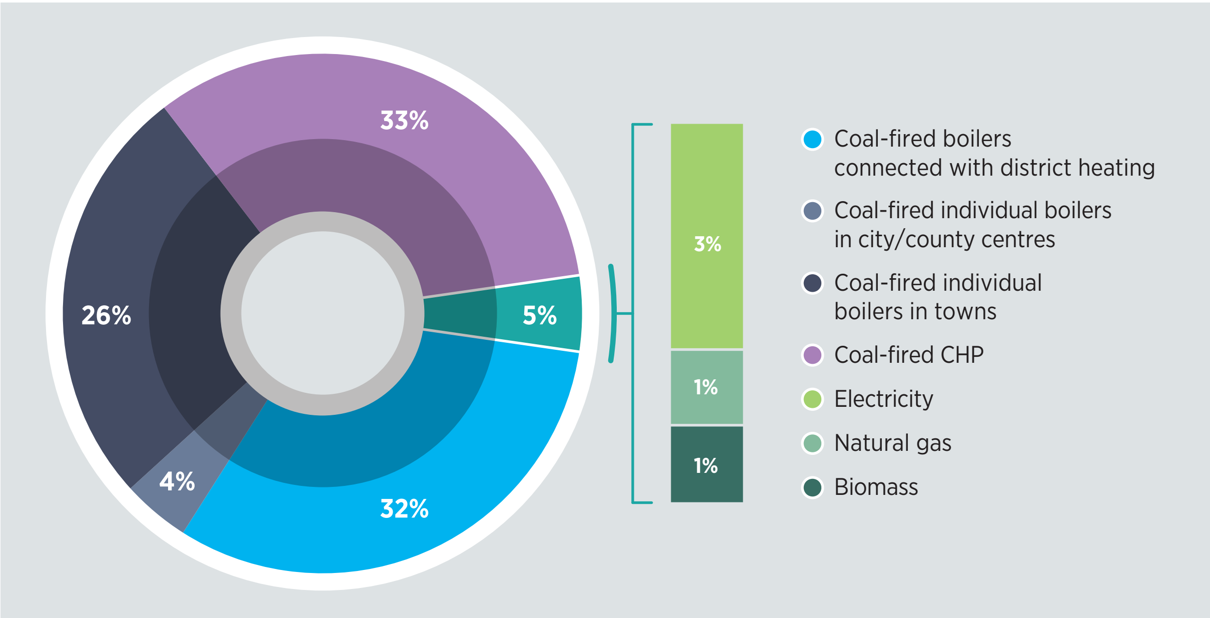
Wind energy provides effective, sustainable space heating

Heat consumption[10], particularly for space heating in buildings, is a major component in the Zhangjiakou energy mix. By 2017, a total of 150 million m² of floor area in the city required space heating services. The heating period spans from 1 November to 31 March, or a total of 151 days. As shown in Figure 12, around 95% of space heating services were met by coal, while electricity, natural gas and biomass, categorised in China as clean energy sources, accounted for only 5%.

District heating systems and heating systems in building complexes represented around 65% of the total space heating area. By 2017, Zhangjiakou had 3 453 kilometres of district heating networks, including 1 092 kilometres of the main network and 2 361 kilometres of pipelines connecting the main network to heating systems in buildings. Between these two types of networks are 270 heat sub-stations. The entire network covers 61.7 million m² of district heating area, or 41% of the total space heating area.

The district heating suppliers in different counties and districts of Zhangjiakou City are shown in Table 2.

Figure 12 Space heating required (based on floor area), 2017



Source: ETRC et al., 2018

10 This covers only the heat demand of residential and commercial and public buildings and does not include industrial process heat.

Table 2 Heat suppliers in different counties and districts

Name of supplier	Year of installation	Capacity	Space area covered (m^2)
Zhangjiakou Central District			
Datang international Zhangjiakou CHP	2010	2 X 300 MW	12 000 000
Datang International Zhangjiakou Power Plant	2013	2 x 300 MW	12 000 000
Zhangjiakou Yuantong Huasheng Heat Supply Company	2010	6 X 70 MW	6 980 000
Zhangjiakou Dongyuan Heat Supply Company	2009	4 X 64 MW	4 280 000
Donghuan Heat Supply Company	2010	2 X 29 MW	800 000
Chongli District			
Zhangjiakou Chongli Fenghui Heat Supply Company	n/a	2 X 58 MW; 3 X 46 MW	2 040 000
Wanquan District			
Tongyuan Heat Supply Company	n/a	4 X 58 MW	n/a
Dongyang Heat Supply Company	n/a	n/a	n/a
Guyuan County			
Haocheng Group Company	n/a	2 X 70 MW; 64 MW; 4 X 29 MW	n/a
Chicheng County			
Chicheng Rixin Huanyu Heat Supply Company	n/a	46 MW; 2X29 MW	1 600 000
Zhangbei County			
Zhangbei Huaying Heat Supply Company	n/a	3 X 72 MW	4 600 000
Zhangbei Xinghuo Heat Supply Company	n/a	46 MW; 14 MW	2 600 000
Kangbao County			
Kangbao Kangda Heat Supply Company	n/a	58 MW; 29 MW	n/a
Kangbao Tianrun Heat Supply Company	n/a	29 MW; 2 X 14 MW	n/a
Yangyuan County			
Yangyuan Xing'an Heat Supply Company	n/a	3 x 38 MW	n/a
Yangyuan Huayang Heat Supply Company	n/a	2 x 29 MW	n/a
Shangyi County			
Shangyi Xinglong Heat Supply Company	n/a	42 MW	n/a
Zhoulu County			
Zhoulu Xuanyuan Urban Heat Supply Company	n/a	2 X 58 MW; 29 MW	n/a
Hua Da Heat Supply Company	n/a	29 MW	n/a
Zhoulu Rongqing Heat Supply Company	n/a	4 x 29 MW	n/a
Huai'an County			
Zhangjiakou Pohua Heat Supply Company	n/a	2 x 14 MW	n/a
Others			
Saibei Haitong	n/a	2 X 14 MW	n/a
Chabei Haoying Company	n/a	2 X 14 MW	n/a

Note: CHP = combined heat and power

Source: People's Government of Zhangjiakou City

In addition to the heating suppliers for the district heating systems, there are 1117 coal-fired boilers with capacity no greater than 35 tonnes of steam/hour, 32 boilers with capacity greater than 65 tonnes/hour and 31 boilers with capacity between these two categories.

Notably, around a third of Zhangjiakou's total area was still heated by individual boilers in buildings in 2017. These boilers are distributed mostly in towns and villages rather than in city or county central areas where either combined heat and power (CHP) or distributed heating facilities supply the heat demand. This indicates that the potential to substitute older heating systems lies mostly in towns and villages, subject to the heat demand density, which is correlated to the population density. This explains why the existing district heating systems are in Qiaoxi, Jingkai and Xiaohuayuan districts, which have higher population densities compared to other areas of the city.

Heat consumption in China is still measured mostly by floor area, although some new buildings built after 2010 and connected to district heating networks are required to install thermal meters at the household level. The effectiveness of actually using the meters varies, however. At present, the average annual[11] heat demand is set at 145 kilowatt-hours (kWh) per m^2 for households, at 181 kWh/m^2 for non-residential (including commercial, service and public) buildings and at 253 kWh/m^2 for industrial buildings. The overall average is set at 188 kWh/m^2 (HEBWJ, 2014), although new buildings have better building energy performance.

For 2020, the heat demand target for the Beijing-Tianjin-Hebei region could be set at 97.7 kWh/m^2 according to a report from Beijing Transportation University (China Energy News, 2017). This points to a big gap that needs to be closed. However, if using the national average of 176 kWh/m^2 – based on the calculation of 700 million tce for 3.2 billion m^2 of floor area for heating demand according to China Geological Survey – the current status in Zhangjiakou is very close to the national average (CGC, 2018).

2.2 Energy supply: Electricity and heat generation

Zhangjiakou is endowed with abundant energy resources, mainly coal, coke and renewable energy resources. Broadly speaking, the city's electricity and heat generation are from both fossil fuels and renewables. Electricity is transmitted through the power grid operated by the State Grid Corporation of China (SGCC), while heat is supplied to end-users either through local heat supply pipelines (district heating) or via individual boilers or stoves (in rural areas).

Coal resources and coal-fired power and heat production

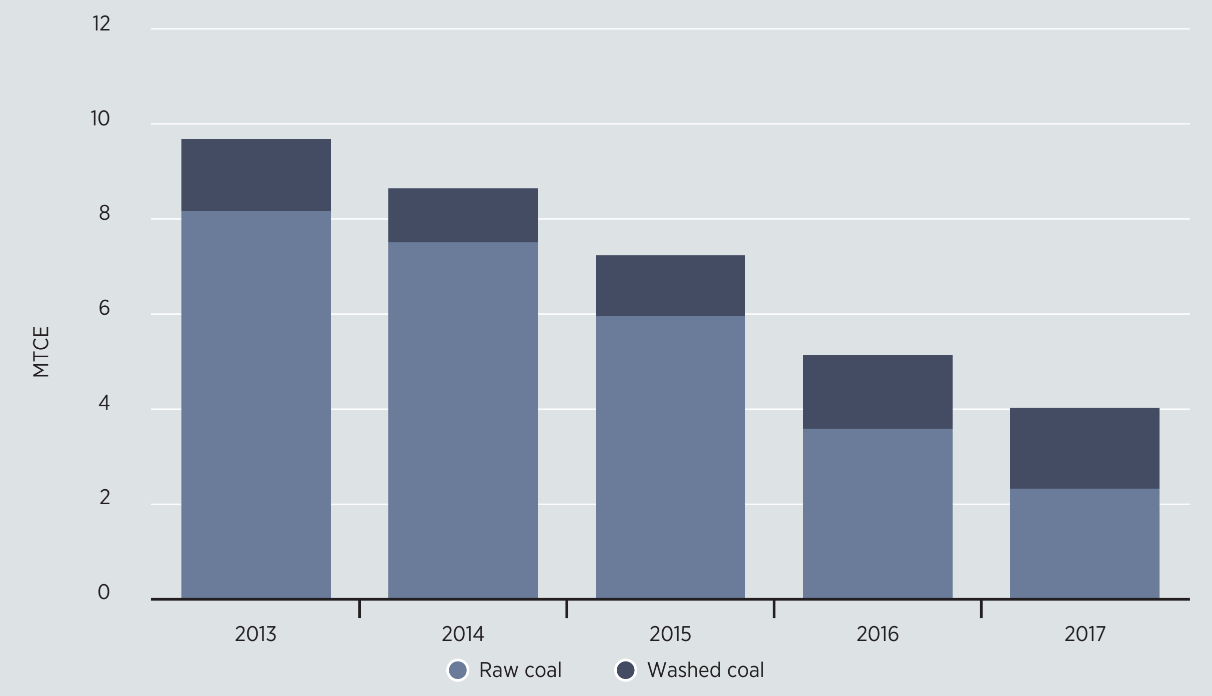
The city has a proven reserve of 282.3 million tonnes of coal, accounting for 18.13% of the total in Hebei Province (Natural Resources Agency of Zhangjiakou, 2002). Coal mining and production was a key source of energy supply until 2012, when the process of phasing out coal began. In 2016, when the 13th Five-Year Energy Plan for Hebei Province was issued, Zhangjiakou was categorised as one of four cities in China (also including Chengde, Qinghuangdao and Baoding) to achieve near-zero coal mining by 2020. This suggests that nearly all the coal mining and production companies in Zhangjiakou would have to be closed down.

During the period 2016-2018, 22 coal mining companies in the city were shut down, phasing out nearly 6.32 million tce of production capacity and greatly reducing the overall coal capacity, as shown in Figure 13. The remaining coal mines are still operating under their full capacities. Fifteen companies with a total production capacity of 8.35 million tce were slated for closure by 2019. In parallel, coal-fired boilers with less than 35 tonnes of steam/hour are being phased out, reducing the need for coal on the demand side.

However, coal still plays a significant role in electricity and heat generation through CHP and heating plants.

11 Note that the annual heating period lasts for 151 days.

Figure 13 Coal production in Zhangjiakou, 2013-2017



Source: Based on data from Zhangjiakou Municipal Statistics Agency

Coal-fired CHP plants

In Zhangjiakou, all of the condensing units in the power plants have been modified to become extraction-condensing steam turbine-based CHP units, which can provide heat as well as power during the winter season. Their overall energy efficiency has improved substantially. However, the modification has compromised the plants' capability to regulate their electricity output during the heating period, an outcome that is attributable to the curtailment of renewable electricity generation from variable resources such as wind and solar.

By 2017, the total installed generation capacity of CHP plants was 4 750 MW. In October 2018, the last CHP plant was commissioned in Yu County, adding 1 320 MW (2 x 660 MW supercritical generators) to the existing coal-fired CHP fleet. Construction of the plant was viewed as an exceptional case, justified by the urgent demand for heat for 3.5 million m^2 of households in Yu County and also by the need for electricity exports to Beijing (140 kilometres away). Associated with this new plant is the only coal mine allowed to operate after 2020.

Heating plants

In addition to the heat production from CHP plants, there are 23 heating plants in the city. The heat grids span 3 453 kilometres including 1 092 kilometres of primary grids and 2 361 kilometres of secondary grids, covering around 90% of the total urban/city area. Whether these grids will be consolidated to improve future operational efficiency remains to be seen. Coke coal is used for iron and steel making. In the case of Zhangjiakou, it is consumed by Xuan Steel Plant, which was established in 1919 and will be closed down by 2020[12]. In 2017, around 2.22 million tonnes of coke coal were produced, the lowest level in five years due to the reduced activity of Xuan Steel.

At the end of 2018, total thermal power installation reached 6 606 MW. With no new thermal power plants allowed to be built, the total capacity is sure to decline before final retirement. It is expected to fall to 5 400 MW in 2021, when two generating units at the Shalingzi thermal power plant are scheduled for shutdown.

12 The blast furnaces will be demolished; whether or not electric arc furnaces will be installed is still under consideration.

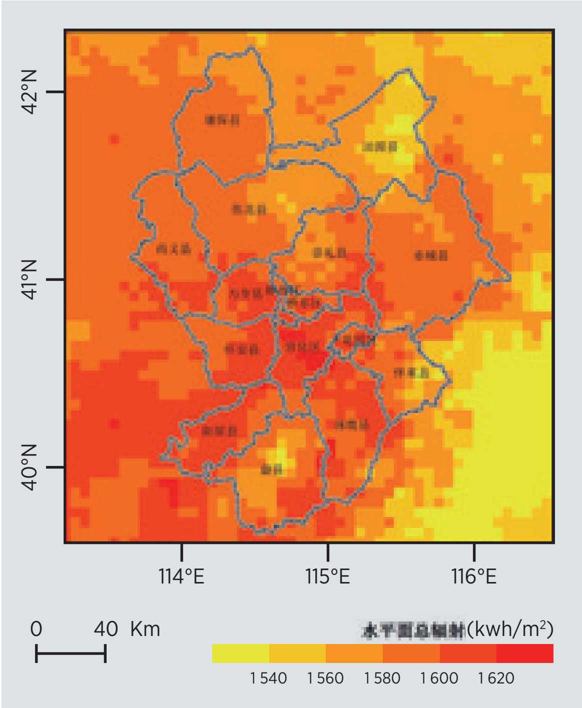
Solar and wind energy

Zhangjiakou is endowed with abundant solar and wind energy resources, as shown in Figures 14 and 15 and in Table 3. Solar energy resources are concentrated in the central and southern areas, but Zhangjiakou has excellent potential across all counties and districts.

Zhangjiakou has high-quality wind resources concentrated in its northern areas, especially Kangbao, Guyuan, Zhangbei and Shangyi counties. According to the plan for the Zhangjiakou National Renewable Energy Demonstration Zone, the city has an estimated 30 GW of technical solar PV potential and 40 GW for wind.

