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Characteristics and prospect of geothermal industry in China under the “dual carbon” target

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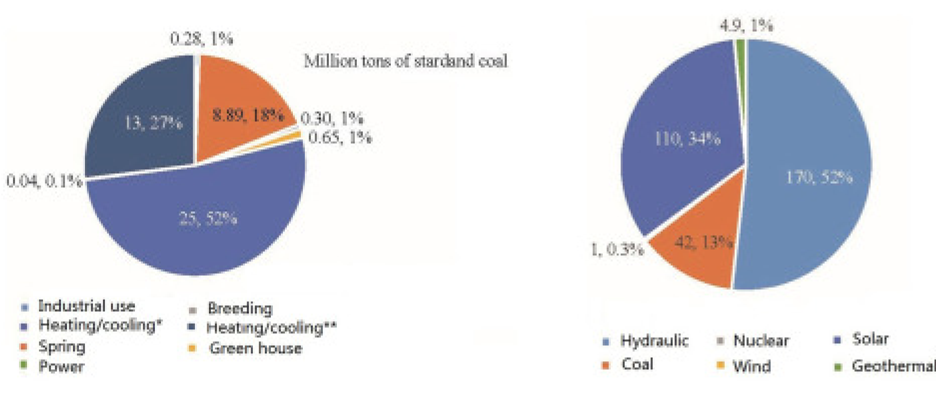
Highlights

- Summary of geothermal energy industry in China during the 13th-Five-Year plan period.
- Characteristics of geothermal energy development in China.
- Prospect of geothermal energy development in China.

Abstract

Geothermal energy utilization in China had been promoted actively during the 13th Five-Year Plan period (2016–2020), with resultant achievements showing unique Chinese characteristics. Buildings (measured by areas) heated/cooled by intermediate-to-deep geothermal energy increased more rapidly than those by shallow geothermal energy. Geothermal power generation was restricted by the distribution of the resource and the sufficiency of local power supply. With the proposition of “dual carbon goal” by the central government of China and the coming era of great development of renewable energy, geothermal energy will be provided more development opportunities in room heating/cooling and power generation in the country ever than before. However, tackling technology bottlenecks and introduction of appropriate policy support are still urgently needed for nurturing a healthy environment for geothermal industry. Analysis suggests that a near-to medium-term development of geothermal energy shall be focused on a comprehensive and efficient utilization both through heating/cooling and power generation. Room heating/cooling by intermediate-to-deep and shallow geothermal energy shall be promoted nationwide according to local resource endowment and economic conditions. Geothermal power generation in Yunnan and Tibet shall be pushed forward in an orderly way. For medium- and long-term development, focus shall be put on power generation by using low to medium temperature geothermal energy and hot dry rocks. The "hot spring+" model shall be adapted in steps on a regular basis. To achieve these, measures including attaching importance to tackling key technologies, promoting standards for geothermal energy development and utilization, strengthening geothermal energy exploration and evaluation, and seeking for necessary policy support shall be taken.

Graphical abstract



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Keywords

Geothermal industry; Post-Covid 19 era; Geothermal heating/cooling; Geothermal power; Policy support

1. Introduction

The outbreak of COVID-19 since early 2020 has been imposing a particularly strong impact on the energy sector. Many countries have introduced new policies to develop renewable energy as a means to fight against pollution and green gas emission, which was believed to be partially connected to the sudden attack of the virus. This trend has been especially apparent after many countries put forward carbon neutrality targets, in which, the development path of renewable energy on a global scale has been further clarified through policy declarations. In this situation, geothermal as a rising star of the renewable energy family has been given more development opportunities. China, one of the key players in geothermal utilization, has been ranking the first with the scale of direct utilization of geothermal energy in the world for quite a long time. However, its ability of using geothermal energy to generate power is still relatively lagged behind. With the advent of the post-epidemic era and the accelerated development of renewable energy, it is very urgent and necessary for the country to formulate a plan for the development of geothermal industry from a new starting point. The year of 2020 was also the last year of implementing the 13th Five Year Plan for Geothermal Energy Exploitation and Utilization (hereinafter referred to as the "Plan"). Summarizing the achievements and failures of the implementation of the Plan is of great significance to the design of development path and improvement of development quality of geothermal energy utilization in the future.

