China's geothermal resources development status, problems and suggestions under the background of carbon neutrality

L Shen, L Liu
Development Research Centre of Chinese Geological Survey, Beijing 100037, China
shenliang@mail.cgs.gov.cn

Abstract. The development and utilization of geothermal resources is of great significance to China's goal of carbon neutrality. Based on the research results of predecessors, through systematic analysis and summary, this paper shows the current research status of geothermal resources (including the utilization of geothermal energy, output characteristics and distribution rules, and classification of geothermal energy) and existing problems (such as unclear understanding of the geothermal formation mode, low survey accuracy and weak basic geothermal geological survey work). Finally, in response to the above-mentioned problems, some countermeasures and suggestions are put forward for the research of China's geothermal resources in the context of carbon neutrality, such as further strengthening policy support and geothermal resource management; reinforcing basic geological surveys and expand geothermal reserve resources, promoting the integration of professional and intelligent monitoring station networks.

1. Introduction
The 14th Five Year Plan indicates that China is transitioning from years of fast, quantitative growth to higher-quality, more sustainable growth, allowing more room to pursue other equally important goals, including environmental ones. China has promised to strive to peak carbon dioxide emissions by 2030 and achieve carbon neutrality by 2060 [1]. China's greenhouse gas emissions are likely to peak by 2030 or perhaps earlier, taking into account the needs of industrialization and urbanization. But how to achieve carbon neutrality by 2060 for China is a question worth pondering. Reaching carbon neutrality requires massive reductions in emissions in China's relatively carbon-heavy economy and means eliminating many more metric tons of CO₂ than many other countries. As we all know, China insists on being green and low-carbon and promoting the harmonious coexistence of human and nature. China will surely implement the "Paris Agreement" in response to climate change. Therefore, we believe that with the strong support of the government and the joint efforts of all walks of life, China has the economic attractiveness and social feasibility to achieve its decarbonization goals, totally.

In the context of the carbon neutral goal, rational development and utilization of clean energy, such as biomass energy, wind energy, hydropower, ocean energy, geothermal energy, hydrogen energy, is an important guarantee for China to build a harmonious socialist society. Geothermal is the natural heat of the Earth, derived from the decay of the radioactive elements in the Earth’s crust and transferred to the subsurface by conduction and convection [2-3]. The Ministry of Natural Resources and the China Geological Survey have conducted detailed theoretical research and technological innovation around geothermal exploration, which have made contributions to the realization of ecological civilization, ecological harmony and sustainable economic development. This article will
start with the research status of geothermal resources, analyze its existing problems, and finally put forward suggestions on the development and utilization of geothermal resources in China.

2. Current status of geothermal research in China

2.1. Geothermal energy utilization

Geothermal is widely used in China, but due to site and equipment constraints, it is mostly used in the following 7 areas [4-5]: ① Heating (33%), mainly for cities such as Beijing and Tianjin District heating, as far as Tianjin is concerned, it has a heating area of 9.4 million and saves 225,100 tons of raw coal annually; ② Hot spring bathing and tourism vacation (32%); ③ Planting (18%), precious flowers, special vegetables, off-season vegetables and the development of sightseeing agriculture have good effects in greenhouses; ④ Agricultural irrigation (2.60%), hot water below 40°C or used geothermal wastewater can be used for agricultural irrigation; ⑤ Power generation (0.50%), mainly including experimental power stations and production power stations; ⑥ Industrial use (0.40%), can be used for printing and dyeing, grain drying, production of mineral springs water, etc.; ⑦ Others (13.60%), such as aquaculture and medical care (figure 1).

![Figure 1 Utilization methods of geothermal resources of hydrothermal type in China](Modified from reference [5])

2.2. The output characteristics and distribution law of geothermal

2.2.1. The output characteristics. As a renewable energy, geothermal can protect the environment. Compared with fossil energy, it is cleaner and environmentally friendly. China is rich in geothermal resources. The geothermal energy stored within 2,000 m of the earth’s surface in major sedimentary basin, is estimated to be equivalent to 250 billion tons of standard coal heat [6].