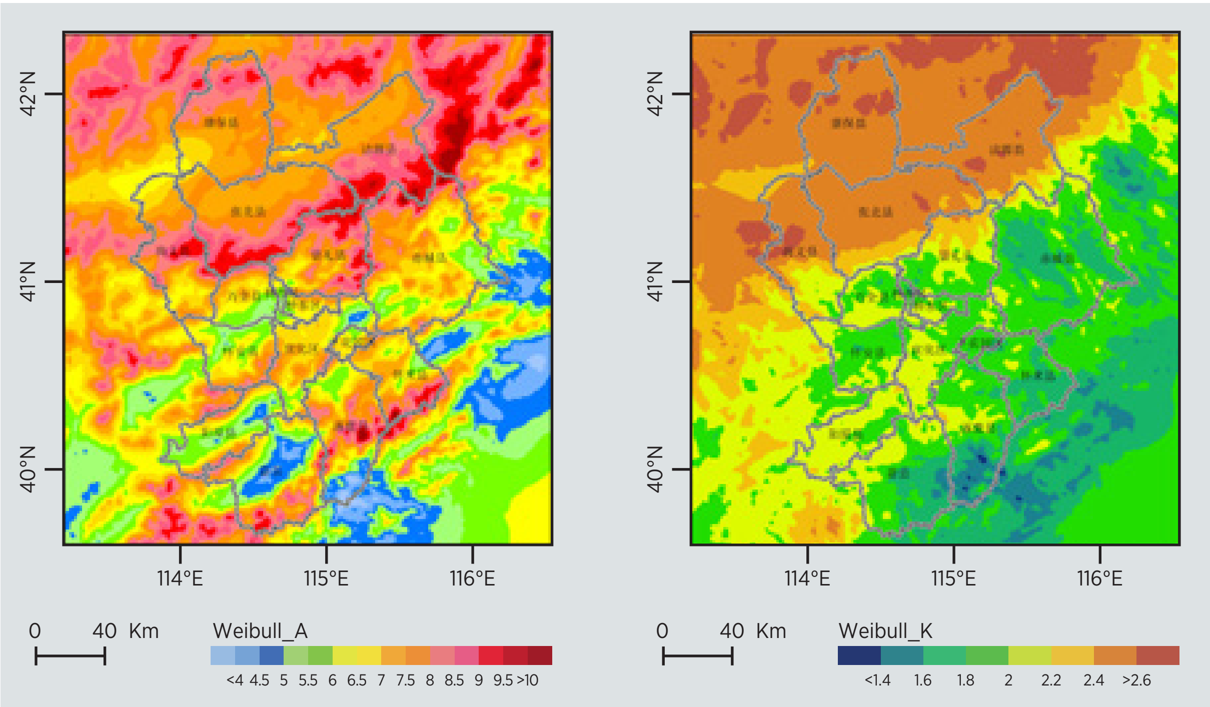
Zhangjiakou is endowed with abundant solar and wind energy resources

Figure 14 Solar energy resource potential measured in direct normal irradiance (DNI) (kWh/m²/year)



Source: People's Government of Zhangjiakou City

Figure 15 Wind energy resource potential measured in Weibull A (m/s) and Weibull K



Source: People's Government of Zhangjiakou City

Table 3 Solar and wind energy resource potential

Location	Wind Weibull_A (90 m)	Weibull_K (90 m)	DNI (kWh/m²)
Qiaodong District	6.82	1.99	1 601.55
Qiaoxi District	6.07	1.95	1 602.91
Xuanhua District	6.69	2.01	1 608.59
Xiahuayuan District	6.55	1.88	1 601.55
Zhangbei County	8.08	2.46	1 582.85
Kongbao County	7.75	2.54	1 585.46
Guyuan County	8.10	2.50	1 559.95
Shangyi County	7.60	2.38	1 594.75
Yu County	6.50	1.88	1 586.15
Yangquan County	6.23	2.06	1 603.26
Huai'an County	6.47	1.96	1 602.59
Wanquan County	6.68	2.01	1 601.62
Huailai County	7.32	1.82	1 583.81
Zhuolu County	6.90	1.82	1 601.28
Chicheng County	7.00	1.87	1 588.07
Chongli County	8.13	2.09	1 587.86

Note: DNI = direct normal irradiance
Source: People's Government of Zhangjiakou City

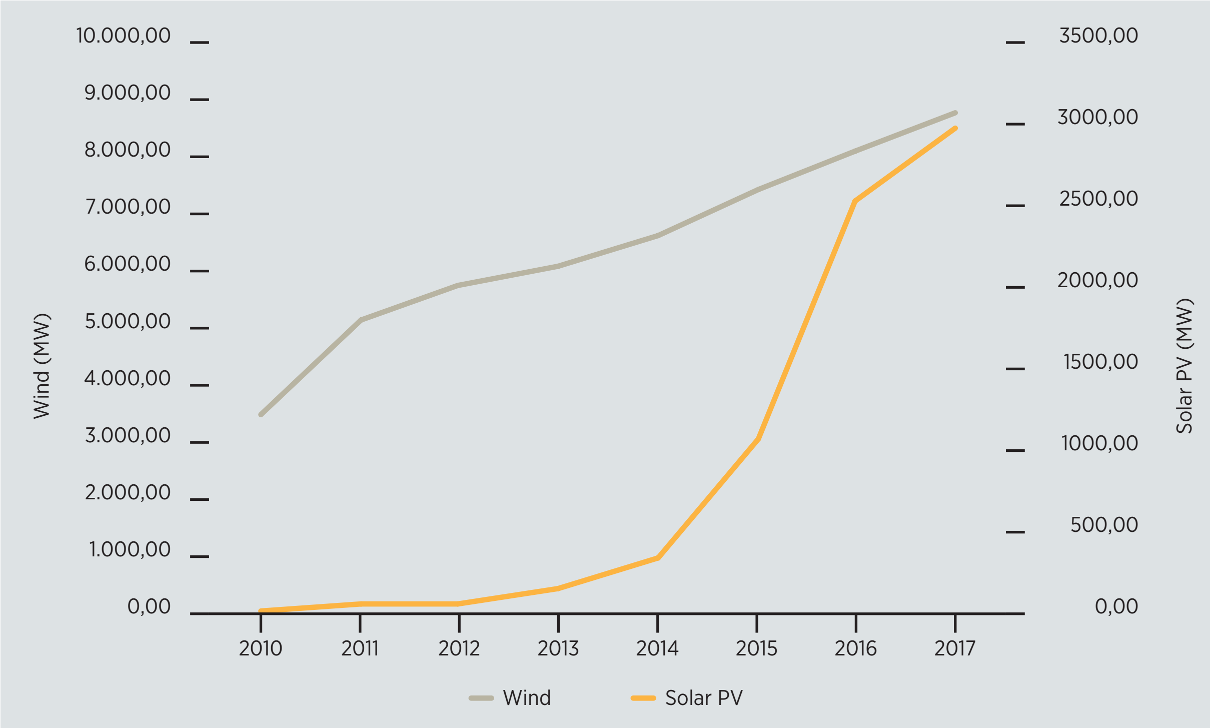
Zhangjiakou started developing its wind power resources as ea1rly as 1993, as one of the pioneers of wind power development in China. Solar PV came more recently, increasing dramatically after 2015 with the decision that the 2022 Winter Olympic Games would be held in Beijing and Zhangjiakou (Figure 16). Although both wind and solar have had impressive growth for nearly a decade, the city showed a 42% increase in renewable electricity generation capacity during 2015-2017 alone.

By 2017, the total installed wind generation capacity reached 8.72 GW, while the solar PV generation capacity reached nearly 3 GW. The city's cumulative renewable generation capacity of 13.45 GW accounted for 73% of the total installed capacity that year, producing around 45% of the total electricity output. Both solar PV and wind power installations continued to increase in 2018, up 15% from 2017. A further 2.4 GW of wind power projects was under construction as of the end of 2018.

Geographically, most of the wind and solar PV power plants are located in the northern and western areas of the city (for example, in Kangbao, Guyuan, Zhangbei and Shangyi) (Figure 17). Because these areas are not close to the local and regional load centres, the renewable electricity must be transmitted through local and regional grids.

With the rapid growth in installed capacity, transmission constraints have emerged as a challenge to the sustained deployment of wind and solar PV. For example, half of the wind power plants in Zhangbei County suffered from curtailment in 2013. Between 2012 and 2013, wind power curtailment in the county increased from 20% to 30%, suggesting that 1 TWh of electricity was wasted in 2013 in Zhangbei alone (China Environment Network, 2014). Since then, enhancing the local and regional grids by increasing the capacity of sub-stations and cables has helped to reduce curtailment.

Figure 16 Installed electricity generation capacity from wind and solar energy in Zhangjiakou



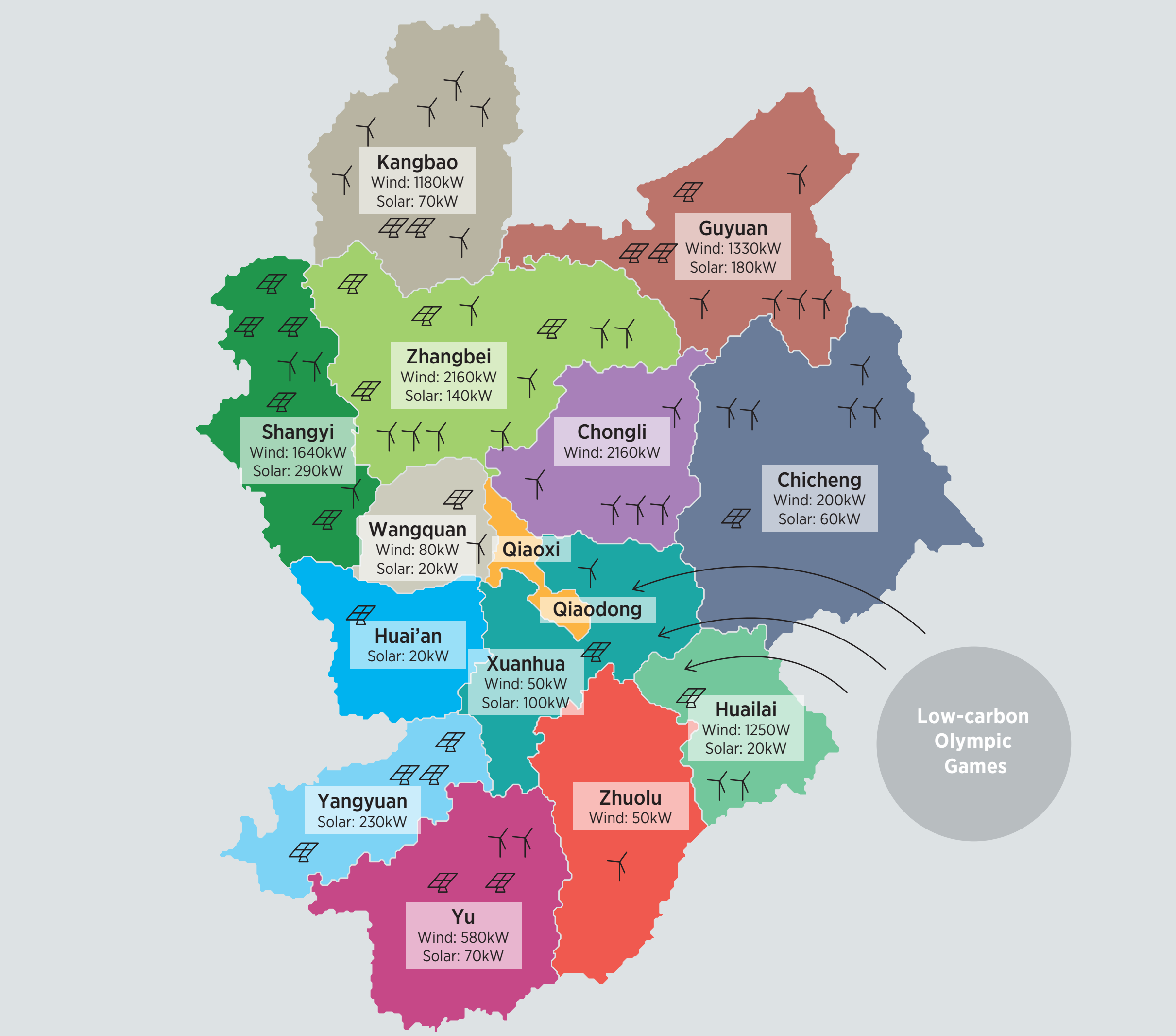
Source: Based on data from Zhangjiakou Development and Reform Commission

In addition, Zhangjiakou has begun using wind power for heating purposes under the so-called Four-Party Mechanism (detailed in section 2.5), which aims to address the curtailment issue by adding more local demand for wind power to accommodate the excessive electricity generated from wind. This option benefits from the temporal matching of wind power output and heating demand, as both occur during the evening and at night, while minimising the investment needed for grid enhancement for longer-distance transmission.

The development of concentrating solar power (CSP) in the city has been much less impressive. By 2017, the installed CSP capacity was only 15 MW plus 6-8 hours of concrete thermal energy storage capacity, a pilot project that has the potential to be scaled up modestly.

The key reasons for the lesser demand for CSP in the city are relatively low direct normal irradiance (DNI) and the continued high share of coal installed capacity, which currently provides baseload power on demand in Zhangjiakou. However, CSP with thermal energy storage is one of the few technologies that could substitute for coal power generation, reduce curtailment of wind and solar, and bring stability to the grid, in addition to producing heat for industries.

Figure 17 Renewable energy development by area in Zhangjiakou



Based on a map from the Zhangjiakou Development and Reform Commission
Disclaimer: Boundaries and names shown on this map do not imply any official endorsement or acceptance by IRENA.

Bioenergy

Agricultural[13] and forestry residues are the primary resources for bioenergy application in the city. These total an estimated 2 million tonnes a year, of which nearly half could be made available for energy purposes, according to the Hebei 13th Five-Year Plan for Biomass-based Power Generation. In addition, municipal solid waste (MSW) production amounts to around 1 million tonnes per year.

Both the residues and MSW pose a threat to the local and regional environment if they are not handled in an environmentally sustainable manner. Burning agricultural residue on farmland was once common practice in China's rural areas, but it has long been banned because it causes air pollution. Violators face serious penalties, and local governments are equipped with advanced monitoring and infrared alarm systems to enforce the strict ban.

Zhangjiakou's capacity for biomass-based power generation is small, at around 25 MW. However, with the promotion of clean heating, biomass-based CHP could play an enhanced role. In January 2018, the National Energy Administration initiated the nationwide 100 Pilot Projects of Biomass-based CHP Heating Programme as part of an effort to battle air pollution from the coal-based heating supply.

13 Nearly 700 hectares of farmland.

Two projects from Zhangjiakou City, with a total installed CHP capacity of 60 MW, have been approved and will provide heat to residential and industrial end-users while generating 370 GWh of electricity annually for injection into the grid (NEA, 2018).

The plan for the Zhangjiakou National Renewable Energy Demonstration Zone has set a 2020 target of 80 MW from biomass for electricity generation only. Given that solar and wind power are already facing curtailment, the target set for biomass for electricity generation may be revised to biomass-based CHP.

Biogas is not widely used in the city, although there is ambition to boost its application in purified biogas for blending into the natural gas supply, according to the plan for the Demonstration Zone. Production of biomass pellets or briquettes is another area that Zhangjiakou aims to develop.

Pumped storage hydropower

In 2015, Zhangjiakou decided to build a pumped storage hydropower station with 1 GW of capacity in Shangyi County, aimed at enhancing flexibility in the regional power grid and taking advantage of off-peak power that is generated preferably from renewable energy sources. The project is under development, with the feasibility study and environmental impact assessment being conducted.

The geological conditions for pumped storage are also very good in Chicheng and Huailai counties, where the potential exists to build pumped storage stations using lessons learned from Shangyi. Once in operation, the pumped storage stations now in the pipeline would greatly facilitate the integration of solar and wind power into the grid.

By the same token, Zhangjiakou has initiated energy storage projects with different technologies including compressed air energy storage.

Geothermal energy

The total geothermal energy potential in the Beijing-Tianjin-Hebei region is estimated at 343 million tce, which can meet the thermal demand for buildings if fully exploited (CGC, 2018). In Zhangjiakou, geothermal resources are concentrated in Chicheng, Huailai and Yangyuan counties, and 18 locations have been identified for potential exploitation of geothermal water resources (People's Government of Zhangjiakou City, 2017). The exit temperature of geothermal water ranges from 36 degrees Celsius (°C) to 55 °C (Yang *et al.*, 2016). At present, much of the resource has been used for the recreation sector (such as hot spring baths/spas), although it could be used to meet the heating demand of buildings.

Unlike with solar and wind energy, geothermal energy with a water exit temperature above 25°C is categorised as a mineral resource, and thus has a levy attached to it. In Beijing, the levy ranges from USD 0.51 to USD 8.8 per cubic metre (m^3) depending on the exit temperature of the water and the intended use of the resource. If it is for residential space heating and for heating greenhouses in the agricultural sector, the levies are at the lower end.

For the entertainment sector, such as hot spring baths/spas, they are much higher. In April 2018, the Zhangjiakou Municipal Bureau of Land and Resources conducted a survey on the geothermal resource in Huailai County, which could signal a potential change in the exploitation of geothermal energy in Zhangjiakou.

2.3 Zhangjiakou local and Jibei regional power grids

Development of the Zhangjiakou power grid began as early as 1917. Over the century of development, this local grid has become a critical part of the State Grid Jibei Electric Power Company[14], for two key reasons.

First, the location of the Zhangjiakou grid is strategically important because it serves as the connection between the Inner Mongolian power grid and the rest of the Jibei power grids (the other four cities) through a 500 kilovolt (kV) transmission line. The Jibei regional grid is responsible for more than 70% of the electricity supply to Beijing, and the reliability and stability of the Zhangjiakou grid must be strictly maintained to ensure the security of supply and transmission across the region.

Second, cleaner/greener electricity needs to be transmitted to Beijing as much as possible. The Zhangjiakou local grid hosts 75% of the total installed renewable power generation capacity in the Jibei regional power system. The need to accommodate a greater share of variable renewable energy (VRE) could boost the risks to power quality or grid stability (Ding *et al.*, 2017). The robustness of the Zhangjiakou local grid would have an impact on the capacity to accommodate VRE in situations where the amount of renewable electricity produced is greater than the consumption.

Table 4 reveals the key parameters for the power grids of Jibei region and the city of Zhangjiakou.

Table 4 Jibei and Zhangjiakou power grids

Key parameters (2017)		Jibei region	Zhangjiakou City
Maximum load (GW)		22.4	2.2
Total electricity consumption (TWh)		149.4	14.7
Renewable share in total installed generation capacity		52%	73%
1 000 kV	Number of sub-stations	2	n/a
	Length (km)	761.5	n/a
	Transmission capacity (kVA)	n/a	n/a
±800 kV DC length (km)		578.1	n/a
500 kV	Number of sub-stations	31	n/a
	Length (km)	11 060.5	n/a
	Transmission capacity (kVA)	n/a	n/a
220 kV	Number of sub-stations	124	18
	Length (km)	10 917	2 495
	Transmission capacity (GW)	n/a	6.06
110 kV	Number of sub-stations	n/a	53
	Length (km)	n/a	2 784
	Transmission capacity (GW)	n/a	4.7
35 kV	Number of sub-stations	n/a	138
	Length (km)	n/a	3 590
	Transmission capacity (GW)	n/a	2.34

Note: kV = kilovolt; kVA = kilovolt ampere; DC = direct current
Source: State Grid Jibei Electric Power Company, 2017; People's Government of Zhangjiakou City

14 Established in 2012, it is the youngest company within the SGCC and is a provincial-level electric power company.

Within the Zhangjiakou local grid, there are five power supply areas: Kongbao, Guyan, Shangyi, Wanquan and Zhuolu.

Depending on their distance from the load centres, the power grids are configurated in one of two ways. The first is a radial network to elevate the voltage from the alternating current (AC) wind farms (690 volts, V) and solar PV plants (400 V) to the higher voltage (35 kV, 110 kV, 220 kV and 500 kV) of the main power grids; this set-up occurs in cases where local power consumption is very small, as in rural areas such as Kangbao, Guyuan and Shangyi. The second configuration is a loop network at the voltage level of 220 kV and stepped down to 110 kV and 35 kV, then connected to the distribution networks (10 kV and below); it occurs in areas that are close to the load centre or that are part of the urban power system, such as Wangquan and Zhuolu.