2. Targets set by the plan and achievements

2.1. Main targets

As the first systematic guidance for geothermal development in the country, the Plan comprehensively analyzed the resource base for China's geothermal industry, and put forward development goals with key projects and implementation paths being outlined. For heating/cooling of buildings, the country aimed at adding geothermal heating (cooling) area of 1.1 billion square meters, of which the shallow geothermal energy heating (cooling) area and geothermal-based hot water heating area(intermediate-to-deep geothermal energy)would be respectively 700 and 400 million square meters during the period. By the year of 2020, the geothermal heating (cooling) area in the country would be collectively up to 1.6 billion square meters, i.e., a 220% increase from the year of 2015, and the power generation capacity by geothermal energy would be 530MW, of which 500MW would be newly added during the period according the Plan.

2.2. Performance and potential

2.2.1. Contribution to energy supply

According to the plan, the consumption of geothermal energy was aimed to reach 70 million tons of standard coal for the year of 2020. Based on the installed capacity of geothermal energy for heating (cooling), power generation, hot springs, aquaculture and agriculture as well as on heating/cooling area, the actual contribution of geothermal energy in China was equivalent to 48 million tons of standard coal in 2020, nearly 70% of planned target. Of the existing geothermal energy utilization, the shallow geothermal energy utilization accounts for 52%, followed by heating, accounting for 27%, and hot spring, accounting for 18%, as shown in Fig. 1. Note that the intermediate-to-deep geothermal heating/cooling consumption is calculated according to the 22 kg standard coal per square meter and the shallow geothermal heating/cooling consumption is calculated according to 30 kg standard coal per square meter stated in a document entitled Clean Heating Plan for Winter in Northern China (2017–2021) issued by NDRC (National Development and Reform Commission), and the rest is calculated according to installed capacity and operating hours (see Fig. 2).

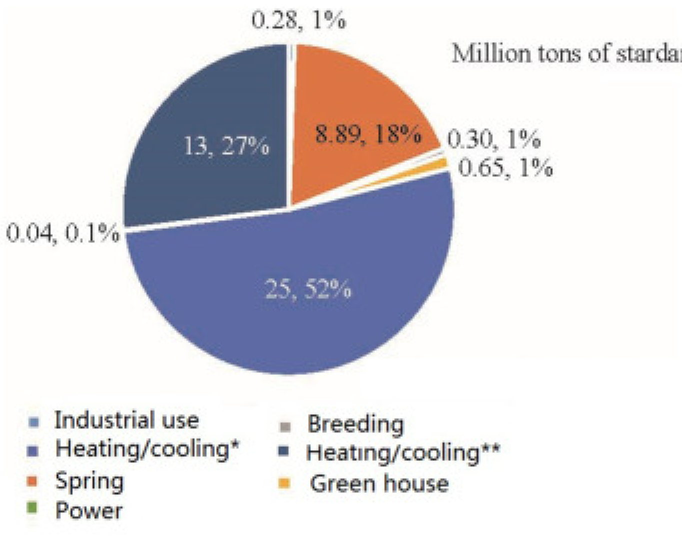

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Fig. 1. Composition of geothermal energy utilization in China in 2020. ∗=by shallow geothermal energy; ∗∗=by intermediate-to-deep geothermal energy.