2.2.2. The distribution law. China’s geothermal resources are mainly distributed in the tectonically active and large sedimentary basins, the former is more focused resources, such as Tibet, Yunnan, Sichuan and southeast coast and Liaodong-Shandong area; the latter wide surface distribution of resources, such as Beijing, Tianjin, Shaanxi, Hebei and other regions. The national survey and evaluation of geothermal resources show that although China’s geothermal resources are abundant, they are unevenly distributed due to factors such as structure, magmatic activity, stratum lithology and hydrogeological conditions (figure 2) [5,7].
2.3. Classification of geothermal resources

2.3.1. Shallow geothermal energy. The burial depth of the constant temperature zone of shallow geothermal field in China's land area is generally lower in the southeast and higher in the northwest and northeast. The overall distribution characteristic of the shallow geothermal field (within a depth of 200m) of the geothermal gradient is that the north is high and the south is low. The average geothermal gradient in the south is 2.45°C/100m. The geothermal gradient in most parts of the north gradually increases from west to east, and the average is 3°C/100m. Mid-temperate zone (alpine region) has low temperature, deep constant temperature zone, high deep temperature, long heating cycle, and deep holes for construction geological conditions; the temperature in the south is high, and the temperature in the upper part of the stratum is low [6, 8].

2.3.2. Hydrothermal geothermal. China's hydrothermal geothermal resources are dominated by medium and low temperatures, supplemented by high temperatures. Hydrothermal geothermal resources can be divided into sedimentary basin-type [9] and uplift-mountain-type geothermal resources based on the tectonic genesis. Uplift-mountain-type middle-low-temperature geothermal resources are mainly distributed in mountainous and hilly areas, such as the southeast coast, Jiaodong and Liaodong Peninsulas. Uplift-mountain-type high-temperature geothermal resources are mainly distributed in Taiwan area, southern Tibet, western Yunnan, etc. Sedimentary basin-type geothermal resources are mainly distributed in Mesozoic and Cenozoic plain basins in eastern China, including the North China

Figure 2 Distribution of geothermal resources in China [5].
Plain, the Jianghuai Plain, and the Songliao Basin. These basins have a large amount of heat storage, a large thickness, and a wide distribution [6, 8].

2.3.3. Dry hot rock. Hot dry rocks are ubiquitous in the earth, but hot dry rock resources with development potential are distributed on the edges of plates or structures such as new volcanic activity areas and areas with thinning crust. There are 4 types of hot dry rocks in China: ①The high heat flux granite type is concentrated in the southeastern coastal area of China, taking the large-scale acid rock mass formed in the Yanshanian as the host body, forming an important target area for hot dry rock; ② The sedimentary basin type is mainly distributed in the lower part of the Cretaceous basin in Guanzhong, Xianyang, Guide, etc. The upper part is the Cenozoic caprock, the lower part is acid rock, and the crust in the deep part has a heat generation mechanism; ③ Modern volcanic type is distributed in Tengchong, Changbai Mountain, Wudalianchi and other regions, and the characteristics of the heat source are closely related to the history and features of the bottom magmatic activity; ④ Intensive tectonic activity type is mainly distributed in the Qinghai-Tibet Plateau [6, 8-11].

2.4. Geothermal survey technology methods
The application of a variety of geothermal resources survey methods provides strong technical support for the development and utilization of geothermal resources in China. These methods include geothermal abnormal phenomenon investigation method, geochemical and geological methods, geophysical prospecting method, remote sensing and telemetry method and geographic information system technology detection method [12]. Effective investigations are usually based on a combination of multiple methods. In order to better understand the geothermal system, an integrated approach must be adopted. With the development of remote sensing (RS), geographic information system (GIS), global positioning system (GPS), 3S technology in-depth research and computer simulation technology, the exploration method of geothermal resources will also make breakthrough progress [11].

3. Problems during geothermal research in China
Although China's geothermal resources research and survey have made remarkable achievements, there are still many problems in China's geothermal development.

3.1. Unclear understanding of the geothermal formation mode
The influence and interaction of various factors related to heat transfer in the development of shallow geothermal energy needs to be studied; the relationship between hydrothermal geothermal and earth heat flow, deep thermal structure and thermal state, heat control factors and geothermal genesis mechanism, tectonic thermal activity and the relevance of natural disasters, etc., has not yet been ascertained; hot dry rocks are still in the exploratory research stage after decades of exploration, and the development and utilization of the formation mechanism and reservoir construction are still in urgent need of further study.