With the rapid installation of VRE over the past five years, the Zhangjiakou local grid has encountered difficulties in accommodating the power output. The curtailment rates for wind and solar PV were once alarmingly high, but since 2017 the situation has greatly improved, due largely to the acceleration of power grid enhancements and to the construction of new power lines and sub-stations, as well as to improved control and operational systems. In 2017, curtailment dropped to 7%, in line with the national target of 5% by 2020.

In addition, the SGCC is investing more than RMB 22 billion (USD 3 billion) to strengthen the transmission corridors by constructing high-voltage direct current (HVDC) lines[15] (People's Daily, 2018) and 500 kV AC lines to disseminate renewable electricity from Zhangjiakou to the region, especially to power Beijing (Tian *et al*., 2018). This includes a ±500 kV voltage-source converter DC line connecting Zhangbei and Beijing, a 1 000 kV transmission line connecting Zhangbei to Shangjiazhuang, and a line between Zhangjiakou and Xiong'an New Area to power the new district with clean electricity.

2.4 Low-carbon 2022 Winter Olympic Games

Following its successful application to host the 2022 Winter Olympic Games, with the expressed intention of promoting the use of low-carbon technologies, Beijing has set "low carbon" as a key objective to achieve. Zhangjiakou, as one of the few cities supporting Beijing in organising the Olympic Games, will host the skiing events in Chongli District.

Chongli is around 50 kilometres from the Zhangjiakou city centre and has a population of 125 600 living in an area of 2 334 km^2. As the skiing venue, Chongli's Olympic facilities will be powered 100% by renewable electricity, and all the buildings in the area will be supplied with heat from the large-scale solar central heating station as well as from ground-source heat pumps and renewable electricity-based electric boilers. Powering the facilities with these energy sources will help Beijing achieve its low-carbon objective. Additionally, the promotion of public transport, clean energy vehicles, car sharing, and other measures would be used to minimise the carbon footprint.

As proposed by the China Electric Power Planning and Engineering Institute, the district's energy supply will be based as much as possible on locally produced renewables. With a DNI of between 1 500 and 1 583 kWh/m^2/year in Chongli, rooftop solar PV could provide only 4.27 MW of capacity. By contrast, the area's wind power potential is sizeable: the installed wind generation capacity has already reached 494 MW, and 150 MW is in the pipeline for 2022. To supply electricity to the Olympic Village, two wind farms with a total capacity of around 250 MW will be connected directly to the Village through dedicated transmission lines. Including the renewable electricity for heating through the centralised electric boilers, total electricity demand for the Village would be around 170 MW, and total annual electricity consumption would be around 506 GWh. The electricity demand for heating is roughly two times the residential demand.

15 Especially the adoption of voltage source converter-based high-voltage direct current transmission (VSC-HVDC).

2.5 Renewable energy targets and promotion schemes

Zhangjiakou City has set ambitious renewable energy targets for 2020 and 2030 in relation to the development of the National Renewable Energy Demonstration Zone (Figure 18). These include:

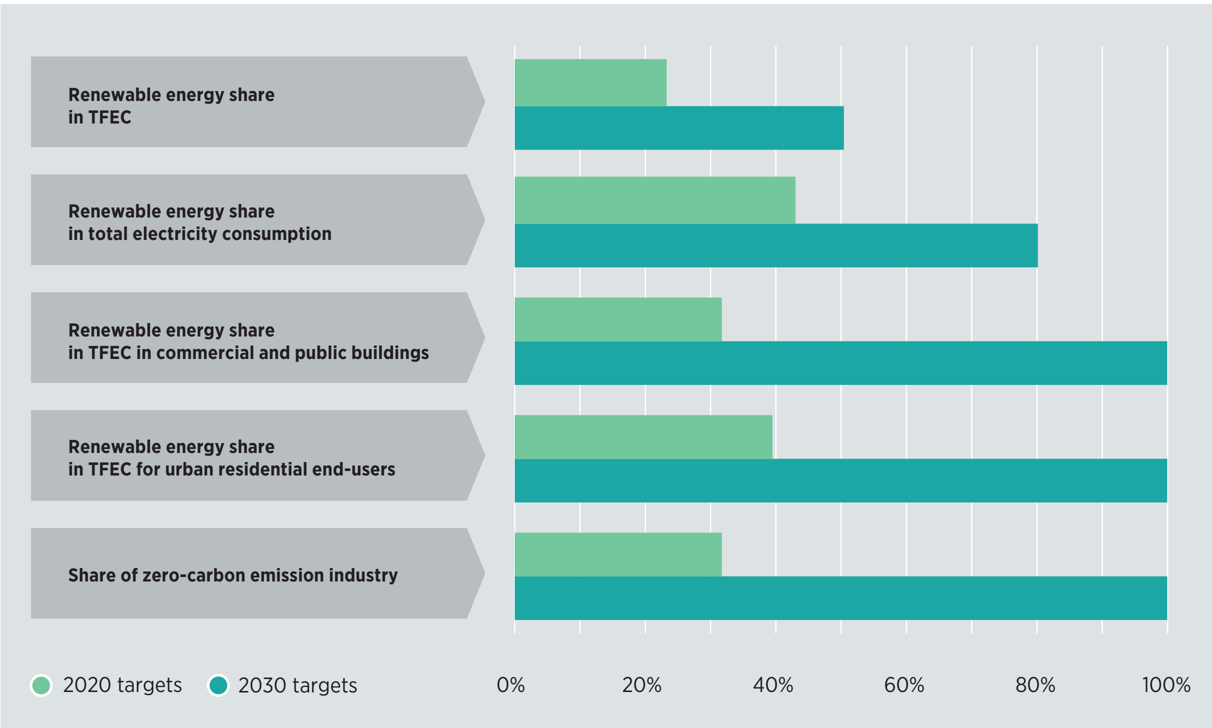
- By 2020, renewable energy sources will account for 55% of electricity consumption, 30% of total final energy consumption (TFEC), 40% of final energy consumption for urban residential end-users and 50% of final energy consumption in commercial and public buildings. In addition, 40% of all industrial enterprises will achieve zero-carbon emissions.
- By 2030, renewable energy sources will account for 80% of electricity consumption, 50% of TFEC, 100% of final energy consumption for urban residential end-users and 100% of final energy consumption in commercial and public buildings. In addition, 100% of industrial enterprises will achieve zero-carbon emissions.

Although the targets are not legally binding, in China's governance system they are treated as key performance indicators for municipal government leaders, and local decision makers are held accountable if the targets are missed. Despite challenges in achieving the ambitious targets, the municipal government has acknowledged that they provide a unique opportunity to position Zhangjiakou in the national energy transformation towards a cleaner, low-carbon and sustainable energy system based primarily on renewables, thanks to the declining costs and improved maturity of these technologies. A series of studies and implementation plans have been made since the targets were established.

The progress so far is impressive. By 2018, Zhangjiakou had achieved a 23% renewables share in TFEC, leading the wave of urban renewable energy development in China, according to a recent evaluation from the Energy Research Institute of China's NDRC (Hebei News Network, 2019).

In addition to scaling up renewable electricity generation through rapid installation, the city has

Figure 18 Zhangjiakou's renewable energy targets



Source: People's Government of Zhangjiakou City, 2016 explored innovative measures to diversify the use of renewable power on the demand side. A key example is the Four-Party Mechanism, formed in 2017 with the aim of accommodating greater integration of VRE sources by applying market principles and encouraging local consumption of renewably generated electricity. The mechanism involves four parties: the government, the grid operator, the renewable electricity generator and end-users.

In actual practice, the Zhangjiakou municipal government – in collaboration with the State Grid Jibei Electric Power Co., Ltd., a subsidiary of the North China Grid Company – has set up a power trading platform focused on renewable electricity transactions. The electricity demand for heating along with the guaranteed prices are to be publicly announced one month in advance for renewable electricity generators to participate. The registered transactions will be executed directly between the sellers (the generating entities) and the buyers (the end-users). The grid company has offered a substantial reduction in the wheeling charge.

Initially, in 2017, the mechanism was aimed mainly at the residential sector in urban areas, but the scope was expanded in 2018 to other end-use sectors, including hydrogen production through electrolysis, the data centres and facilities associated with the 2022 Winter Olympic Games, and households in rural areas. With reduced wheeling charges and discounted electricity prices from generators, end-users could enjoy rates as low as 2.2 US cents/kWh, equivalent to the heating cost from centralised coal-based thermal plants.

Since November 2018, this innovative business model has been extended to areas outside of Zhangjiakou in the Beijing-Tianjin-Hebei region. Transactions under the Four-Party Mechanism were projected to reach 3 000 GWh, heating 20 million m^2 of space, by 2020.

Following the initial success, the municipal government is seeking to establish a longer-term objective for energy transformation in concert with strategic goals that the city has set for other economic and industrial sectors.

2.6 Key short-term actions to improve energy system performance

To increase the use of renewables, Zhangjiakou has identified the following key actions that can be executed in the short term.

Improving the operational flexibility of the grid

Although the curtailment issue has been eased compared to a few years ago, it remains a potential challenge, due mainly to the continued rapid deployment of wind and solar power generation systems, the lack of ample transmission capacity and the high outputs from coal power plants.

Heat supply over the cold winter period is essential for Zhangjiakou, and coal-fired CHP plays an important role. This has confined the flexibility that coal-fired CHP could provide to the grid over winter. Without this constraint, many of the units in the CHP plants could be suppressed to around 50% of their full capacity if and when needed. Some of the units, for example at Datang International Zhangjiakou CHP plant, could technically go further but at the expense of higher emission of conventional pollutants, which are constantly being monitored online by the local environmental authority. This has prohibited the CHP plants from this option and has also resulted in high operating levels for coal-fired CHP plants.

To address this issue, the National Energy Administration has required all coal-fired CHP plants to proceed with technical modification to enhance their flexibility capacity without compromising performance[16]. The goal is to complete the technical modification by 2022. This will be followed by the deployment of a monitoring system to keep track of the operation hours and their contribution to enhancing the grid's flexibility for accommodating higher shares of VRE sources.

Another measure to improve grid operational flexibility is the electricity-for-heating option. High-efficiency electric heaters with storage have been steadily deployed in Zhangjiakou. This option is more applicable for building blocks/compounds, especially for new residential areas.

16 This is a bridging solution towards a renewable-dominant future energy system.

Retrofitting, however, is presented as an option for existing buildings. Both are in use in Zhangjiakou. Apart from the centralised option, individual air-source heat pumps offer another promising option, if their operation can be interruptive, which is technically feasible and can be compensable economically. Zhangjiakou has plans to install 100 000 air-source heat pump units by 2021.

Waste energy as an untapped potential

Recyclable waste energy from CHP plants presents an untapped potential for increasing the overall efficiency of the energy system. According to a rough estimate, around 20% of the energy inputs of a thermal power plant in Zhangjiakou City are lost from the cooling system. Table 5 presents the estimated potential for recyclable waste energy from CHP plants in Zhangjiakou.

By 2021, as many as five units in three plants (two Datang plants and the Xuan'hua plant) are to be modified to make the recycling of waste heat technically feasible.

Waste heat can be found in other facilities, such as industrial processes and data centres. Shenghua Chemical Factory of Zhangjiakou has identified technical options to collect, transmit and supply the waste heat to up to 2.5 million m^2 of building space by 2021. Similarly, Zhuolu Cement Factory has identified a potential to heat nearly 1 million m^2 with recycled waste heat.

Several data centres located in Zhangbei, Xuanhua and Huailai counties are planning to install heat pumps to make use of the heaters from the data servers to provide 7 million m^2 of space heating in the next few years.

Table 5 Energy potential from waste recycling via Zhangjiakou's combined heat and power plants

CHP plants	Waste energy potential (MW)	Space heating potential (m^2)
Datang Xujiazhuang	154	2 960 000
Datang Shanglingzi	1 460	28 080 000
Xuan'hua CHP	154	2 960 000
Huai'an CHP	336	6 460 000
Wei County CHP	1 148	22 080 000

Source: People's Government of Zhangjiakou City

3. STRATEGIC PATHWAYS TO CREATE A LOW-CARBON ZHANGJIAKOU BY 2050

Key points

- Urban energy transformation is a global trend, and cities play a central role in global climate change. China is stepping up its efforts to decarbonise its urban energy systems.
- With renewables being clearly defined as a key competitive advantage for the city, Zhangjiakou's future energy system will be able to be transformed to a green and low-carbon system.
- Electrification and hydrogen production through electrolysis are two important technological pathways for Zhangjiakou to become a low-carbon city by 2050. Other factors, such as the regional grids and energy storage, in addition to renewable energy generation, have a crucial role to play in the transformation process.
- Because Zhangjiakou has also undertaken an initiative to upgrade its current industrial sectors, urban energy system planning must be strategically harmonised with industrial sector development to ensure that the new energy demand can be met as much as possible by renewables.
- Policy and market innovation can play an important role in creating a healthy ecosystem for the development and application of advanced technologies and systems, as well as for the creation of novel business models, to achieve a high share of renewables that enables Zhangjiakou to become a low-carbon city by 2050.
- Zhangjiakou City has very promising potential to achieve a low-carbon energy future. More significantly, it can trigger a change in paradigm and become a role model for other Chinese cities to follow as they seek to chart out their own pathways to a low-carbon 2050.

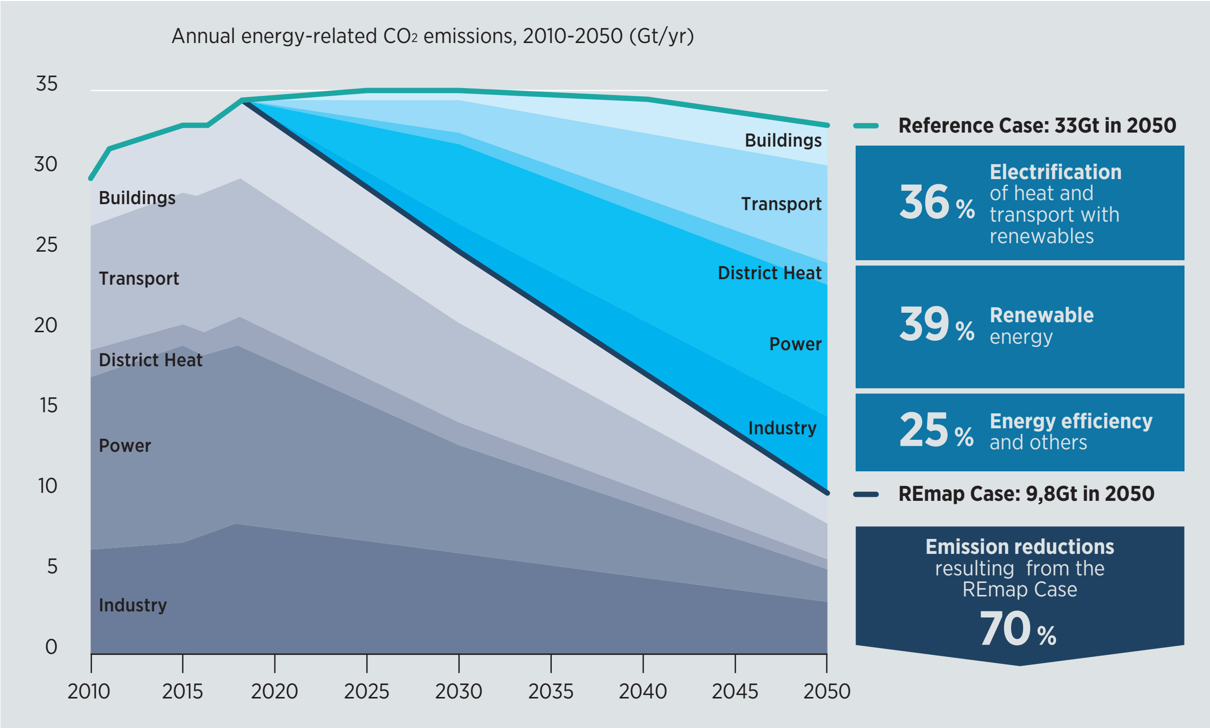
3.1 Low-carbon cities: Global and national perspectives

Since the Paris Agreement was adopted in 2015, global carbon emissions have continued to rise despite the increased use of renewables and improved energy efficiency (Jackson *et al.*, 2018). The impacts of climate change are being felt at all levels, including in cities as they experience unusually hot summers or cold winters, which in turn spurs greater demand for energy to regulate indoor temperatures. To meet global climate targets, decarbonisation must accelerate to outpace energy growth, and deep energy-related emissions cuts of as much as 70% by 2050 in comparison to the reference scenario are required to keep global temperature rise well below 2°C (Figure 19). Analysis indicates that renewable energy and energy efficiency measures, combined with deep electrification, can deliver more than 90% of the needed emissions reductions over the next three decades (IRENA, 2019a).

Cities must play a central role in global climate change mitigation, in part because of their high contribution to global carbon emissions. Worldwide, cities are responsible for 67-76% of global final energy consumption and for 71-76% of energy-related CO_2 emissions (Seto *et al.*, 2014). More importantly, cities hold great potential to mitigate emissions of all kinds by 2050, when they will need to accommodate two-thirds of the world population.

To realise such potential, transformative action at the city level is needed today. Renewable energy for cities, in the form of either centralised or distributed generation, can help address the intertwined climate and energy challenges and empower cities with greater energy independence and security while also providing an economic engine and social benefits such as job creation.

Figure 19 Global reduction of energy-related carbon emissions until 2050: Current plans vs. energy transformation



Reference Case = Pathway set by current policies and plans
REmap Case = IRENA's roadmap for energy transformation with accelerated uptake of renewables
Source: IRENA, 2019a

This will create new opportunities, encouraging innovative solutions for addressing urban energy challenges while also providing new dynamics for sustainable economic and social development. Emerging smart technologies for cities enable better communication, and big data analysis makes it possible to identify patterns of energy use decision making in a networked energy infrastructure with a precision that previously was not possible. Based on such data, integrating and managing renewable energy systems will be easier and possible at even the household level.