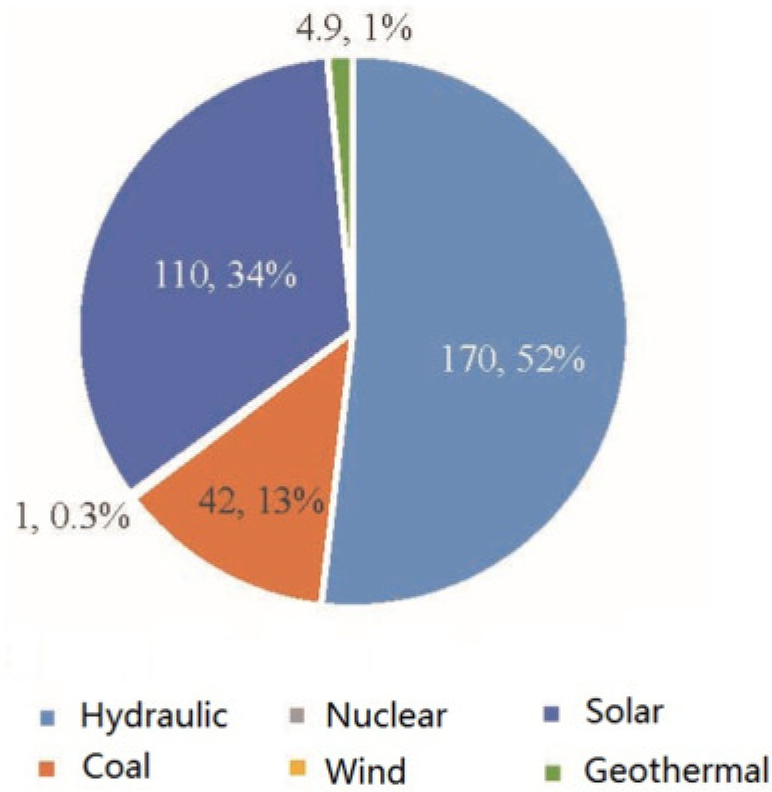

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Fig. 2. Installed power generation capacity of different energy forms in China in 2020.

2.2.2. Achievements in different sectors

Data shows that the heating/cooling area by intermediate-to-deep geothermal energy exceeds expectations during the planned period. The goal set in the Plan for the year of 2020 is 1.1 billion square meters (400 million square meters by intermediate-to-deep geothermal energy and 700 million square meters by shallow geothermal energy. The heating/cooling area by geothermal energy achieved in the year was 898 million square meters, of which about 480 million square meters are driven by intermediate-to-deep geothermal energy (20% higher than the goal) and 418 million square meters by shallow geothermal energy (40% less than the goal). The total geothermal heating/cooling area reached 1.392 billion square meters, 87% of the goal set by the Plan. This indicates that the intermediate-to-deep geothermal energy had been well utilized for heating and cooling since the National Geothermal Utilization Conference held in Xiong county, Hebei Province and the issue of several anti-pollution policies.

The fact that shallow geothermal energy used for heating/cooling for the year was less than expected can be attributed to an excessive and out-of-order development by some less-qualified companies, which had entered the industry during the very early stage when the requirements for utilizing shallow geothermal energy were not specified by relevant authorities. Meanwhile, certain irrational restrictions on the utilization of shallow geothermal energy issued by local governments also hindered in one way or another the realization of the goal set in the Plan.

As for geothermal power generation capacity, it was expected that by the end of 2020 the cumulative installed geothermal power generation capacity was only 49 MW, which was only 9.2 percent of the goal set in the Plan. Analysis shows that this gap between the realized and the planned capacity is due to the following reasons.

In the 1970s and 1980s, China made significant progress in medium and low temperature geothermal power generation. Technologies developed at the time already allowed power generation with geothermal-heated water at 70 °C. However, a lack of government support and capital investment as well as the resultant talents insufficiency had led to a stagnation in the development of low-temperature geothermal power generation technology since then. With currently available technologies, geothermal power generation is only possible with water temperature above 150 °C, and geothermal energy resource that is capable of heating water to such temperatures are mostly distributed in Yunnan and Tibet (Lu, 2020).

At present, the only geothermal power projects in China are the Yangbajing and Yangyi projects in Tibet. Tibet and Yunnan with their vast high-temperature geothermal energy have been regarded as the most fit for geothermal power generation in the country. However, with abundant renewable electricity supply, local governments of the two areas are not so keen to the idea of utilizing geothermal energy to generate more power. During the Plan period, there were only 22 MW of newly installed geothermal electricity capacity as hydropower, solar power etc. Dominated power supply in Tibet. The situation in Yunan Province is just the same. The local government planned to increase installed power generation capacity to 100 GW by the year of 2020 and 101 GW by the year of 2025 but with hydropower playing the major role.

3. Development opportunities and challenges of geothermal industry under the dual carbon target

After the "dual carbon” target being put forward by the central government of China, the whole society has been responding with quick actions. Utilizing geothermal energy has been deemed as one of the most feasible measures to add to the adjustment of energy mix for the country.

3.1. Opportunities for geothermal energy industry

At the macro level, the “dual carbon” target has paved the way for the development of geothermal energy in the country. The Strategy for a Revolution in Energy Production and Consumption (2016–2030) proposed by the Chinese central government sets up a goal of achieving non-fossil energy accounting for 20% of primary energy consumption by 2030. However, according to the statistics of the Energy Department of NDRC, by the year of 2020 (NEA, 2020), the percentage of non-fossil energy had already taken up 15.8% of the primary energy consumption in the country. Based on this faster-than-expected performance of renewable energy, the central government adjusted its non-fossil energy development target from 20% to 25% for 2030. The non-fossil energy in the country is mainly used for heating and power generation, which matches well with the utilization of geothermal energy. The new carbon peak and carbon neutral target together with the abundant geothermal resources in the country would facilitate further the development of the energy in the field of heating/cooling and power generation.