3.2. Low survey accuracy and weak basic geothermal geological survey work
The survey accuracy of geothermal resources in most areas of China is 1:1,000,000. Only Tianjin, Beijing, Lubei Plain, Guanzhong Basin, along the Qinghai-Tibet Railway and the Pearl River Delta have reached the accuracy of 1:25,000; In a few geothermal fields, such as Yangbajing, Yangyi, and Xiongxiang, individual geothermal surveys have reached an accuracy of 1:5000 [8]. In key geothermal development areas, no or few formal geothermal surveys have been carried out. The basic geothermal geological survey work is weak, and the reserve resources are insufficient. There are less than 100 geothermal fields that can be used for further exploration or development and utilization planning after the approval of the resource reserve management department. The lag in survey evaluation has caused the contradiction between supply and demand in the geothermal market to become increasingly prominent, which has seriously affected the formulation of geothermal resource exploration and development plans, resource utilization and the active development of the geothermal industry.
3.3. Single and extensive geothermal development and utilization
The development and utilization of geothermal energy in China is mainly for heating and tourism. Except for a few areas, such as Yangbajing in Tibet and Bazhou in Hebei, which use geothermal resources for cascade development and they are used for power generation, heating and greenhouse planting, most areas have single geothermal resources utilization. This extensive use has caused the water level to continue to drop. For example, the water level of a geothermal well in Xi'an has dropped below 200m; the heating tail water discharge in winter is higher than 35°C, causing chemical and thermal pollution and increasing the cost of urban sewage treatment [8]. It should be developed into cascade utilization of geothermal resources for power generation, heating, bathing, agriculture and industrial drying.

3.4. Imperfect monitoring network
Monitoring data such as water level and water temperature during the development and utilization of geothermal resources are of great significance to the utilization efficiency, sustainability and scientific research of geothermal resources. At present, China's geothermal monitoring work is rarely carried out. Except for Beijing, Tianjin, and Hebei, which have carried out relatively more monitoring work, other provinces have basically no monitoring data, and the monitoring methods are backward, the monitoring projects are single, and a scientific monitoring system has not been formed.

3.5. Weak basic research on rapid response to emergency incidents during geothermal development
Although geothermal is a renewable clean energy, in fact, geothermal development will also bring some environmental problems. First of all, the development of geothermal heat and excessive extraction of underground hot water will cause the groundwater level to drop, causing local ground sinking, destroying roads, and breaking underground pipelines. Secondly, due to the high temperature and high pressure of underground hot water, the ability to dissolve chemical substances in surrounding rocks is strong. Therefore, the water often contains dozens of chemical elements, some of which are harmful to the human body, such as fluorine, arsenic and certain radioactive substances. Therefore, the development of geothermal heat pollutes drinking water sources and causes endemic diseases. In recent years, China has made significant progress in the construction of a rapid response system for sudden geological environmental events, but basic research on rapid response to various disaster events caused by geothermal development is still weak.

3.6. Backward technical equipment, immature key technologies and relatively weak talent reserve
Geothermal equipment originated in the petroleum industry. With the development of deep level and high-temperature geothermal exploration, the temperature and pressure resistance of domestic equipment can no longer meet the requirements of the survey. It is difficult for logging equipment to break through 175°C for many parameters, and for monitoring equipment to break through 100°C. The technical parameters of foreign equipment are relatively better, but they are expensive [8]. Foreign countries have formed a monopoly in the equipment industry, and only provide expensive technical services [3]. There is a lack of refined "heat-finding" geophysical exploration equipment. Drilling tools, drilling fluids, and drilling guides need to be improved in terms of high temperature, high pressure, hard rock, drilling efficiency, and safety. This is the main reason for the backwardness of domestic exploration equipment. Secondly, China's deep geothermal resources exploration and development, geothermal well formation and thermal storage transformation key technology reserves are still in their infancy. There is no mature "heat finding" technology, and a systematic geothermal resource detection technology system (drilling and completion, circulating fluid, well logging, cementing) and evaluation methods (parameters, software); lack of large-scale and sustainable geothermal resource extraction technology (reservoir construction, downhole heat exchange), and efficient ground utilization technology (power generation equipment, recharge, anti-scaling, cascade Utilization). A number of technologies need to be overcome urgently. In addition, China's geothermal human resources are relatively scarce, and the research strength is relatively weak, which is extremely inconsistent with the
rapid growth of geothermal resource development. In recent years, China's senior geothermal technical talents mainly come from units engaged in geothermal resource survey, evaluation and technical research, universities, and key enterprises to jointly organize short-term training courses. So far, among more than 2,000 colleges and universities in China, only one university has a geothermal major. It is difficult to form a geothermal talent training mechanism that combines production, learning, and research. This has led to the relatively weak strength of my country's geothermal technical talent research.