Around the world, a growing number of cities have committed to facilitating the global energy transformation by setting carbon emissions reduction targets, raising public awareness of a low-carbon future, enacting policies in favour of clean energy development and sharing their success stories. Globally, some 2 165 cities have signed pledges to reduce emissions by 40% from 1990 levels by 2030, and more than 200 cities have set targets for 100% renewable energy (Box 2).

China's urbanisation over the past half century has been remarkably rapid and unique in scale. Yet the movement that helped bring millions out of poverty has also sharply increased urban energy consumption and degraded the environment in and around cities. City dwellers now make up 60% of China's population of 1.4 billion. The resulting challenges have brought the country to a crossroads in energy and environmental security. China is contemplating how to sustain continued urbanisation, with another 255 million city dwellers set to be added in the next three decades (UN DESA, 2015).

Recognising the need to step up energy efficiency improvements, scale up the use of renewables, reduce environmental impact and make its burgeoning cities liveable, China has initiated a series of national programmes encouraging cities to develop forward-looking urban energy development strategies and to take aggressive actions in the shift towards a low-carbon and clean energy future.

Box 2 **100% renewable energy: The example of Malmö, Sweden**

The city of Malmö in Sweden has set targets that are far more ambitious than both the national plan (50% renewables by 2020) and the European Union's target for the country (49% by 2020). The city's ambition is to produce the largest possible share of its energy locally. By 2020, Malmö's greenhouse gas emissions are expected to decrease by at least 40% from 1990, and the city is expected to be climate neutral, setting the pathway for all municipal operations to run on 100% renewable energy by 2030.

A suite of actions for sustainable energy use has been identified and put in the pipeline for implementation:

- Identify measurable targets for solar PV and solar thermal systems, hydropower, wind and biogas;
- Investigate and increase the share of renewable energy generated within Malmö's boundaries;
- Set up pilot areas for low-energy design in the buildings sector and the production of local renewable energy;
- Encourage the formulation of clear national rules concerning the establishment of plants for thermal gasification, wind power and other forms of renewable energy;
- Promote an increased share of renewable energy in the district heating supply to Malmö.

The goal of 100% city-wide renewable energy also requires full electrification of Malmö's transport system. The city initiated a series of activities to decarbonise its transport sector, including establishing a new eco-car strategy using biogas, hydrogen or electricity (including plug-in hybrids) to phase out ICE vehicles; promoting the use of bicycles; and developing a new generation of clean energy charging/refilling infrastructure.

Malmö's actions and indicators in the area of transport reflect more ambitious targets than at the national level. Sweden has targeted a 10% renewable energy share in the transport sector by 2020 and a fossil fuel-free transport sector by 2030.

Source: IRENA et al., 2018

Solutions must be identified from the long-term, system-wide perspective while also embracing intensified innovation in technologies and business models that are constantly disrupting business as usual. An urban energy transformation strategy will be essential to guide cities on the path towards a low-carbon future.

In practice, there are three approaches for cities to reduce their carbon footprints, with the ultimate goal of transforming largely fossil fuel-based urban energy systems into renewably powered systems. The first is to import energy carriers such as renewable-based electricity and other forms of energy commodities; the second is to produce renewable energy locally using sources within the city boundary; and the third is a hybrid scheme of these two options.

To achieve a low-carbon future energy system, merely decarbonising the power system is not enough; cities must also link non-electricity end-users with the power sector using sector coupling approaches and different enabling technologies such as EVs and heat pumps. Energy efficiency and conservation have a crucial role to play as well. In addition, to ensure energy security, it is important to diversify energy sources and to not limit energy generation to only a few technologies.

Low-carbon cities can either import renewable-based energy carriers or produce renewables locally

3.2 Energy outlook: Analytical insights and discussion

To assess the outlook for Zhangjiakou's energy transformation, analysis of three target years – 2022, 2035 and 2050 – was conducted by applying the EnergyPLAN model (Figure 20).[17] The model allows for technical and economic analysis of an integrated urban energy system covering electricity, natural gas and heat supply as well as end-use sectors such as transport, buildings and industry. The coupling of energy systems with end-use sectors is essential to unlock the potential of alternative energy technologies, including a high share of variable renewables. The installed capacities and renewable energy source variabilities are used to simulate energy generation, while interactions among different energy carriers, converters and storage types are also analysed, based on different energy simulation strategies.

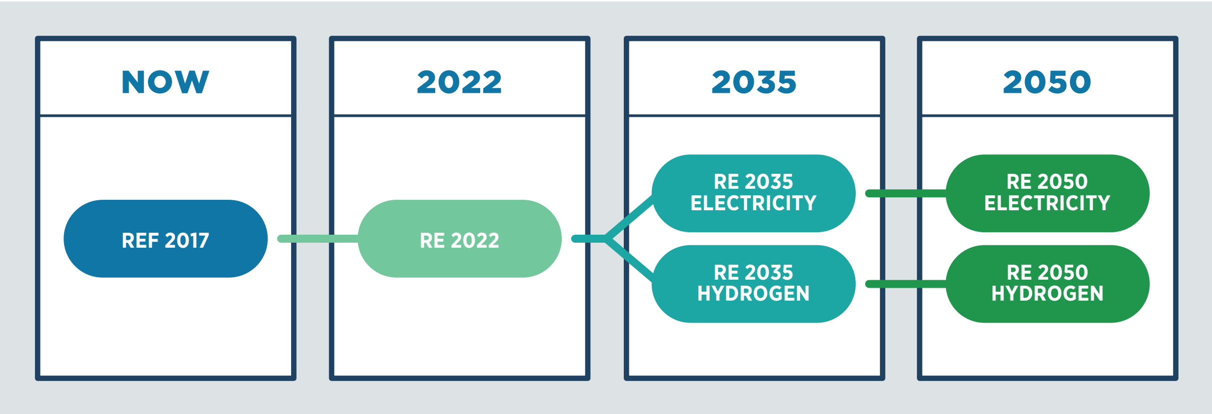
A priority rule-based simulation is run according to the following technical analysis selected: heat and electricity balance of the loads and supply while maximising the integration and utilisation of renewable energy, avoiding critical excess electricity production. Time-series representations of the renewable energy potential, current energy demand and projection are preferred to account for the intermittency of VRE systems in future energy supply scenarios.

This section presents the key modelling results. Based on these results and on the assumptions applied, particularly regarding the selection of technological pathways, an array of scenarios was constructed. This is followed by discussion around the key potential challenges that might emerge and their impact on the dynamics driving the energy transformation process at the municipal level.

For 2022, the focus is on the extent to which renewable energy use could be accelerated in Zhangjiakou with the aim of supporting achievement of the low-carbon target set for the 2022 Winter Olympic Games. A strong political commitment and a huge amount of investment have been made towards this end. The study explored a portfolio of technologies that could be applied to increase the renewable energy share in Zhangjiakou, thereby contributing to realisation of the low-carbon target.

For 2035, two alternative scenarios, with a focus on hydrogen and electrification, respectively, in relation to the business-as-usual scenario provide some insights regarding the implications of selecting different key technological pathways on shaping the future energy landscape and of the benefits of deploying enabling technologies such as energy storage.

Figure 20 Overview of EnergyPLAN model-based scenarios



Source: IRENA analysis

17 EnergyPLAN involves software for national or regional energy plan analysis from Aalborg University, Denmark, peer-reviewed with more than 76 articles published at the country or state level (Østergaard, 2015).

For 2050, given the more distant time horizon from now, there are greater uncertainties in the model results. More-advanced technologies that cannot be foreseen at this moment are likely to become available during 2035-2050. Despite this, the technologies in the EnergyPLAN are forward looking and embrace many of the future clean energy options.

The limitations of the model should be considered, however, when local authorities interpret the results with the aim of making concrete action plans. Because of these limitations, the results will be used mainly as a basis for strategic discussion around the directions that could lead the city to a low-carbon future by 2050, rather than for quantitively representing the energy mix in 2050.

Description of reference year: 2017

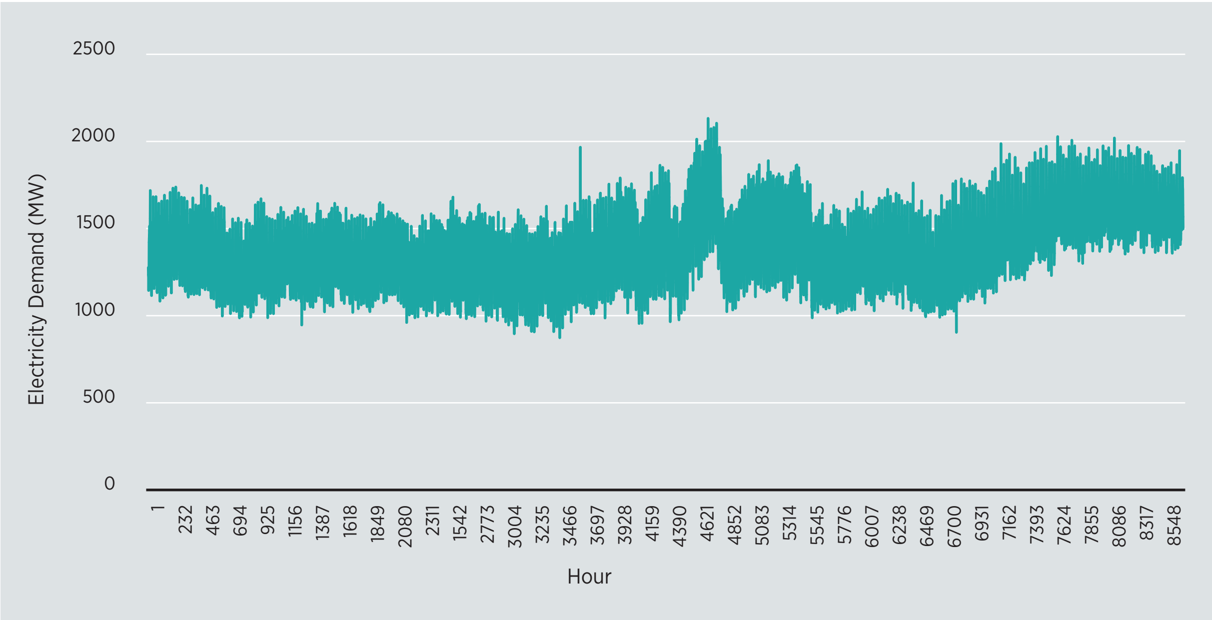
The year 2017 was selected as the baseline for this study because of the need for a relatively complete set of data for the model operation, and because of information and documentation that were available to aid in generating the analytical insights. Existing datasets were used to generate both the simulated hourly electricity loads and the heat load (Tables 6 and 7 and Figures 21 and 22). The other relevant data can be found in section 2. Zhangjiakou City exports a large share of the electricity produced locally to neighbouring regions, including Beijing. Therefore, this large potential of electricity exports is kept in the scenario analysis, making the city a potentially large exporter of renewable energy in the future.

Table 6 Electricity consumption in Zhangjiakou, 2017

Description	Base scenario (2017)	Unit
Electricity consumption	14.69	TWh/year
Electricity fixed export	31.01	TWh/year
Electric transport	0.58	TWh/year
Electric heating (household)	0.38	TWh/year
Electric heat pump (household)	0.1	TWh/year
Total electricity	**46.76**	**TWh/year**

Source: IRENA analysis

Figure 21 Electricity consumption in Zhangjiakou for reference year 2017



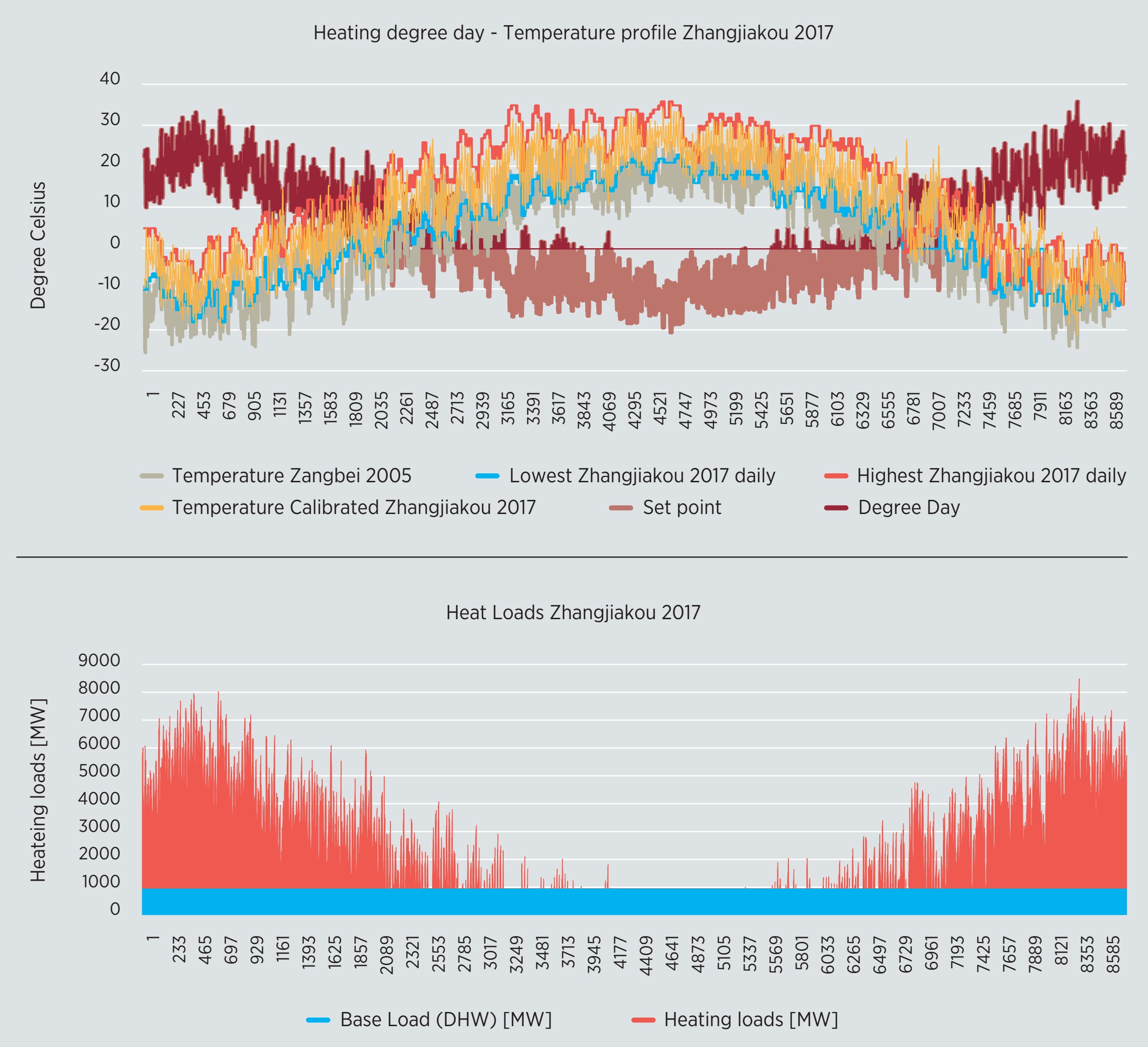
Source: IRENA analysis

Table 7 Heat consumption through household units and the district heating network, 2017

Heating demand	Description	Base scenario (2017)	Unit
Household			
	Coal boiler	5.6	TWh/year
	Solar thermal storage capacity	1.6	TWh/year
	Natural gas boiler	0.23	TWh/year
	Biomass boiler	0.23	TWh/year
	Heat pump	0.3	TWh/year
	Electric heating	0.38	TWh/year
District heating		**14.63**	**TWh/year**
Total		**22.97**	**TWh/year**

Source: IRENA analysis

Figure 22 Heating degree days and average temperatures in 2017



Note: The heat load variabilities for space heating are calibrated with Zhangjiakou's measured total loads.
The base loads for domestic hot water are represented in blue.

Source: IRENA analysis

A simulation using the EnergyPLAN model was performed using the 2017 data to validate the accuracy of the model against the actual data. The result is within the acceptable range of errors, as presented in Table 8. For virtual renewable energy sources, a correction factor is applied accounting for the difference between theorical and actual efficiency during operation, also reflecting the curtailment rate for Zhangjiakou.

Description of energy scenario for 2022

Currently, the industrial sector in Zhangjiakou remains dominated by energy-intensive industrial sectors, notably iron and steel. In the immediate term, any major transformation would be hard to predict, except for closing down the blast furnaces of Xuan Steel, which is likely to occur before the Winter Olympic Games in 2022. Another major change that can be anticipated is the installation of additional renewable energy for the Olympic Games, as discussed previously.

Given the high likelihood of occurrence of these two major assumptions, as well as other factors that might be substantially changed by then, we describe the 2022 energy outlook in one scenario only, known as **RE_2022** (Figure 23).[18] This scenario was constructed based on three main factors: an increase in renewable energy, particularly wind and solar PV; a loss of industrial energy load of 42%[19], attributed to the shutdown of Xuan Steel; and the use of electricity to meet half of the remaining load.

The renewable energy share could reach 47.7% by the end of 2022, indicating a high probability of achieving the city's 2020 renewable energy target. Reduction of the industrial energy load is a big contributor. However, for this analysis a water electrolyser with a proton exchange membrane is also modelled with an efficiency of 72% to produce hydrogen from renewable energy sources (Mathiesen *et al.*, 2013). Heat pumps, modelled with a coefficient of performance (COP) of 3, also contribute to the increase in the renewable share.

Table 8 Zhangjiakou's actual electricity output from installed systems in 2017 vs. total supply in simulation

Electricity generation	Supply 2017 (TWh)	Supply simulation (TWh)	Correction factor difference [%]
Coal-based power plant	23.42	24.80	+5.7 %
Wind	17.27	17.26	-1.08
Solar PV	1.61	1.61	-4.2
CSP	-	0.02	-
Biomass power	0.09	0.09	-
Total	42.39	43.78	+3 %
Total		**22.97**	**TWh/year**

Source: IRENA analysis

18 Note that the primary energy is defined as energy carrier in the EnergyPLAN.

19 The actual resulting loss needs to be determined subject to the possible replacement by electric arc furnaces; in either case the load will be substantially reduced because of the shutdown of the blast furnaces.

A micro-CHP plant, driven by hydrogen with an estimated efficiency of 50% thermal and 30% electric, is another important technology that was modelled.