At the industrial level, the "geothermal+" model helps stabilize the renewable energy supply system. According to the 2015 survey and evaluation by the China Geological Survey of the Ministry of Land and Resources, the annual recoverable shallow geothermal resources in 336 towns and cities are equivalent to 700 million tons of standard coal. The intermediate-to-deep geothermal resources in the country are equivalent to 1.25 trillion tons of standard coal with 1.9 billion tons of standard coal of equivalent recoverable annually. The country also contains hot dry rock buried at 3000–10,000 m deep that are equivalent to 856 trillion tons of standard coal. Although accounting for only a relatively low share of primary energy consumption, geothermal resources are no less abundant than wind and solar in the country. Furthermore, geothermal power generation is better than wind and solar power generation in that it is more stable and seldom affected by season and weather changes. In areas rich in wind and sunshine, geothermal energy can be an ideal supplement source through a “geothermal+” power generation model. It is highly likely that geothermal energy fully plays its latecomer advantage and expands quickly at a relatively high speed in a foreseeable future.

Statistics show that the installed capacity of wind power and solar power in China has maintained a rapid growth in the past decades. In 2019, the installed capacity of non-fossil energy accounted for 41% of the total installed capacity, with the total installed capacity of wind and solar reaching more than 400 million megawatts, while that of geothermal power being only 49MW (Fig.3). There are plenty of room for geothermal energy to grow in the country, especially when coupled with solar and wind power to provide more reliable electricity supply for the economy.

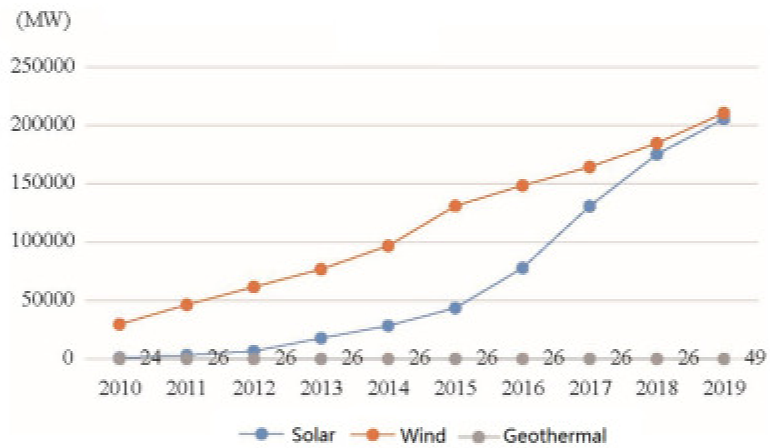

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Fig.3. Installed capacity of wind, solar and geothermal power generation in China from 2010 to 2019, showing that the power generation by geothermal energy are dwarfed by solar and wind power generation.

3.2. Challenges in developing geothermal industry

The utilization of geothermal energy in China has long been carried out in an extensive way. During the process, management deficiency and a lack of key technologies, especially the low level of reinjecting geothermal tail water into sandstone, had led to pollution and other environmental issues. The heat balance problem in the process of shallow geothermal utilization is also prominent due mainly to a limited application scale as the ground source heat system is neither well optimized nor user-friendly. In general, the geothermal industry chain in China has been bottlenecked both at the exploration and development of geothermal energy and at the end user level, with key technologies being absent as the major obstacle.

Geothermal development policies and taxes are likely to be less favorable in the coming years because of the increasing emphasis on environmental protection and a more diversified development pattern of alternative energy. Energy supply has been gradually improved and is now relatively sufficient in most areas in China. This, to some extent, also makes a dent in the utilization of geothermal energy. Local governments are less interested in taking measures, say, adopting taxation reducing policies, to promote the development and utilization of geothermal energy. Moreover, some local governments tend to be more stringent with managing the geothermal industry when gas price is predicted to be low. The closure of many geothermal wells in Hebei and Shandong provinces in 2020 is a case in point. After the wells were shut down, the government's alternative for heating energy was mainly coal and gas, at a time when the domestic gas market was to be operating at a low price during the winter heating season. This is a brutal strike on geothermal energy development. A calculation based on a standard of 1 CNY/m^3 of resource tax according to the new version of the resource tax that was implemented on September 1, 2020, shows that most geothermal energy enterprises in China could hardly make ends meet.