4. Suggestions and enlightenment for China's geothermal resources research

Under the background of carbon neutrality, based on the current status and existing problems of China's geothermal resources research, the following suggestions are made:

4.1. Further strengthening policy support and geothermal resource management.

According to the target of "30 carbon peak, 60 carbon neutrality", it is necessary to accelerate the transformation of the coal-based energy structure and vigorously develop green and clean energy for China. Regarding the future development and utilization of geothermal energy, on the one hand, under the premise of implementing the policy of "developing while protecting and protecting while developing", scientifically compile geothermal development and utilization plans and strengthen management. On the other hand, it attaches importance to the collaborative research of geothermal energy production, research and application, and continues to study related technologies for geothermal utilization. Leading at the national level is needed. The government will increase investment in scientific research; increase investment and intensity in geothermal exploration, continuously improve the accuracy of regional geothermal resource exploration and evaluation, and carry out forward-looking problems that need to be solved urgently. In addition, formulate relevant support policies to provide a strong guarantee for the efficient development of geothermal resources, increase financial support and tax concessions, and promote the healthy and orderly development of the geothermal industry.

4.2. Reinforcing basic geological surveys and expanding geothermal reserve resources.

In response to the weakness of basic geothermal surveys, there is an urgent need to improve the accuracy of China's geothermal resource surveys, carry out detailed and formal geothermal surveys in key geothermal development zones, and expand reserves of reserve resources. Ultimately alleviate the contradiction between exploration evaluation and geothermal market supply and demand, and actively promote the formulation of geothermal resource exploration and development plans, resource utilization, and the healthy development of the geothermal industry.

4.3. Promoting the integration of professional and intelligent monitoring station networks and strengthening the construction of a unified geothermal monitoring system.

China is weak in satellite remote sensing monitoring of geothermal resources. With the establishment of a unified management system for land and space and a unified supervision system for natural resources in China, the need for unified geothermal monitoring information will become increasingly prominent. In order to meet the needs of geothermal resources management, on the one hand, we must vigorously strengthen the construction of professional monitoring station networks, on the other hand, we must promote the integration of professional monitoring resources, complement and support each other, and provide real-time, accurate and comprehensive geothermal monitoring for the advent of the era of geological big data.

4.4. Strengthening basic research on rapid response to emergency incidents in the process of geothermal development

Timely, accurate, and reliable scientific information is the basis for the government to initiate and implement emergency management of sudden geological environmental incidents. Monitoring,
scientific research, and early warning technology research and development for sudden environmental events and natural disasters in the process of geothermal development is one of the important strategic tasks proposed by the USGS and the European Union in accordance with national needs. For China, it is necessary to carry out research on the temporal and spatial distribution rules and occurrence mechanism of geothermal development disaster events, improve the ability to recognize disaster events, and clarify the conditions for initiating rapid response; rely on the geothermal monitoring network to improve the early warning capabilities of sudden disasters; respond to ground subsidence, destruction of roads, and underground pipelines, establish and improve cooperation and rapid response mechanisms. Strengthen on-site data collection during and after the disaster to provide a scientific basis for the preparation of disaster management plans in the process of geothermal development.

5. Conclusions
It is clear that China's geothermal resources research and survey have made remarkable achievements. However, there are still many problems in geothermal development. From the above analysis, it can be seen that China's geothermal resources research still needs continuous in-depth research by generations of geologists to realize theoretical and technological innovations, in order to realize China's sustainable development, harmonious coexistence of human and nature, and the goal of carbon neutrality by 2060.

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