By 2022, the industry sector in this scenario would have taken a major step to reduce coal consumption in the city, moving to cleaner fuels and resulting in significant loss of the load. However, this is not the only contributing factor. The residential and transport sectors, with the clean technologies, also play an important role. As estimated, Zhangjiakou could develop up to 20 000 tonnes of annual hydrogen production capacity for 3 000 hydrogen-fuelled vehicles, if the local government can accelerate deployment by mainstreaming the project review and approval procedures while maintaining the necessary oversight on overall planning and safety.

Description of energy scenarios for 2035

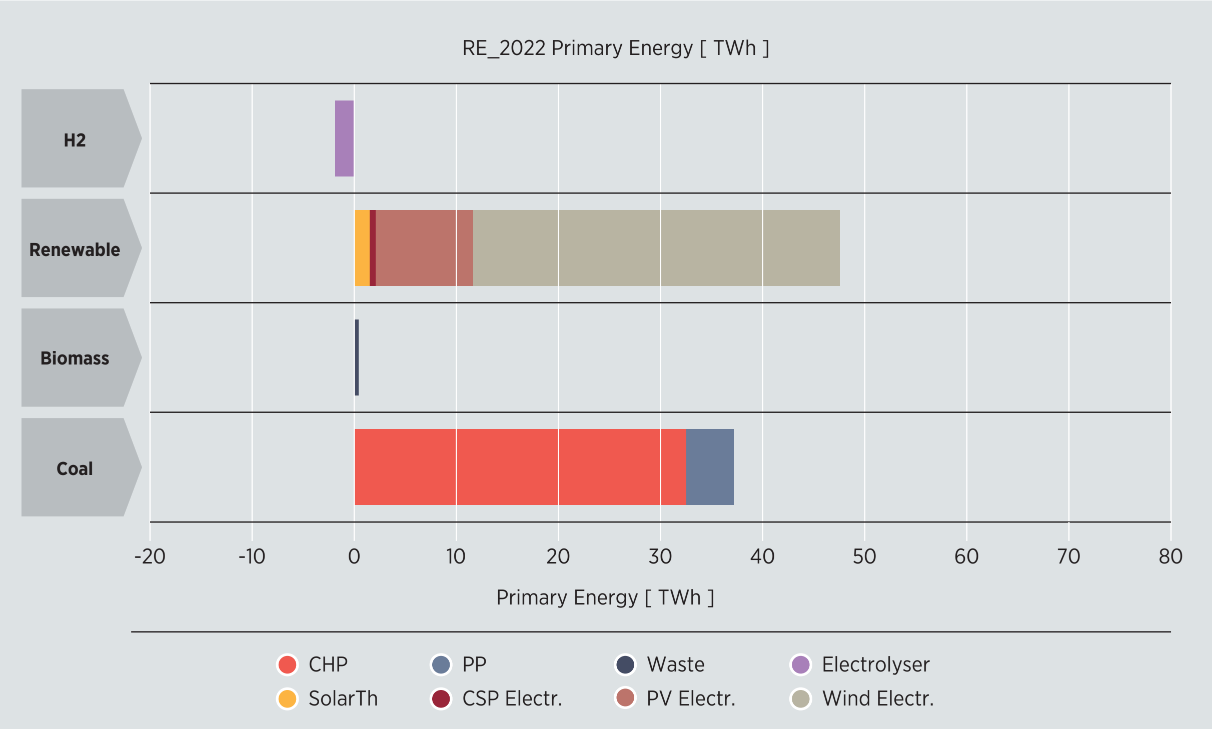
The analysis for 2035 was carried out with consideration of the 2030 targets set by the government. Given that the 2035 scenarios are closely relevant to the 2030 targets, they were examined with extra care, with additional insights arising via discussions with local experts.

Following the current rapid growth of renewables, the existing plan, if fully executed, can reasonably be expected to achieve the overall government targets. However, whether the city could achieve 100% zero-carbon emissions for the industrial sector and completely phase out fossil-based transport fuels deserves a separate discussion.

This study presents two advanced scenarios for 2035, in addition to the business-as-usual scenario whose results are largely in line with the 2030 targets. In the two advanced scenarios, which emphasise electricity and hydrogen, respectively, higher shares of renewables can be achieved.

Figure 24 presents the **RE_2035 Electricity** scenario, in which the role of electricity is enhanced. Under this scenario, the electrification of all non-electricity end-use sectors, particularly scaling up EVs, should be the prevailing trend during 2017-2035. For industrial sectors, there would be a 20% increase in electricity consumption due largely to sector-coupled technologies.

Figure 23 Renewable power generation in 2022



Source: IRENA analysis

The residential sector would see a 1% to 22% increase in the use of stand-alone/individual heat pumps from business as usual, and large-scale heat pumps would be used in district heating systems, which are expected to cover nearly 60% of heat demand in the area.[20]

In terms of energy performance in buildings, China recently stepped up its efforts to develop near-zero building standards for new buildings by halving the energy consumption standards set in 2016. In parallel, building retrofitting with fiscal support from the Ministry of Finance is now underway.

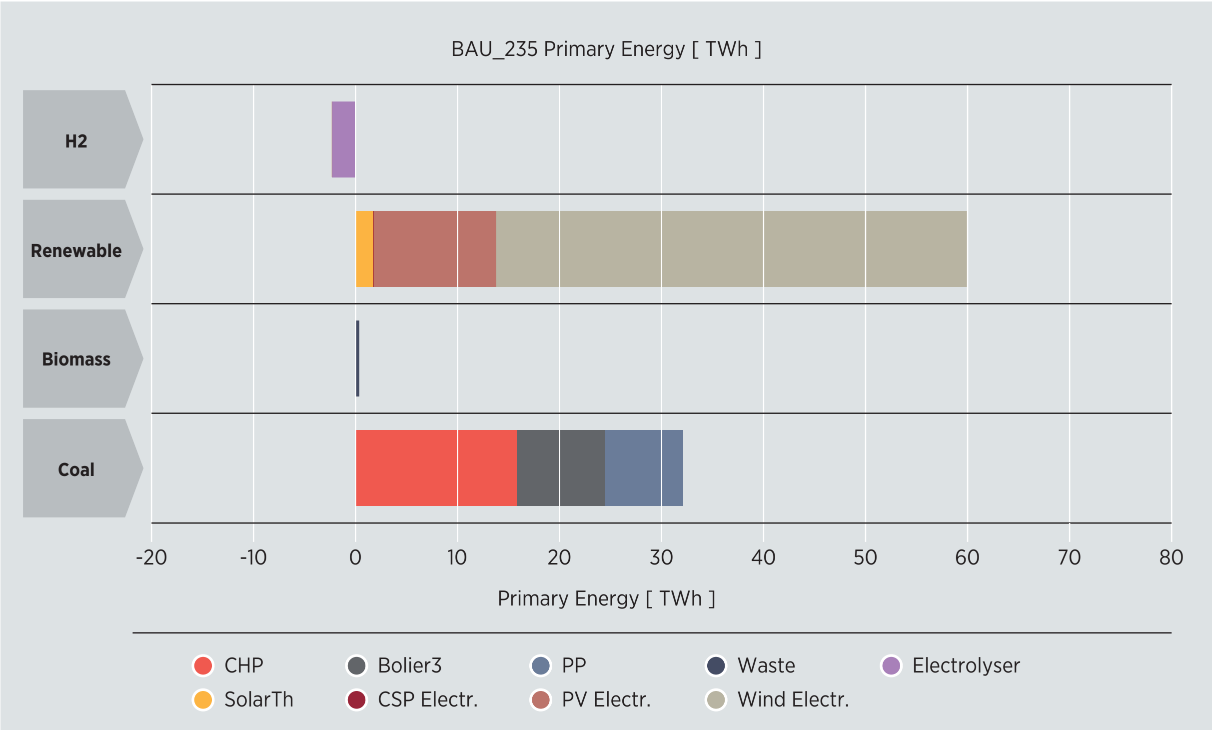
In view of these elevated measures and the relatively small building stock in Zhangjiakou, the thermal energy demand of buildings could be halved from the business-as-usual scenario down to 45 kWh/m^2/year by 2035, also providing a target value for future cities. This is a positive step towards 30 kWh/m^2/year, regarded as the international value for passive buildings in a cold climate zone (Institute PH, 2015). In turn the improved building energy performance would make the use of heat pumps technically feasible.

In terms of generation, wind remains the lion's share followed by solar PV, while CSP and biomass-based electricity generation are negligible (Figure 25). If electric appliances and other technologies perform as desired, the renewable share could increase to 75%, up from 53% in the business-as-usual scenario.

In this scenario, electrification of the transport sector would nearly wipe out the demand for fossil-based transport fuels. Subject to the charging infrastructure, the share of EVs could change by a range of 10%. Smart charging would lead to more EVs due to the economic incentives associated with the ancillary services this could provide through vehicle-to-grid (V2G). This in turn would facilitate the integration of variable renewables in the grid (IRENA, 2019b).

Nevertheless, because most urban residents live in multi-family or high-rise buildings in China and do not have access to their own parking lots that can be connected with a charging facility, the impact would be less remarkable than in a city/country where single-family houses with their own garages prevail, thus facilitating the installation of their own charging facilities.

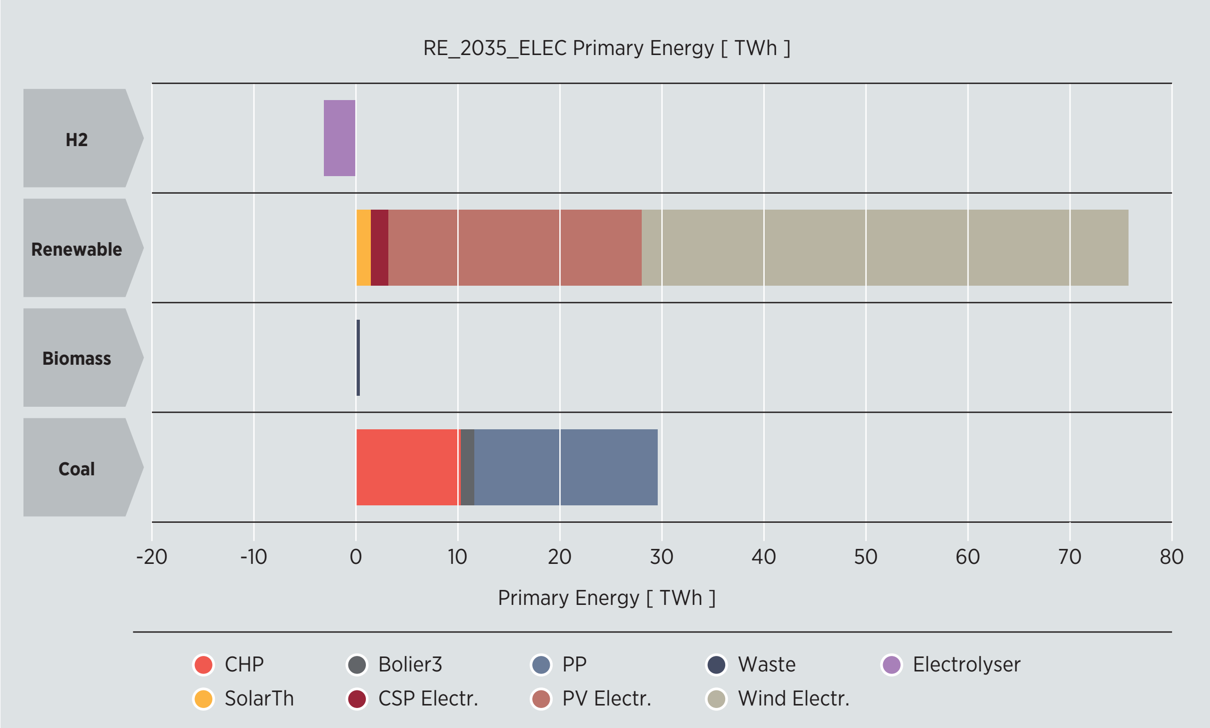
Figure 24 Renewable power generation in 2035: Baseline scenario



Source: IRENA analysis

20 The share of district heating network coverage in the area would nearly double during 2017-2035, which would occur in both the business-as-usual and the other advanced scenarios, as it is related to urbanisation and population density in the central built environment.

Figure 25 Renewable power generation in 2035: Electricity scenario



Source: IRENA analysis

One of the uncertainties in this scenario is the performance of air-source heat pumps in a cold climate. At present, air-source heat pumps are the prevailing technology used in this region.

At the normal outside temperature, the COP could reach 3-5, while in the cold winters it could drop to less than 2 depending also on the difference between indoor and outdoor temperatures (Zhang *et al.*, 2017). In this case, a back-up heating system is needed, mostly electric heaters. This would lower the overall system efficiency and thus make less economic sense, even with renewable electricity. One solution would be to improve the heat pump installation standards and the system configuration as well as innovative technologies to achieve the desired COP even in cold climate zones (IEA, 2017).

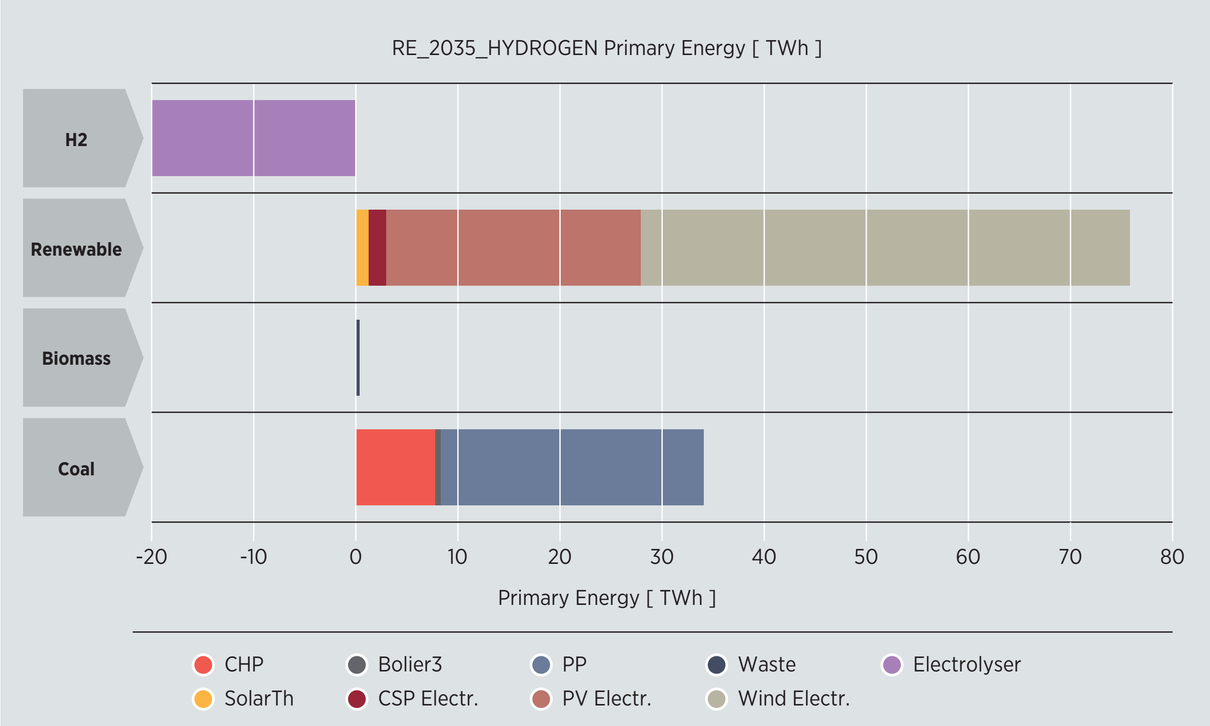
RE_2035 Hydrogen is the other advanced scenario, in virtue of the growing technological maturity of renewable hydrogen production and its increasingly diversified end-use sector applications (IRENA, 2018). The scenario's energy mix for primary energy production in 2035 is illustrated in Figure 26, which counts more on hydrogen as a preferable energy carrier.

Hydrogen is viewed as a strategic area that the municipal government is passionate about and has already undertaken significant efforts to develop the infrastructure and diversification of applications.

As early as 2018, Zhangjiakou became the frontrunner in the use of hydrogen buses and the development of the needed infrastructure. Through two pilot sizeable projects in Wangshan Industrial Park and Gu County, Zhangjiakou City has built a cumulative production capacity of hydrogen through renewable-powered electrolysers of up to 2 300 tonnes/year. Such early experience gained in production, road transport and storage safety, as well as the operation of refilling stations – coupled with the growing research and development (R&D) capacity – will accelerate both the technological innovation and the scale-up of hydrogen applications in a variety of sectors in Zhangjiakou.

This trend in hydrogen development in the city is expected to continue to 2050. Hydrogen as a transport fuel to substitute petrol and diesel is a key feature of this scenario. By 2035, hydrogen would be expected to meet 21% of the total transport energy demand.

Figure 26 Renewable power generation in 2035: Hydrogen scenario



Source: IRENA analysis

The hydrogen scenario also presents a technical option for provision of heat either through injection into district heating networks or through micro-CHP grids. By 2035, around 15% of the total heat demand would be met by hydrogen. Furthermore, the 9% of the heating demand allocated to natural gas would be replaced by an electrofuel produced by CO_2 hydrogenation, which is aligned with Beijing's plans to promote an increase of carbon capture and storage technology.

One of the areas for promising hydrogen use in the industrial sector is iron and steel making, where hydrogen can be used as a reduction agent in replacing the coke coal used in the conventional technology. With the improved cost competitiveness of renewable generation, this technological pathway makes better economic sense and has substantial environmental benefits, for instance carbon emission reduction from energy-intensive industries. (IRENA, 2019c). By 2035, 21% of hydrogen can be used for industrial purposes in Zhangjiakou, equivalent to 10% of the projected demand for the industry sector.

Description of energy scenarios for 2050

Zhangjiakou's 2050 energy landscape will be influenced by the national long-term energy outlook. As projected under the Below 2°C scenario in the *Chinese Renewable Energy Outlook 2018*, electricity will be the dominant energy carrier at 53% of TFEC by 2050, representing more than a doubling from the 2017 level at 23%, while renewable-derived hydrogen will account for 6% of TFEC (CNREC, 2018).