4. Development pathway design for a high-quality geothermal industry in the future

4.1. Overall planning

With the advent of the post-epidemic era, geothermal industry development is once again drawing attention. The overall development and utilization pathway for geothermal energy in China for the future may be summarized as a simultaneous development of heating and power generation or heating before power generation, a comprehensive utilization, and taking efficiency enhancement as priority. From the point of view of a sequential resource utilization, the priority is given to the development of heat supply, which is used mostly for residential heating, hot spring tourism, breeding and industry, for the near and medium term. With the mature of geothermal power generation technology, geothermal power industry may be pushed forward as required for the medium and long term, during which an efficient utilization of resources, better coordination of geothermal and other energy sources on the basis of thermoelectric utilization, and forming a "geothermal+" model of coordinated development of various new energy sources will be pursued. At the same time, guided by the stepwise utilization of geothermal resources, the traditional design methods of geothermal power generation and geothermal heating are changed through technological transformation and innovation, so as to realize the stepwise utilization and efficient utilization from high temperature to low temperature geothermal energy, and maximize the economic value of the exploitation and utilization of geothermal resources (Wang, 2020a,b).

4.2. Roadmap

4.2.1. A nationwide promotion of heating/cooling by intermediate-to-deep geothermal energy

Intermediate-to-deep geothermal resources (also referred to as hydrothermal geothermal resources) in China are mainly distributed in the Songliao Basin, Bohai Bay Basin, Hehuai Basin, Jianghan Basin, Fen-Weihe Basin, Ordos Basin, and Yinchuan Plain. At present, state-owned oil companies including Sinopec and PetroChina as well as a large number of private energy companies have been deeply involved in the development of these resources. Based on the "Xiongxian Model" of geothermal development and utilization, Sinopec has basically realized the goal of creating 20 smog-free cities with geothermal heating/cooling programs. At the same time, Sinopec proposed to upgrade the Xiongxian Model according to the changing situation by marching from small and medium-sized counties to rural areas and to medium-and large-sized cities. A batch of heating/cooling programs are expected to be carried out in accordance with the distribution of intermediate-to-deep geothermal energy and experiences gathered after years of practices.

4.2.2. Shallow geothermal energy heating/cooling system to be focused on areas with hotter summer or colder winter

Shallow geothermal energy can be sourced locally from soil or even surface water and urban sewage. The future direction for using it will be focused on selecting areas with conditions suitable for its implementation, especially by using heat pumps, which have the advantage of higher energy efficiency ratio than ordinary air conditioning or air source heating pump and of more competitive in terms of operation cost. Liaoning, located in the northeast of China, is now one of the provinces with a large installed capacity of ground source heat pumps that support a heating/cooling area of more than 70 million square meters.

At present and in the foreseeable future, room heating in southern China during winters will become an important fulcrum of regional economic development and an important symbol of improving people's quality of life. The annual heat transfer of geothermal energy heating pump systems (including buried pipes and groundwater heating pumps) in all provincial capitals in China is about 3 trillion kWh in summer (5 months a year), equivalent to about 383 million tons of standard coal, and 10.1 billion square meters of cooling area; and 1.5 trillion kWh in winter (4 months a year), equivalent to about 183 million tons of standard coal, and 11.9 billion square meters of heating area. Regions with hot summer and cold winter in China generally have abundant shallow geothermal resources, making it suitable for the application of heating pump technology (Ma et al., 2015). At present, geothermal energy heating pump projects have been carried out in almost all regions in the country (Fig. 4). The shallow geothermal heating/cooling in areas with extremely hot summer and cold winter regions (in the middle and lower reaches of the Yangtze River for instance) in southern China are perfect for using the shallow geothermal energy to adjust room temperature, especially when combined with the on-going urban construction and new rural house construction. The surface water that can be used to cool room temperature in these southern areas amounts to 800 billion cubic meters per year, and China's urban sewage treatment capacity can be as high as 100 million cubic meters per day, all indicating great heating/cooling potential. Areas with hot summer and cold winter account for more than one third of the total and are also regarded as important heating/cooling sourcing areas.