Both electricity and hydrogen are critical for the decarbonisation of Zhangjiakou's energy systems through the use of the city's full potential of abundant renewable energy sources.

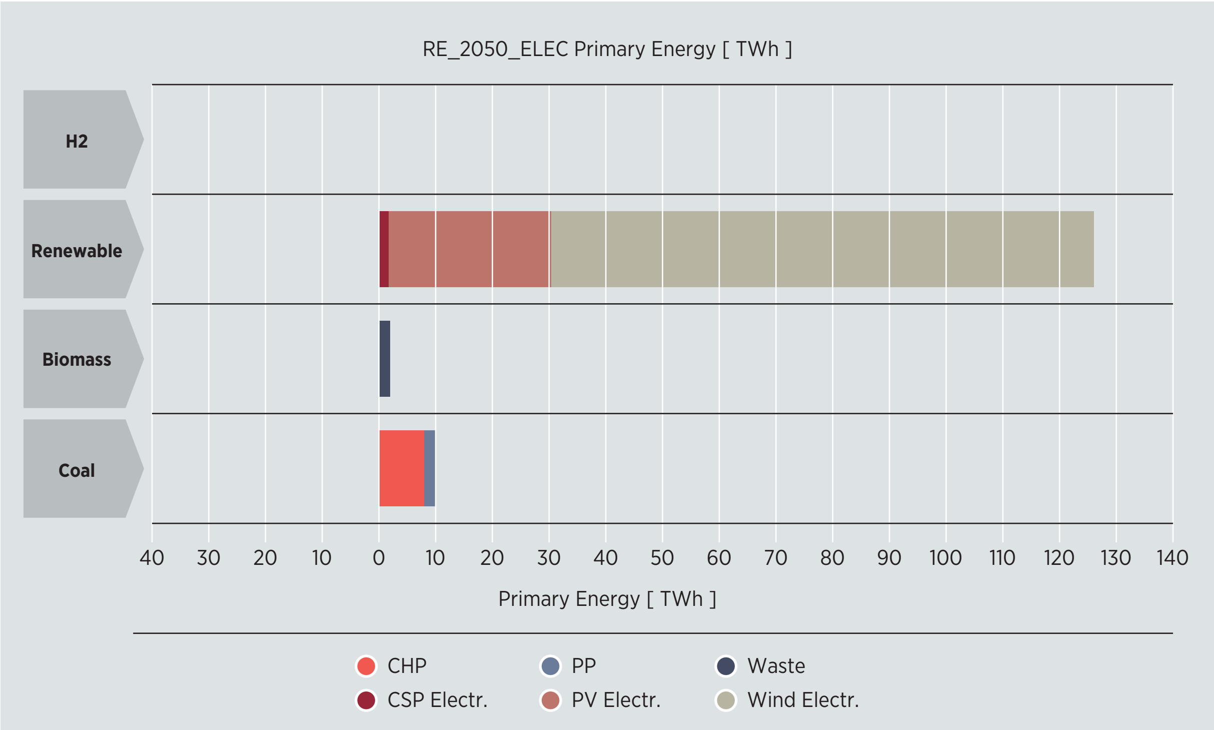
Against this backdrop, the scenarios were crafted, following the RE_2035 Electricity and RE_2035 Hydrogen scenarios described above to remain some level of consistency. Notably, the 2050 scenarios are more indicative compared to the previous analyses, given the greater degree of uncertainty inherently embedded in such a long timespan, particularly for a country like China.

In the **RE_2050_Electricity scenario**, industry would be fully electrified (Figure 27). This is feasible due in part to the reduced industrial energy consumption resulting from the phase-out of energy-intensive industries in Zhangjiakou. The 30 GW of solar PV and 40 GW of wind energy potential would be fully exploited, with the increased use of heat storage including seasonal energy storage among other enabling technologies such as smart charging for EVs and for stabilising the grid with a high share of VRE sources. By 2050, around 93% of the energy needed would be provided by renewable sources in the form of electricity, heat and renewable hydrogen.

Given that the urbanisation trend will continue, and the urban population would live in a more compact environment to benefit from the sharing economy and from higher resource efficiency, district heating networks would be expanded to cover 74% of the total heat demand in 2050. Biomass, geothermal and solar thermal in association with large-scale heat pumps would supply heat to end-users through the district heating network. For areas where district heating does not make economic sense due to the low demand, electricity for heating would become a prevailing option.

As with any other systems with high penetration of variable renewables, the system flexibility is a vital element to ensure the stability and reliability of the energy supply. Towards this end, energy storage, particularly heat storage as a cost-efficient buffer, has an important role to play. As estimated, 1 GWh of heat storage capacity would be available in 2050, which could add additional flexibility to the system on top of other options such as improved operational procedures, battery electricity storage, EVs as storage, and renewable-based hydrogen production via an electrolysis system and storage.[21]

Figure 27 Renewable power generation in 2050: Electricity scenario



Source: IRENA analysis

21 The electrolysis process to produce hydrogen can be operated in correspondence to variable electricity production from renewable resources, if the storage system is deployed. Thereby, the grid load can be managed more effectively while at the same time the capacity factor of renewable energy systems can be improved (Kroposki et al., 2006).

The **RE_2050_Hydrogen** scenario presents another technological pathway to accommodate even higher shares of renewable in the energy mix, as illustrated in Figure 28.

The increase is attributable to the greater flexibility in this scenario compared to the RE_2050_Electricity scenario, because hydrogen is relatively cost efficient to store at a large scale over a long time, and its production process through electrolysers is interruptible to better match the availability of VRE production from wind or solar.

Additionally, local biomass and biodegradable MSW could further increase the use of renewables in the energy mix, when more feedstock could be made available through improved measures in waste (including agricultural residues) collection and handling processes.

Electricity still plays an important role in this scenario, while hydrogen acts as a booster that helps to achieve full exploitation of renewable energy potential.

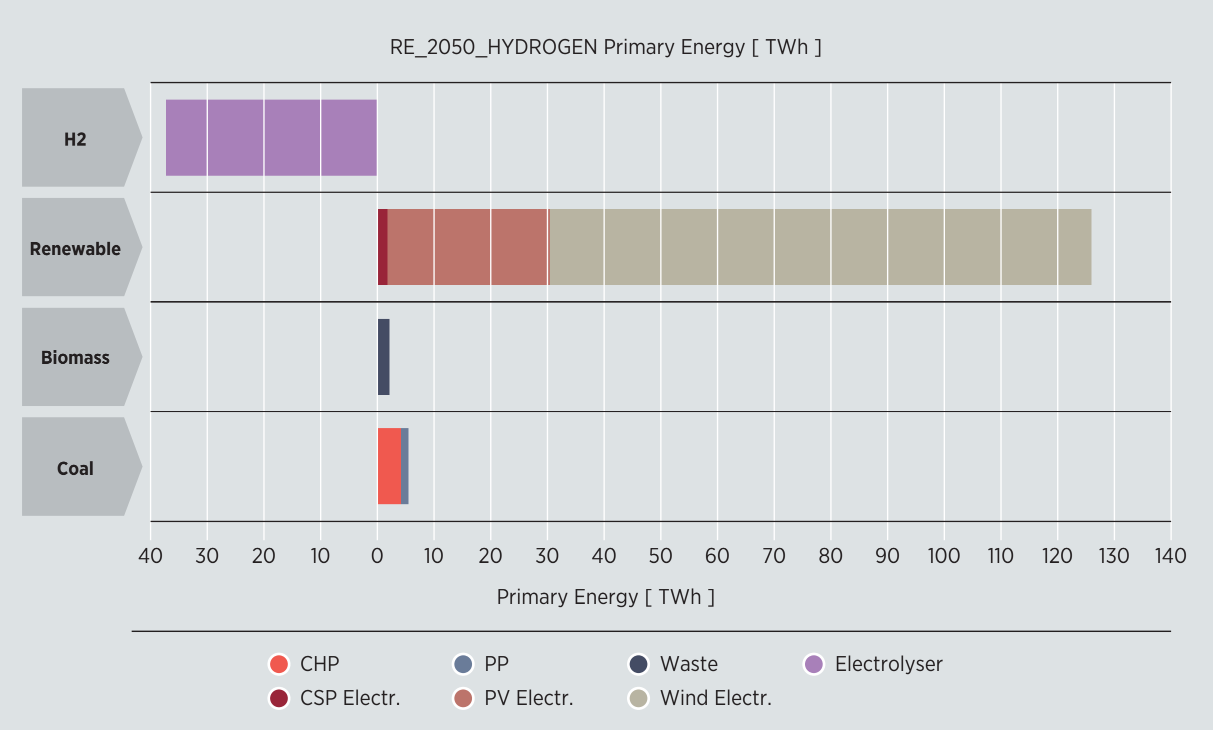
Implications of scenarios on costs

The equivalent annual costs assume a discount rate of 7.5% (IRENA, 2017). The investment costs for the capacity expansion planning and the maintenance of the different systems are included. The projected costs are based on the learning curve for the deployment, and decline due to the manufacturing and technology improvements of renewable energy (IRENA, 2019c; IRENA, 2019d).

Currently, the installed capacity of wind greatly exceeds that of solar PV. In the coming years, Zhangjiakou plans to increase its solar capacity to catch up with wind capacity, as shown in Figure 29. The expansion planning of solar PV is reduced in 2050 compared to that in 2035, reaching the maximal local capacity assessed by experts.

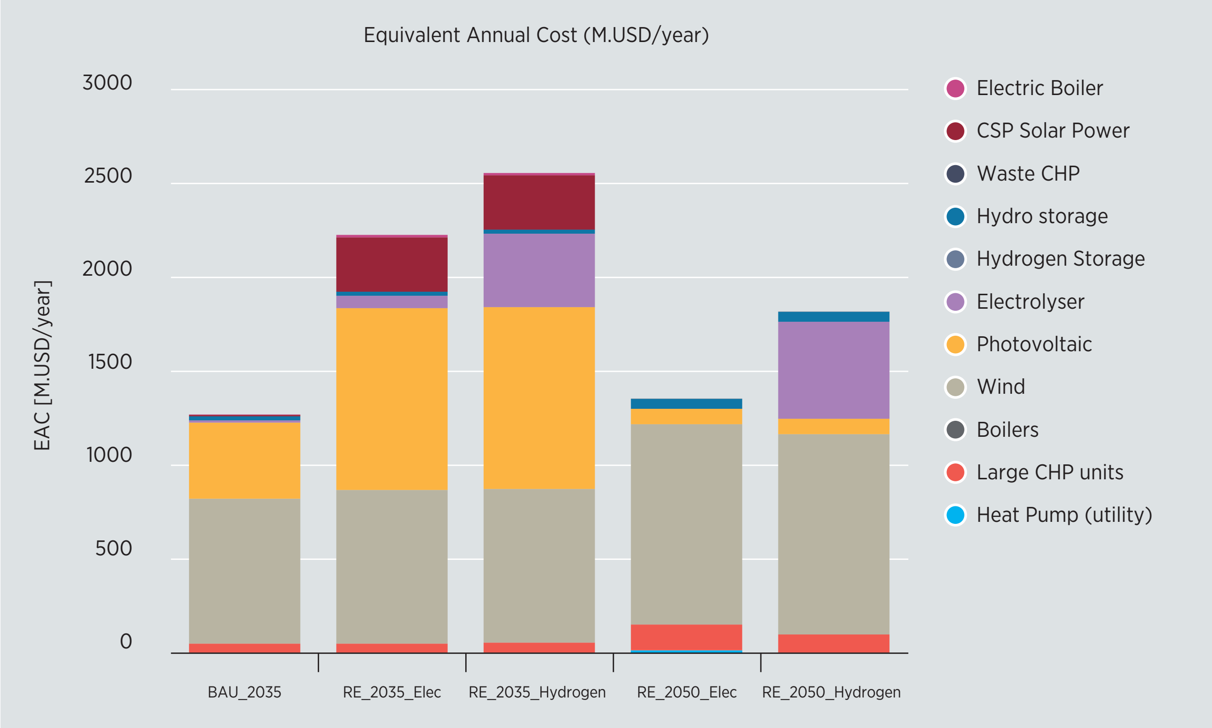
An increase in the capacity of CSP and solar PV provides more flexibility and security of supply – decreasing the risks associated with a system relying mostly on wind power – by diversifying the technology portfolio.

Figure 28 Renewable power generation in 2050: Hydrogen scenario



Source: IRENA analysis

Figure 29 Cost implications of different renewable power scenarios



Source: IRENA analysis

Costs are shifted slightly when considering the hydrogen strategy. However, the fuel costs, which are not plotted due to high uncertainties, would largely decrease in the hydrogen-based scenario compared with the electrification scenario (hydrogen acting as seasonal storage and buffer).

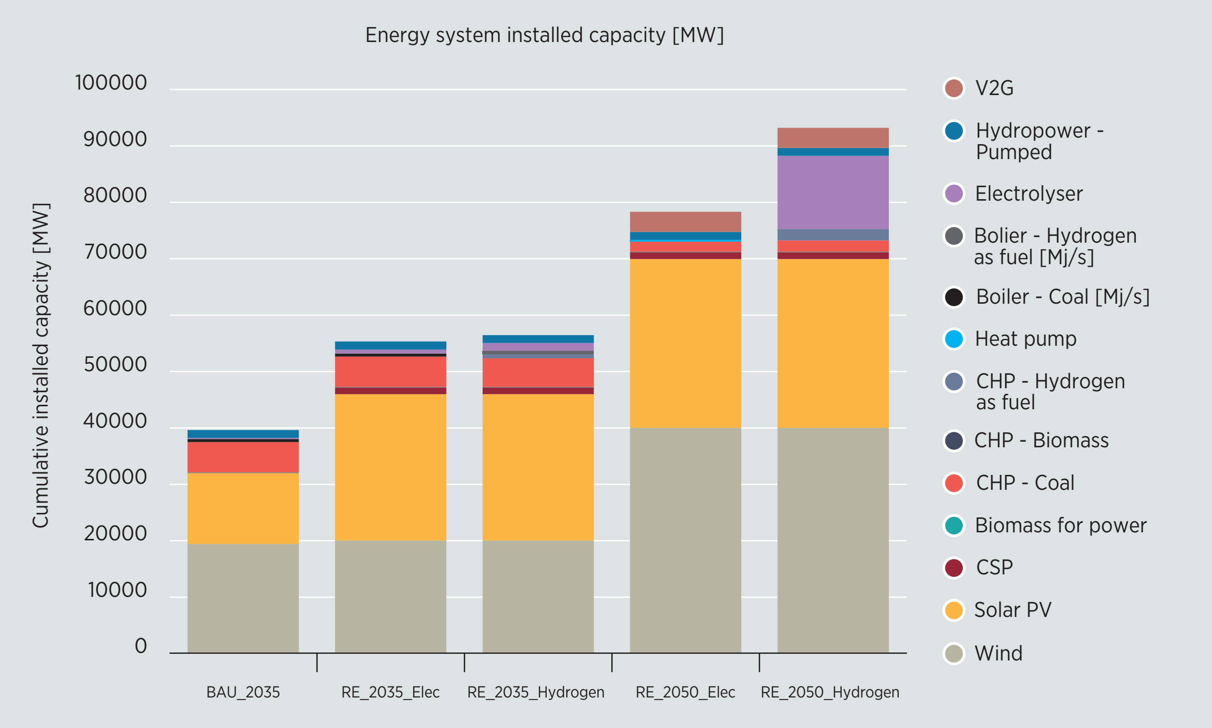
Chinese cities need a new energy paradigm, whereby coal-fired systems give way to variable renewables, battery storage and smart grids

Summary remarks on scenarios

With renewable energy clearly defined as a key competitive advantage, along with the strategic restructuring of industrial sectors affecting energy demand over time, Zhangjiakou's future energy system will be fundamentally transformed in comparison to today's system. Such a transformation needs to be understood in both the regional (Beijing-Tianjin-Hebei region) and national contexts, given the interconnectivity of energy systems at various levels in China.

Across all the scenarios described above, the core element is the extent to which local renewable energy resources would be exploited in terms of the generation capacity and the contribution to both the overall energy supply as well as to different sectors. Figure 30 shows the installed capacity of the energy systems in different scenarios and target years. Along with the anticipated greater degrees of electrification in future end-use sectors, electricity is undoubtably an important energy carrier in all scenarios.

Figure 30 Cumulative installed power generation capacity, 2035-2050: Different scenarios for Zhangjiakou



Note: V2G = Vehicle-to-grid; CHP = Combined heat and power; CSP = Concentrating solar power; PV = Photovoltaic
Source: IRENA analysis

However, energy storage and other enabling technologies become crucial if electricity is to be generated mainly from VRE.

In the case that the power density as well as the scale of storage of electricity does not have a revolutionary technological breakthrough as anticipated, the other forms of energy carriers, such as hydrogen, will have an important role to play in shaping the future energy landscape, which has been reflected in the hydrogen scenarios. This is particularly the case in Zhangjiakou, which has already taken the lead in China's application of hydrogen FCEVs. The spillover effect into other sectors/applications could be reasonably anticipated, such as hydrogen for industrial and residential uses.

The advantage of integrating a larger share of hydrogen-based systems towards 2050 is given by the very high share of VRE, making it beneficial to produce hydrogen from the surplus of renewable electricity. In the electrification scenario, thermal capacity and the implementation of seasonal storage need to be substantially increased to reach the same level of flexibility. An estimation of 50 GWh of heating storage combined with high flexibility in the electricity demand could match the performance of hydrogen-based systems in the integration of renewable energy in 2050.

In all the scenarios, biomass could be another promising source to explore further; it was not fully covered in the scenario development due to scepticism about the su fficiency of feedstock supply and the collection and handling system. Along with the ongoing campaign for a circular economy in China, the current situation around sorting and recycling of MSW would be improved, which might also cause some uncertainty in terms of supply for incineration; on the other hand, the biodegradable portion for energy recovery might increase.

Further analysis on this front and on agricultural and forestry residues would be needed in future study to better understand the local dynamics and outlook in the waste-to-energy sector.