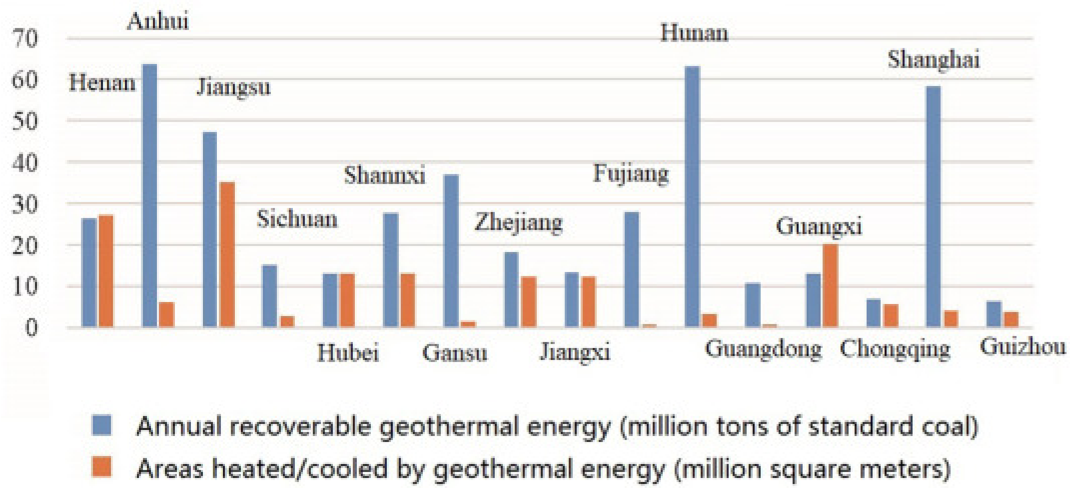

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Fig.4. Statistics of shallow geothermal energy utilization in areas with hotter summer and cooler winter.

4.3. Focus for the near future and the medium and long term

According to the World Energy Assessment, a report issued by the World Energy Council in 2015, the world average utilization efficiency of geothermal power generation is 72%, and the direct utilization efficiency of the resources is 27%. Geothermal energy has the highest annual utilization hours of all renewable energy forms through power generation. Unlike solar and wind power, geothermal power can be very stable as it is available for more than 90% of the time throughout the year, which means a very high utilization efficiency (GIEC, 2018).

4.3.1. Near- and medium-term development of geothermal power generation

Since the beginning of this century, China has experienced frequent extreme weathers, like heavy rain, snow and freezing, resulting in tight power supply in many areas. Extremely cold weather puts forward new requirements for power supply, and as a result, power supply stability has become one of the important development goals of public service for local authorities. It will be further highlighted as the “dual carbon” goals set up new requirements of continuously increasing the proportion of non-fossil energy in energy mix. In view of the diversification of power supply in various regions of the country, the development of geothermal power generation is of practical significance in terms of green power and stable power supply. The stable power supply from geothermal resources can effectively make up for the "short board” caused by the intermittence of wind, solar and hydro power supply. The development of geothermal power generation in areas with geothermal, wind, hydropower and solar energy resources at the same time can create synergize when coupled with hydropower, photovoltaic power generation and solar power generation, thus effectively improving the supply stability. As far as the current situation is concerned, Yunnan and Tibet, enriched with high-temperature geothermal resources and suitable for geothermal power generation at the current level of technology, are perfect candidates for pilot geothermal power generation projects. This may also explain why the Plan chose the two areas as the breakthrough points for geothermal energy development in the country.

Statistics show that the geothermal power resource potential in Tibet exceeds 3000 MW. At present, the geothermal resources in Tibet are mainly used for power generation, with the Yangbajing and Yangyi areas being the chosen locations. The Yangbajing Geothermal Power Station is now the largest geothermal power station in China, and also the only power station in the world that uses the shallow Quaternary geothermal energy for industrial power generation. The station has an installed capacity of about 27 MW, once accounting for as much as 60% of the load of Lhasa's power grid. A cumulative power generation of 3 billion kWh has been achieved since the 1970s. The Yangyi Geothermal Power Station is the highest geothermal power station in the world (about 4650 m above sea level) (Zhou, 2018). It has achieved a full 100% recharge of used water, with an annual power generation capacity of 190 million kWh (Wang and Wang, 2002).

Belonging to the Yunnan-Tibetan tropical zone, Yunnan Province sits in the suture zone between the Eurasian plate and Indian plate and is also one of the places with the most active and intense tectonic activities in the recent geological history of China (**Gao and Y, 2006**). With numerous hot springs (taking up 28% of the country's total and ranking the first among all provinces in the country), the province has geothermal anomalies too significant to be ignored. The average terrestrial heat flow value of the province is about 10% higher than the representative mean value in the country (63–68 mW/m^2). Two areas, Tengchong and Ruili in western Yunnan Province and near the suture zone, host many high temperature geothermal fields as a result of extremely frequent magmatic activities. Geothermal fields in Tengchong are estimated to have a heat storage temperature of 230°C, indicating great power generation potential. However, the current emphasis of geothermal development in Tengchong is not in power generation but in various non-electric utilizations (Yin et al., 2006). This is partially due to the fact that the province has adequate power supply and partially due to the priority taken by the local government, who are more interested in luring tourists with geothermal energy through air holes, aerated ground, boiling springs, boiling fountains, hydrothermal explosions and geysers, etc., which indeed have brought considerable income to the local government. However, natural resources distribute unevenly in the province, with the western part being rich in hydraulic resources and geothermal resources, but lacking coal and natural gas; the eastern part being relatively abundant in coal but lacking of hydraulic and geothermal resources; and the western part relying only on hydraulic power, and frequently experiencing power shortages during dry seasons, when geothermal power generation may serve as a perfect rescue.

4.3.2. Medium- and long-term geothermal power generation to be focused on utilizing low temperature geothermal energy and hot dry rocks

Recent geothermal power generation projects have been mainly relying on using high-temperature geothermal resources. While for medium- and long-term plan, low temperature geothermal power generation will be the focus provided that the key issues of medium and low temperature geothermal power generation technology are tackled and regional development conditions are taken into account. Demonstration projects of medium and low temperature geothermal power generation are likely to be carried out first in provinces of north China as well as Jiangsu, Fujian, Guangdong and other southern provinces and then to be expanded to all the areas to achieve an all-around development by drawing upon the experience gained from these projects [NEA, 2017]. As mentioned above, China was more than once in sync with the international level in geothermal energy utilization during the 1970s and 1980s, when China was capable of generating power by geothermal energy in areas at altitudes above 4000m (Zhao et al., 2023). Unfortunately, the progress was put on hold for some economic reasons. Today, things are changed. Issues that had impeded the progress of geothermal energy utilization no longer exist. With current economic and social development level of the country, it is completely theoretically possible that China will soon make breakthroughs in key technologies for medium and low temperature geothermal power generation.

In 2011, China Geological Survey carried out an assessment of the hot dry rock resources buried between 3 and 10 km deep in land areas of the country. It shows that the resource is equivalent to about 856 trillion tons of standard coal, of which, hot dry rocks of 150 °C–250 °C buried between 3.5 km and 7.5 km are equivalent to 200 trillion tons of standard coal (Zheng and Zheng, 2020). Even if only 2% of this resource was developed, it would be a huge amount of energy. During the 13th Five-Year Plan period (2016–2020), the China Geological Survey made breakthroughs through four hot dry rock exploration wells drilled in the Chabucha area of Gonghe Basin, Qinghai Province. In the long run, hot dry rock power generation can be combined with photovoltaic projects in Qinghai to contribute to the establishment of a carbon-free power grid in northwestern China.

4.3.3. A multistep route to be followed with "hot spring+" direct geothermal energy utilization model

Hot springs and geothermal energy heated breeding and greenhouses have been the most convenient and popular ways of directly utilizing geothermal energy and will be used in years to come. From the perspective of efficiency, a multistep utilization with "hot spring+" geothermal development model is recommended (Jiang et al., 2018). In addition to traditional geothermal utilization such as using hot springs to lure tourists, new forms of tourism products, such as providing geothermal energy for agriculture and aquaculture, setting up holiday villages with geothermal energy as the theme, are also to be developed according to local conditions with aim of filling the gap between off-peak and peak seasons, and of realizing an intensive and sustainable development of hot spring tourism.

5. Measures to ensure a sustainable development of geothermal industry

Technological innovation is important for the geothermal industry to leverage its late-comer advantage and create synergy with wind, solar, hydropower and fossil energy to contribute to national energy security and transition. Years of development has seen important progress made in resource assessment, wellbore design as well as other development and utilization technologies for geothermal energy with a number of technological breakthroughs being made and an industrial chain taking shape. However, technical "short boards" still exist to varying degrees both in exploration and in utilization of the resources. Taking the recharge technology for geothermal wells as an example, the recharge ratio of geothermal wells in China is only 20%–30% due to the fact that most operators do not have a clear understanding of the recharge mechanism and that advanced technologies are not well applied. And this has been posing environmental challenges to local governments. In recent years, many universities have set up geothermal energy related courses to train talents for geothermal energy development and utilization. And various types of research and development institutions for geothermal energy development and utilization have also been established to carry out scientific research projects with some winning awards. Cooperation between universities and institutions of China and other countries on deep drilling and hot dry rock research has been quite fruitful with achievements boosting China's geothermal technology research and development in parallel with the international level. To take the development of the geothermal industry to a new level, the government, enterprises, trade associations and other organizations need to join hands to support the geothermal technology innovation.