3.3 Key technology options

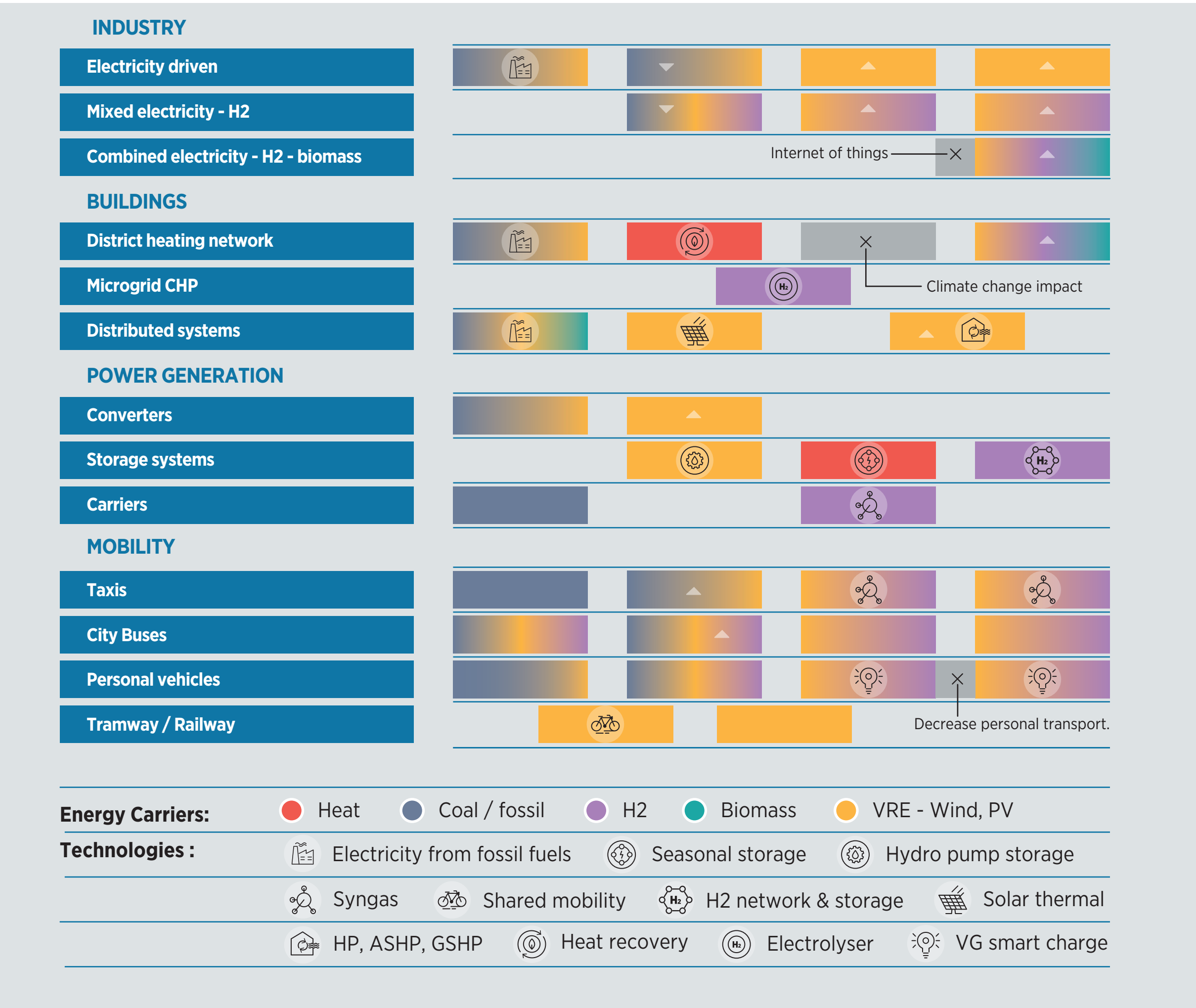
Realising high shares of renewables is pivotal to achieving a low-carbon energy system for Zhangjiakou. To achieve this goal, a suite of enabling technologies such as hydrogen, energy storage and smart charging must be effectively integrated in the process of optimising the solutions. Figure 31 presents the key technologies that are modelled in the analysis.

This section briefly discusses some of the technologies that will have greater impact on the realisation of Zhangjiakou's low-carbon outlooks for 2050, as presented in the previous section. Their current development and outlook at the global level are discussed in general terms.

Hydrogen for industrial and transport use

The use of hydrogen has been growing in recent years, and attention has shifted from the transport sector to areas that are harder to decarbonise such as industry, intensive/long-haul transport, chemicals and heating. This can be fossil fuel-based (grey hydrogen), fossil fuel with carbon capture (blue hydrogen) or produced from renewables (green hydrogen). Industrial use of green hydrogen can add demand-side flexibility for renewable energy inputs and is predicted to become a low-cost option for storing and transporting large quantities of electricity over long time periods. In the future, an 8-18% share of hydrogen in TFEC has been predicted, but in the short term, use is limited by costs to specific applications that are highly efficient.

Figure 31 Technology options for energy transformation: Different scenarios for Zhangjiakou



Source: IRENA analysis

Hydrogen is sure to trail other decarbonisation strategies because of the need for dedicated new supply infrastructure and pipelines (although there is potential to use existing gas pipelines for this purpose). It thus may be limited to countries that target its use as part of ambitious climate objectives. Several countries have now developed pilot and early-commercial projects for green hydrogen, which show a trend towards larger electrolysers (up to 100 MW plus) and improved technology. These include Germany, the Netherlands, Norway, Australia, France, the UK, the US, Canada, Chile, Japan and China. Japan is one of the biggest hydrogen importers and is a global leader in residential fuel cells, with 223 000 units installed as of late 2018.

Challenges

The primary challenge to the use of hydrogen is cost. Hydrogen is currently 1.5 to 5 times more expensive than natural gas per unit of energy. Yet green hydrogen is predicted to become competitive with average-to-high natural gas prices in the future due to falling renewable electricity and electrolyser prices. Reducing energy losses from production, transport and conversion is critical. For now, large-scale use is also limited by government regulations, which can be unnecessary barriers to investment.

In addition, hydrogen transport[22] and storage as well as the operation of refilling facilities requires stringent safety regulations, which are either lacking or still under development. Given that hydrogen for transport is a new area, the responsibilities among the different governmental agencies need to be better defined. For instance, in China road transport of hydrogen needs to meet the safety regulation designed for natural gas. To meet this standard, the pressures of the hydrogen stored in the tank need to be nearly halved when hydrogen is transported from one storage facility to another by road. At the terminals, the pressures need to be increased, resulting in wasted energy and an increase in the operational costs.

Uses in transport and industry

Currently, most hydrogen production is fossil fuel-based and is used mostly in oil refining and as a feedstock for ammonia production, but other markets will be able to benefit from more widespread use including iron and steel making, liquids for aviation, marine bunkers or feedstock for methanol, synthetic methane and synthetic oil products. Hydrogen is also being used increasingly in oil refineries for diesel production, but this will fade with the decreasing use of oil.

In the iron and steel industries, reduction using hydrogen can transform ores into value-added metals. This can result in large reductions in greenhouse gas emissions of 80-95% when compared to conventional production. However, to be economically competitive it will still rely on the lowering of renewable electricity prices, as well as on further technology developments for efficient scale-up.

In the transport sector, more than 380 hydrogen re-fuelling stations are installed currently, and the FCEV stock (passenger cars and trucks) is also increasing (11 200 units at the end of 2018). FCEVs are still 50% more expensive than ICE vehicles but will benefit from scaling. Long-distance, heavy-duty transport is potentially a more attractive market for FCEVs due to the popularity of battery electric vehicles. Hydrogen buses are already in use in China, with Europe and Japan also developing their own fleets.

Another emerging technology is hydrogen as a raw material for liquid fuels (electrofuels or e-fuels), which act similarly to petrol, diesel and jet fuel. These are easier to store and integrate into the existing infrastructure than hydrogen. They can be used to power heavy vehicles (*i.e.*, aviation, freight and shipping) and for heating buildings and as petrochemical feedstocks. However, further processing also incurs more efficiency and financial losses.

22 Means of transport other than through pipelines.

Box 3 Hydrogen in Japan and Europe

Different countries have explored the application of hydrogen in their energy systems. An interesting example is Japan, which implemented a series of research and demonstration programmes between 2002 and 2010. After this the government promoted the "Basic Hydrogen Strategy", which aims to accomplish a world-leading hydrogen-based society by 2050 by encouraging the competitiveness of hydrogen among conventional fuels and promoting its implementation in the residential, commercial, industry and transport sectors (METI, 2017). With this strategy, Japan has achieved commercialisation of more than 250 000 units of residential fuel cell micro-CHP, 2 400 fuel cell vehicles have been deployed, 100 hydrogen stations have opened, and fuel cell public transport vehicles have been introduced (*e.g.*, Toyota's "SORA" FCEV bus) (NEDO, 2018).

In Europe, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU), a public-private partnership promoted by the EU, aims to demonstrate by 2020 fuel cell and hydrogen technologies as one of the pillars of future European energy and transport systems. The European Union launched an initiative in 2017 to support regions and cities to deploy these technologies. Under the scope of this initiative, for the industry and transport sector, the region of Emscher-Lippe (Germany) implemented a large hydrogen offtake in the chemical industry with its own pipeline network, as well as public transport planning to introduce fuel cell trains, and a municipal waste company tested two fuel cell garbage trucks (EU, 2018). Additionally, Europe has been implementing demonstration projects for residential fuel cells. Germany installed 560 residential fuel cells (solid oxide fuel cells and polymer electrolyte membrane fuel cells) between 2008 and 2013, and between 2014 and 2016, 1 000 systems were installed across 12 European countries.

The deployment of hydrogen for industry and transport will start with facilities that directly feed medium- to large-scale industries and other large consumers. It then will expand to use transport fleets, which will be able to supply smaller consumers and eventually include the use of shipping cargo for intercontinental transport.

Smart charging for electric vehicles

Although the impact on electricity consumption of charging EVs has been shown to be limited, it can cause large increases in peak demand and place high stress on local distribution grids. However, this can be mitigated with smart charging (IRENA, 2019b). EVs can become micro grid-connected storage units when parked (which is typically about 95% of the time), and smart charging can be used to control the charging cycle to fit the needs of both the vehicle user and the power system. This reduces the curtailment and costs associated with reinforcing local electricity grids that would otherwise be incurred.

Smart charging is most effective when coupled with a predictable generation profile (*e.g.*, solar PV). The current status of development and outlook can be found in Box 4. Additionally, smart charging coupled with renewable energy sources hybridised with battery storage could provide an option for charging EVs with low-carbon/renewable electricity.

At the beginning of 2019, China had 2.6 million EVs on the road, accounting for 48% of worldwide electric light-duty vehicle sales. Additionally, in 2017 China was home to 340 000 electric buses that use battery swapping stations, which could also be used as a source of increasing grid flexibility. The government has shown strong support for EV charging, including setting a 4% penetration target for EVs as a share of total passenger cars and launching an ultra-fast charging infrastructure project. In this context, the SGCC, the world's largest power grid, has already installed 160 000 public charging points with plans to build another 10 000 stations and 120 000 poles by 2020 with powers of up to 360 kW.

Box 4 Current development status and outlook for smart charging

Various mechanisms are being used to encourage consumers to charge EVs during off-peak grid hours through different pricing and technical options. The simplest is time-of-use pricing, which encourages consumers to move charging activity to off-peak periods. Direct control mechanisms for smart charging will be necessary as a long-term solution at higher penetration levels and to deliver close-to-real-time balancing, including:

- V1G – unidirectional controlled charging: allows for changes in the rate of charging;
- V2G – vehicle-to-grid: smart grid controls vehicle charging and returns electricity to grid;
- V2H/B – vehicle-to-home/building: vehicles supplement power supply to the home and as back-up power but does not affect grid performance.

Smart charging solutions currently make use of slow chargers, which provide the most grid flexibility, and fast chargers, which cannot aid in grid flexibility but are used for electric mobility needs.

SYSTEM FLEXIBILITY		LOCAL FLEXIBILITY	
Wholesale market	**Transmission System Operator**	**Distribution System Operator**	**Behind-the-meter**
• Peak-shaving • Portfolio balancing	• Frequency control • (primary, secondary and tertiary reserve) • Other ancillary services (*e.g.*, voltage management, emergency power during outages)	• Voltage control • Local congestion and capacity management	• Increasing the rate of Renewable Energy self-consumption • Arbitrage between locally produced electricity and electricity from the grid • Back-up power

Using V1G, charging patterns are controlled to support real-time balancing of the grid. V2G would help distribution system operators manage congestion and allow customers to optimise for the price of electricity and renewable share. Battery swapping and using charging stations with buffer storage will also increase flexibility. However, in densely populated cities, charging will be focused on hubs, which can create localised regions of high stress on the electricity grid. V1G is a mature technology, but V2H/B has yet to reach market deployment outside of Japan.

EV batteries can provide fast responses, but their power capacity and therefore time of use by the grid is limited. Therefore, they would need to be aggregated to act as a viable virtual power plant (500 vehicles needed for 1-2 MW). Charging strategies also must be tailored to the renewable energy source used.

Although the current storage capacity in EVs is marginal, EV penetration is expected to increase significantly to 2050, with larger batteries and higher driving ranges. If the correct incentives are put in place, smart charging will be the default functionality so that there is a sharp increase in flexibility potential from EVs in 2020-30, when it should start to level off due mainly to the large-scale uptake of autonomous vehicles and to reduced average parked time (due to vehicle sharing) and the development of ultra-fast chargers. Rising EV penetration increases the need for common standards of charging infrastructure, smart grid-enabled charging stations, cars that allow for V2G and interoperable solutions between charging stations, distribution networks and EVs.

Source: IRENA, 2019e

Outlook for energy storage technologies

Worldwide, energy storage deployment reached a record high in 2018, nearly doubling from 2017. The behind-the-meter (BTM) energy storage market is made up of both commercial and industrial and residential customers (IRENA, 2019f). With the exception of a small number of early adopter markets, such as Japan and Germany, commercial activity is largely limited to commercial and industrial customers, and only a relatively small capacity of residential systems has been deployed. Nevertheless, consumer-located storage has become a valuable asset for the power grid.

In 2018, BTM storage expansion was particularly strong, almost three times that of 2017, and reached over 8 GWh globally. BTM storage matched grid-scale storage investments for the second consecutive year, and deployment in both categories reached record levels in 2018, with significant growth in the Republic of Korea followed by China, the US and Germany.

New markets have emerged quickly wherever governments and utilities have created supportive mechanisms, including in South-east Asia and South Africa, indicating that storage continues to need policy support.

For utility-scale applications (excluding battery storage installed behind-the-meter) (IRENA, 2019g), global revenue was around USD 220 million in 2014, with Asia Pacific, Europe and North America being the first movers in the market. This market is expected to grow in the coming years, and the annual revenue for all applications is expected to increase from USD 220 million in 2014 to USD 18 billion in 2023. Annual battery storage capacity is expected to rise from 360 MW to 14 GW over the same period.

For utility-scale projects in 2014, battery use for renewables integration comprised 29% of the total battery energy storage systems installed, followed by peak shaving (20%), load shift (18%), ancillary services (17%) and other applications (16%). Renewables integration is expected to remain a primary application in 2023, providing 40% of cell-based revenue. This will be followed by load shifting application (37%), peak shaving (15%), ancillary services (3%) and others (5%). However, these numbers do not include household solar PV installations, which represents a significant market opportunity. IRENA (2016)

Wood Mackenzie Power & Renewables projects a 13-fold increase in grid-scale storage over the next five years, bringing energy storage deployment from 12 GWh in 2018 to a 158 GWh market by 2024. This would result in USD 71 billion in investment in battery storage systems, with USD 14 billion of that in 2024 alone. This growth will be concentrated in the US and China, which will account for 54% of global deployments by 2024, followed by Japan, Australia and the Republic of Korea in a second tier of growth markets, and Germany, Canada, India and the UK rounding out the list.

3.4 Importance of strategic urban energy system planning

Strategic energy system planning needs to be done in co-ordination with the changing dynamics of energy demand and generation. As with other cities in China, Zhangjiakou has undertaken an initiative to upgrade its current industrial sectors – a transformative move to a new generation of industrial development for the city. This will affect its future energy demand as much as how such demand can be met in terms of the energy source and where it is generated geographically.

Implications of industrial transformation on energy demand

In general, industrial transformation has a significant impact on economic development, environmental quality and energy balance (Chenery *et al.*, 1986; Simonen *et al.*, 2014; Sakamoto, 2011). Over the wave of globalisation, energy-intensive industries were relocated from developed to developing economies, notably China, for a variety of reasons, mostly for lower manufacturing costs and cheaper energy.

In a new era of industrial strategic relocation, affordable and reliable energy is key to industrial production when choosing a location for setting up facilities (IRENA, 2014). With growing political pressure for the increased deployment of renewables, businesses are incentivised to use renewable energy sources rather than fossil fuels. Businesses increasingly have goals to reduce their emissions and are also held to national or local government standards for their emissions. For example, in Flanders, Belgium, legislation introduced in 2007 dictated that the regional government would financially support only "carbon neutral" new industrial developments (Maes, 2011). The extent to which this can influence the relocation of industry can be compared with other drivers such as market and political conditions.

A sub-set of industrial cities that has developed recently are eco-industrial parks, or communities of businesses working together in the same location to maximise environmental, economic and social performance (UNIDO, 2017). The focus of these parks is to minimise resource consumption through the exchange of materials, energy, water and by-products, but part of the technical requirement of the park is to maximise the use of renewable sources (Taddeo, 2016). Industrial parks have limited spatial quality and so are limited in the size of renewable energy technologies that can be used for generation on-site. Therefore, they would benefit from locations where the renewable energy potential is high or that use imported electricity. Microgrids can also be used to consolidate the intermittent energy supply and the combined demand profiles of businesses on the site (Maes, 2011).

However, relocation of industry is costly and would not be implemented without an expected net cost gain. Therefore, renewables would not be the sole driving factor causing industry to relocate.

Another reason for this is that such companies also had a strong incentive to switch to reduce their carbon footprint (as was the case for Belgium). There are cheaper ways to do this, such as by adding renewable energy technology to existing locations, purchasing green electricity and purchasing renewable energy guarantees or emission credits (Maes, 2011).

Currently, the availability of higher-quality renewables might not be appealing enough to cause industrial processes and economic businesses to overcome cost barriers associated with relocation of their operations. Yet the expansion or selection of sites for new industrial facilities, especially where there is a business focus on sustainability, is a different story. To encourage movement towards high-renewable energy areas, governments can use policy in the areas of energy and carbon pricing to level the costs of fossil fuels and renewable energy (IRENA, 2014); otherwise they can impose regulations on new developments (Maes, 2011) or use tax exemptions (Kalyuzhnova and Pomfret, 2017).

Relevance to Zhangjiakou

In China, upgrading of the industrial structure is evolving, and higher technologies and lower environmental impact are key attributes of the process. Zhangjiakou is no exception. The results of the city's industrial upgrading will have implications not only for the scale of future energy demand but also for its geographic distribution. Energy-intensive industries, which are often major polluters, will be replaced by high-tech and environmentally friendly industries in pursuit of green development. The remaining heavy industries will also have to improve their environmental performance by applying energy efficiency and cleaner production measures.

For instance, with the planned shutdown of Xuan Steel and the potential upgrading from blast furnaces to electric arc furnaces, the energy demand from industry would be greatly reduced. By the same token, as big data centres are established in some counties of Zhangjiakou, the distribution of electricity consumption will change. Based on the city's big data development plan, 1.5 million servers are to be put into operation in Zhangbei County in the coming years, adding around 14 TWh of annual electricity consumption, which would double the current level. As advanced information technology industries such as the Internet of Things, cloud computing, and big data develop rapidly, the industry's power demand will continue to grow from 2020 to 2030, with the addition expected to exceed 20 TWh annually.

The demand for electricity needed to produce hydrogen from renewables will increase as well. In addition, smart manufacturing will substitute for conventional production facilities, offering better energy and environmental performance. For energy production, including of electricity and heat, generation should be as close as possible to the loads to reduce transmission losses. In this regard, distributed generation could prevail.

With forward-looking strategic plans, Zhangjiakou can offer some unique opportunities for businesses to reduce their environmental impact through scaled-up use of renewable energy sources.

3.5 Role of policy innovation and new business models

In general, cities have less authority to make their own policies. Nevertheless, nearly all have some level of autonomy, as each city is unique and cannot be governed by the same specific policies set by the central or federal government. This has created a space for innovation in policy making in support of renewable energy deployment locally.

Globally, this trend is picking up steam, thanks to the improved cost-competitiveness of renewable energy systems and the multiple social and economic benefits associated with locally produced renewables, such as job creation, stimulation of local business development and improvement of air quality.

Increasingly, the security of local energy supply with, for instance, distributed and more reliable energy generation – an increasingly important factor from a climate resilience perspective – has become an important element that local policy makers have to factor in when they establish a long-term policy framework and development target.

In a broadened but forward-looking context, the concept of smart cities provides another good opportunity and promising outlook for urban renewable energy systems. Worldwide, agrowing number of cities are testing different configurations for future intelligent local/community/neighbourhood-based grids that can integrate a variety of new technologies and base the energy supply on local renewable energy sources.

The emergence of innovative and disruptive technologies requires innovative thinking in designing policies and regulations that can move ahead of the curve to provide the guidance for technology development and the creation of new business models. For instance, household rooftop solar PV opened up a new market segment, while community-based virtual power plants extend such innovation to a new level, further challenging the traditional utility-dominated business models.

In China, power sector reform is under way. One of the anticipated changes is the opening of local/community or industrial park-based distribution networks[23] to private investors and independent operators[24]. Pilot projects have already begun. This signals that a higher level of local energy governance could be anticipated, yielding greater power to local governments in China to plan and manage their energy systems.

Many Chinese cities have their own power plants, where local policy makers could make a difference by guiding future investment towards low-carbon energy infrastructure. By doing so, local business communities would be incentivised to create innovative business models and capture new opportunities. The leasing model for solar PV, particularly for commercial and industrial buildings, is exemplary in this regard.

Nevertheless, as with all industrial policies, there is a need for a longer-term plan that would allow the companies that would be affected to develop a proper strategy to cope with the transformation, through which the overall system costs and risks will be substantially reduced.

Zhangjiakou City has a unique advantage, as the nationally designated test bed for renewable energy innovation in technology development and applications as well as in policy and regulatory designs. Politically, it has secured the support of the national authorities. Not only was the city granted authority to develop the country's first National Renewable Energy Demonstration Zone, but institutionally the steering committee for implementing the workplan has been established, with the vice-chairman of the NDRC, the provincial vice-governor and the deputy administrator of the National Energy Administration being co-leads.

This guarantees effective cross-ministerial co-ordination on the approval of innovative policies and regulations to be proposed by the local government to scale up renewables in the Demonstration Zone. A final advantage that Zhangjiakou could leverage in designing innovative policies to spur the development and deployment of new technologies and applications is its long-standing partnership with the Chinese Academy of Sciences in advancing the city's renewable energy scale-up.

Overall, policy innovation can play a significant role in creating a healthy ecosystem for the development and application of advanced technologies and systems and for the creation of novel business models to achieve a high share of renewables, which would enable Zhangjiakou to become a low-carbon city by 2050. Furthermore, the experience gained, and lessons learned, can and should be shared nationwide, an important mandate that the National Renewable Energy Demonstration Zone was given.

23 This refers to grids with a voltage level no greater than 110 kV.

24 The national policy was issued in March 2015.

4. LOOKING AHEAD

Key points:

- Renewable energy for cities, in particular, cannot be planned in isolation from the evolution of industrial sectors, the change in urban form, and the existing urban infrastructure facilities, urban renewable energy systems and their impact on society, the environment and applications of other technologies including smart city technologies.
- Energy planning tools based on geographic information systems (GIS) can help with the optimisation of the generation, distribution and allocation of the renewable energy potential with both demand and urban development.
- Developing stronger and flexible power grids for regional electricity exchange presents another good opportunity to achieve the low-carbon goal in a more cost-effective manner with high shares of renewables.
- Hydrogen derived from renewables has been increasingly viewed as a promising solution to increase the demand-side flexibility of the power system through which high shares of renewables can be achieved.
- Strengthening institutional capacities at the city level is crucial for practising urban energy planning and for adopting renewables as a source of energy supply. Zhangjiakou needs to establish a demonstration and training facility for advanced renewable energy systems to help other Chinese cities in this regard.
- Zhangjiakou could benefit tremendously from engaging with the international community.

Zhangjiakou has been in a unique position to build its energy transformation strategy around renewable power generation, the upgrading of its industries and diversified end-use applications of renewable energy sources. The experience that it gains throughout the transformation process will be of great value and significance, given the privilege that the State Council has granted the city to test and demonstrate plausible renewable energy-based options for energy transformation in China. This will potentially create an interesting model for other cities with excellent renewable energy resources to follow.

In addition, because the local power grid is pivotal for regional grid connections not only to Beijing – a big load centre that is expected to rely increasingly on imported electricity – but also to the grid of Inner Mongolia, a region with high wind energy potential, Zhangjiakou could develop into a hub for balancing the regional renewable electricity market. Such experience provides inputs for those cities connected with large-scale renewable electricity generation facilities to integrate the development of their low-carbon scenarios with regional development similar to Zhangjiakou's case in the context of the Beijing-Tianjin-Hebei region.

The previous sections analysed the current energy situation of Zhangjiakou City and charted out the pathways leading to a low-carbon future. The electrification and hydrogen scenarios have some level of relevance to almost all Chinese cities, given the accelerating electrification of end-use sectors in these cities, notably the adoption of EVs and various alternative options for coal-based heating systems and the revitalisation of hydrogen as an energy carrier to fuel the low-carbon future.

This section identifies the key strategic areas where the specific actions, if designed well and implemented effectively, would be able to facilitate the transformation of Zhangjiakou's current energy system onto the strategic pathways defined in this study.

4.1 Energy planning

This section covers three thematic components in the energy planning domain with high relevance to this study. Zhangjiakou should consider adopting these components at different stages of its energy infrastructure development and planning. On these thematic components, knowledge exchange with other cities can be easily made through international co-operation platforms.

Engaging in long-term energy system planning

Long-term energy planning is an essential component of the energy sector as well as of energy policy-making processes at the national and the municipal levels. Long-term energy plans feature quantitative scenarios and targets for the energy mix that meet overall policy goals, which can help establish a stable and predictable investment environment and provide a framework to inform recommendations on where to direct investment.

Renewable energy for cities, in particular, cannot be planned in isolation from the evolution of industrial sectors, the change in urban form, and the existing urban infrastructure facilities, urban renewable energy systems and their impact on society, the environment and applications of other technologies including smart city technologies. Urban energy system modelling behind long-term energy scenarios can take such factors into account, allowing for system-wide and strategic policy assessments for a city.

Zhangjiakou would benefit from developing a long-term energy plan following the strategic pathways outlined in this report. The long-term energy plan needs to address new technologies, business models and disruptive innovations appropriate to its local context.

The city context also requires an appropriate level of temporal granularities and spatial boundaries when applying an energy system planning tool or model, given the unique geographic and production patterns of renewables such as wind and solar. This should also be in alignment with the transformation of the industrial sector as discussed in section 3.4.

Such an energy plan would help Zhangjiakou establish a longer-term framework for guiding its energy sector transformation and the mobilisation of needed investment as well as private sector engagement on various fronts. For instance, a longer vision for the new policy, allowing the private sector to invest in building the local distribution grids, would provide some extent of certainty and assurance to the investors and operators of such grids.

Adopting GIS-based spatial planning tools and methods

Energy planning tools based on geographic information systems (GIS) can help with the optimisation of the generation, distribution and allocation of the renewable energy potential with both demand and urban development. Various trade-offs have to be assessed spatially and temporally. For example, GIS-based quantification of the investments for energy infrastructure, buildings refurbishment, waste management and distributed energy system development will facilitate the planning and operations of an integrated and dynamic system, according to the city morphology and human activities. The development of a city model, including different layers of GIS-based data, can facilitate implementation of the energy transformation by providing a visual quantification of all the aspects for urban planners to consider.

Sophisticated tools such as technologies for remote sensing and light detection and ranging (LIDAR) can be employed to develop more accurate models. This enables the development of high-resolution three-dimensional modelling of the urban context to capture urban phenomena such as micro-climate (urban heat islands), greenhouse gas emissions, and renewable energy potential and building energy demand simulation at multiple scales. An advanced toolbox is available in QGIS and/or ArcGIS software to compute such complex simulations. These multi-scale models, from building to city scale, enable the planning and integration of renewable energy based on overlaying layers addressing the matching of renewable energy potential, supply and demand (Nowacka and Remondino., 2018).

The GIS analysis can be further enhanced by combining it with advanced statistical software such as R[25], allowing in-depth analysis of energy demand patterns as well as forecasting, which is particularly of use in the situation of Zhangjiakou, requesting advanced methods for the optimal control of an energy system including a high share of VRE.

Developing stronger and flexible power grids for regional electricity exchange

When higher shares of variable renewables such as solar and wind are integrated in a connected power grid system, it is also crucial to view them in a regional context. This helps to gain a better understanding of regional balancing of renewable energy generation and consumption. The flexibility of different parts of the overall grid system would provide useful insight regarding how much and where variable renewables could be accommodated without jeopardising grid stability and reliability if no grid enhancement measures are taken.

The regional grid to which the Zhangjiakou power system is connected is also linked with the Inner Mongolia power grid where massive wind farms have been built. Zhangjiakou could achieve its low-carbon goal in a more cost-effective manner if balancing at the regional level could be better achieved. There is a need for a further regional grid stability study on this front.

Zhangjiakou could further explore the use of existing infrastructure with a switch to hydrogen

4.2 Diversification of end-use applications of renewables through hydrogen

To enhance the flexibility of thegrid and thereby accommodate greater shares of variable renewables, the end-use sectors need to be more engaged in grid operation. Electrification of the end-use sectors is widely acknowledged as an effective approach to have more players on the demand side that the grid operators could possibly engage with in maintaining grid stability.

Recently, renewable-derived hydrogen has been viewed as a promising solution to increase the demand-side flexibility of the power system, as variable renewables could be converted into an energy carrier through electrolysers, which can be used whenever needed. Thus, hydrogen can be strategically advantageous, drawing on the key combination of low-cost variable renewable power, cost reduction and efficiency increases in electrolysers.

Zhangjiakou could further explore the potential to use existing infrastructure for the deployment of a hydrogen-based strategy – for example, the re-use of an existing, or short-term planned gas distribution network for the transport of hydrogen. Better assessment is needed of the materials and end-use issues. An optimal evaluation of the costs for upgrading to hydrogen networks is also worth considering in today’s designs, aimed at easing the transformation towards a hydrogen-based system at the first planning phase.

In addition to the implications of hydrogen production and transmission for existing infrastructure, Zhangjiakou could assess the option of having green hydrogen produced on-site from renewable energy capacity at large industry sites. This could include launching hydrogen production and use demonstration projects, in which hydrogen would be used as a sub-product, for example to produce electrofuel or ammonia.

25 R is an open source software for advanced statistical analysis, including data mining methods. It includes geo-spatial analysis packages allowing advanced GIS computation for extracting, reclassifying GIS-based data and analysing data correlation for different applications such as time-series forecasting.

4.3 Strengthening institutional capacities

Establishing local energy planning capability

As discussed in section 4.1, local energy planning is critical for the long-term development of renewables. However, such urban energy plans are often developed by a contracted firm that may use proprietary tools or methods that cannot be transferred. This can result in published plans, but without a process for updating them as they are dependent on the availability of outside support. An urban energy system should be planned by the users of such a plan, and their capacity to develop plans or at least to understand planning should be cultivated to allow for independence and timely updates when necessary. The capacity can be created within government institutions to develop scenarios through the use of modelling results in urban energy system planning. To do this, however, the institutional and human capacities for urban energy system planning are just as important to establish in Zhangjiakou.

Establishing a demonstration and training facility for advanced renewable energy systems

Given that Zhangjiakou is mandated to establish the National Renewable Energy Demonstration Zone, a strong facility equipped with advanced renewable energy systems for the purposes of demonstration and training in Zhangjiakou City is crucial to assume the important role as demonstrator to the rest of China in scaling up the use of renewables at the local level. Such a facility could also benefit from existing similar facilities, such as the SGCC's training centre with an integrated solar, wind and energy storage system, and the real-world renewable energy projects installed in Zhangjiakou through collaborative agreements with project owners or developers. In addition, the facility can serve as a platform for Zhangjiakou to communicate with the rest of the world on knowledge exchange, technical collaboration, training for officials from other developing countries and co-operation in technological innovation.

This could start with hydrogen, as Zhangjiakou is the leading city in hydrogen development. A facility or even training programme around renewable energy-derived hydrogen production and use will be needed to not only better understand the dynamics between the renewables and hydrogen sectors but also serve as a platform to increase knowledge exchange with other cities and the hydrogen industry as a whole. It could be built on the basis of the established hydrogen research team led by renowned scholar Prof. Ouyang Min'gao. An innovative element of such a facility is that it can be a joint initiative of the public and private sectors based on the public-private-partnership model.

4.4 Engaging with international communities

Cities are waking up to the need to address climate change through energy transformation. But they are not doing this in isolation. Promoting efforts to achieve a low-carbon future for cities involves many active partners, including civil society groups such as ICLEI, C40 and the Global Covenant of Mayors, as well as global and regional platforms such as UN-Habitat's World Cities Day, the IRENA Assembly and the Asian Development Bank's Asia Clean Energy Forum.

Zhangjiakou could benefit tremendously from engaging with these partners in exchanging knowledge and sharing experience and lessons. More importantly, joining such groups and participating in these activities could help Zhangjiakou speed its renewable energy development and deployment and explore more opportunities to forge joint R&D programmes at various scales.

Cities are waking up to the need for energy transformation to address climate change

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矾山黄帝城太阳能跨季节储热试验示范项目简介

5. CONCLUSION

The geographic location of Zhangjiakou confers the city a unique advantage to develop and adapt around its available local renewable energy potential, developing the industry and research to enhance technological solutions able to optimally harvest and distribute local renewable energy. The municipal government has set an ambitious target following the city's designation in 2015 as the National Renewable Energy Demonstration Zone.

With its abundant renewable energy resources and its proximity to Beijing, Zhangjiakou is in a unique position to embark on a renewable-based development strategy along with its continued industrial restructuring. To capitalise on such opportunities, this report has developed strategic pathways with a longer time horizon. The implementation of energy transformation pathways leading to decarbonisation of the city, for a low-carbon city horizon of 2050, represents a technical challenge for the integration of high shares of renewable energy. The analysis finds that the city can achieve a very high renewable energy share by 2050 through either an electrification- or a hydrogen-focused pathway.

The EnergyPLAN model was applied to quantify the possibility for Zhangjiakou to maximise its use of available local renewable energy sources to meet future energy demand in 2035 and 2050. The key finding is that achieving fully exploited renewable energy is technically possible; however, flexibility solutions must be tapped in full to reliably supply the energy demand under different climatic conditions.

This can be achieved through smart vehicle-to-grid charging, sector coupling and the use of wasted heat from industry within low-temperature networks to boost overall system efficiency, as well as by increasing storage capacities coupled with grid expansion planning to limit critical excess electricity generation, especially for scenarios with more than 50% electricity generated from variable energy sources. After 2035 and onwards, renewable shares can be achieved of over 70% in all scenarios by 2050, if the challenges can be strategically addressed.

Technology alone cannot work effectively. Innovations in policies and in business models are also important. Zhangjiakou has been given a special mandate to explore effective policy options in scaling up renewable energy applications. An innovative policy scheme known as the Four-Party Mechanism has been put into effect – mostly for the heating sector given the city's long heat season – and has generated positive results. Potentially, such a scheme can be applicable to other sectors as well, such as hydrogen production.

Based on the energy transformation paths via different scenarios, a general set of policy options with a focus on addressing the key challenges identified are provided to guide local authorities in accelerating the shift to a low-carbon city by 2050.

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