5.1. Promoting the implementation of standards on geothermal energy development and utilization

At present, China has already established a primary standard system for the development and utilization of geothermal energy, including standards for the construction of general facilities, the exploration and assessment of the resources, the drilling and completion of geothermal wells, geo-heating/cooling, power generation as well as the comprehensive utilization of produced geothermal water and resource protection. From 2017 to 2020, a total of 57 specific standards for geothermal energy industry have been formulated, including 4 for basic general purposes, 13 for geothermal exploration and evaluation, 18 for drilling and completion, 4 for power generation, 7 for heating/cooling, and 11 for comprehensive utilization of produced water and protection of the resources. The growth of geothermal industry needs the escort and guidance of "standards”. The implementation of these standards can effectively help the industry to avoid all kinds of pitfalls during the development and utilization processes and provide a legal framework for the development and utilization of the resources.

5.2. Strengthening resource surveys and exploration

The geology of geothermal energy in China is complicated in that, with well-developed faults, the fault-related geothermal fields, even buried in shallow Tertiary strata, are difficult to develop. Those buried deep in faulted areas are even harder to deal with because of a lack of reliable seismic data. Many faults of interest are mainly evaluated by poor-quality gravity and magnetic data, resulting in an overall low success rate of exploration. Other challenges include inadequate investment, weak technical strength and outdated equipment. The geothermal utilization in China is still at a low level and basically confined to certain locations. Exploration of the resources is largely restricted by the regional economic level. At present, except for Beijing, Tianjin, Hebei, Shaanxi etc., the geothermal energy in most parts of the country is still waiting to be developed. Experiences gained in the past few years have proved that the potential of geothermal energy utilization can be tapped as long as exploration and evaluation are stressed and carried out (Wang and Wang, 2002). In 2017, the Chinese Ministry of Natural Resources officially launched a geothermal energy survey in the Beijing-Tianjin-Hebei region with focus on the Xiongan Area and Dongli District of Tianjin. The result shows that the recoverable geothermal resources of Xiongan are equivalent to 380 million tons of standard coal and the annual exploitable geothermal energy of the Dongli District is equivalent to 1.25 million tons of standard coal. It is worthy of continually strengthening the survey and exploration of geothermal resources so as to lay a more solid resource foundation for the development of geothermal industry in the country.

5.3. Actively seeking for necessary policy support

Wind and solar power generation in China is now entering the stage of de-subsidization. And the success is closely linked to the financial support and tax preferential policies from the central and local governments. This could be introduced to promote the development of geothermal energy. Even the United States, which has the largest amount of installed geothermal power, has introduced a series of supportive policies to encourage the development of geothermal energy, including setting up renewable energy quotas, offering tax breaks and providing loan guarantees since the 1970s. Turkey, where the geothermal industry is growing the fastest during recent years, has set high benchmark electricity prices and offered subsidizes for the use of domestic geothermal energy equipment. Whereas in China, the on-grid price of geothermal power generation is set according to the price of coal power (Anonymous, 2011), making it impossible for geothermal power generation projects to profit. Because of low rate of return, most investors and operators have to be very cautious about investing on geothermal power projects. And this may partially contribute to the failure in achieving the targets of geothermal power generation set in the Plan. To make things worse, the Chinese government newly introduced a resource tax policy in 2020 that had imposed great cash flow pressure on companies working on geothermal energy development. It is strongly suggested that a preferential tax rate be applied to geothermal projects. Also, to ensure a sustainable development of the industry, the government shall closely monitor the industry, especially the application of produced water recharge technology while subsidize the industry to help it hold footing in power generation.

6. Conclusion

The COVID-19 pandemic has profoundly changed the outlook of world's economy and significantly promoted the structural adjustment of the energy industry. In the post-COVID-19 era, more countries choose the path of green and low-carbon development. Energy transition has been and will be happening in many parts of the world. The geothermal industry finally has its turn. However, necessary policy support is still needed to facilitate the development of the industry. Management and technological innovations are two important aspect of a sound and healthy geothermal industry.

Under the situation of sufficient supply of fossil energy and rapid development of other non-fossil energy forms, geothermal industry may need to rely more on its own initiatives to realize a vigorous development.

Conflict of interest statement

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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