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Evaluation of Geothermal Resources Potential in China

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Abstract

China's geothermal resources are widely distributed and they feature multiple types. They are distributed with obvious patterns and along certain geographies. Based on the survey results of geothermal resources in China during the 12th Five-Year Plan period, and on the basis of systematic analysis of the distribution and characteristics of geothermal resources in China, this paper assesses the potential of shallow geothermal resources, geothermal resources of hydrothermal type and geothermal resource of hot dry rocks type. China's geothermal resources are relevantly abundant. Geothermal resources can efficiently cut emissions and save energy. They can also effectively reduce dust haze.

1. INTRODUCTION

Geothermal resources are green, low-carbon, recyclable and renewable energy. China's geothermal resources are rich and widely distributed. Vigorously promoting the development and utilization of geothermal resources and improving the energy structure are important measures to cope with global climate change and carry out energy conservation and emission reduction, and are of great significance to solve the increasingly serious global environmental problems. The unclear status of geothermal resources has seriously affected the formulation of geothermal resources exploration and development planning and the development of geothermal industry. During the"12th Five-Year Plan" period, China completed the survey of shallow geothermal energy in 336 cities above the prefectural level, the survey of geothermal water resources in 31 provinces (regions and cities), and the survey of dry hot rock resources was launched. The occurrence conditions, distribution characteristics and development and utilization status of geothermal resources in China were basically identified. Based on the survey results of geothermal resources in China during the 12th Five-Year Plan period, and on the basis of systematic analysis of the distribution and characteristics of geothermal resources in China, this paper has carried out the potential evaluation of China's shallow geothermal energy resources, hydrothermal geothermal resources and dry-hot rock resources, providing technical support for the sustainable and scientific development and utilization of geothermal resources.

2. DISTRIBUTION LAWS AND CHARACTERISTICS OF GEOTHERMAL RESOURCES

2.1 Concept of geothermal resources

There are a large diversity of geothermal resources in China. According to their geological features, hydrothermal transfer modes, temperature scope and exploitation and utilization methods, the geothermal resources can be categorized into shallow geothermal resources, hydrothermal geothermal resources and hot dry rocks resources. More specifically, shallow geothermal resources mean the geothermal resources beneath the ground surface (usually within constant temperature zone and the depth of 200m) and with temperatures lower than 25℃, and available for exploitation and utilization under the current technological and economic conditions. Hydrothermal geothermal resources mean that groundwater absorbs geothermal energy from the porous or fractured rocks, forming hot water and steam that can become the economical alternative energy sources through the proper exploitation. Dry hot rocks refer to the high-temperature rocks with the temperature of over 200℃, locating in the depth of several thousand meters, containing limited or no fluids inside.

2.2 Distribution of geothermal resources in China

The hydrothermal geothermal resources in China are of high regularity and zone-related, unevenly distributed due to some factors as geological features, magmatic action, lithology and hydrogeological conditions. There are some high-temperature geothermal resources in China, but moderate- and low-temperature geothermal resources constitute a major part. The high-temperature geothermal resources are mainly found in Southern Tibet, Western Yunnan, Western Sichuan and Taiwan, where more than 200 high-temperature geothermal systems have been found(Liao zhijie, Zhao ping, 1999). The moderate- and low-temperature geothermal resources are mainly found in large sedimentary basins and fractures in mountain areas. The geothermal resources in the mountain areas are mostly smal, the geothermal resources in basins, especially large sedimentary basins are featured by their favorable reservation conditions, numbers of formations, large thickness and broad distribution. The temperature of geothermal reservoir increases along with depth. Since geothermal resources in basins have considerable resources, these basins should be the regions where geothermal resources have the highest potentials for exploitation. The sedimentary basins-type geothermal resources are mainly distributed in the eastern part of China, including Qionglei Basin, Songliao Basin and Erdos fault basins. These geothermal resources can all be categorized as the moderate- and low-temperature geothermal resources. Apophysis mountains geothermal resources are mainly found in the southeastern coast of China, Taiwan, Southern Tibet, Western Sichuan, Western Yunnan, Jiaodong Peninsular and Liaodong Peninsular(Cheng moxiang, et al, 1994; Chen moxiang, Wang jiyang, et al, 1994).

The shallow geothermal resources are distributed throughout the world. Specifically, they are mainly found in the shallow underground part of the global continents. It is true that bedrocks (except limestone) have a higher conductivity coefficient, but their thermal capacity is lower than loose Quaternary rock strata. Due to difficulties in drilling and reinjection, its geothermal resources are more difficult to be exploited and utilized, compared with the loose Quaternary rock strata. So the loose Quaternary rock strata is an ideal place for shallow geothermal resources are exploitation. The loose Quaternary rocks are soft and drillable strata, so the vertical ground-source heat pumps can be more easily used. Also the loose Quaternary rock strata have the higher water yield coefficient than bedrocks (except limestone) so groundwater based heat pumps could be easily applied. The limestone in bedrocks has plenty of cavern water in the well-developed Karst fissures. Despite the drilling difficulty, recharge is quite easy, number of necessary wells for groundwater heat pumps is small, so it can be also used as location of use for groundwater based heat pumps.

The dry hot rocks are distributed almost all over the world. In fact, the dry hot rocks resources are available in all the continents. Nevertheless, the places where the exploitation and utilization of dry hot rocks have the largest potentials locate in the new volcanic areas or the regions with thin crust. These regions are mainly distributed along the edge of plates and tectonic structures. Based on the geological structure in China, the dry hot rocks resources could be divided into four types, i.e. the high radioactive heat generation type, the modern volcano type, the sedimentary basin type, and the inner-plate tectonic active belt type (Gan Haonan, 2015). Different dry hot rocks genesis models vary greatly in depth, radioactive heat generation, thickness of shallow coverage, the regional tectonic activities.

2.3 Characteristics of geothermal resources in China

Based on terrestrial heat flow, earth temperature gradient and ground surface temperature, it is possible to estimate temperature profiles of geothermal reservoir within the certain depth. In general, the regions with stronger tectonic activity or more recent tectonic-thermal events usually have higher heat flow rates, ancient plates with steady structure have lower heat flow rates. According to the collected and measured heat flow data in China , heat flow rates is unevenly distributed in China. Generally, Southern Tibet, Western Yunnan and the eastern coast have the highest value with the average of 90～150mW/m^2, and even up to 304 mW/m^2 in some regions. Then, Northern Tibet and Taiwan have an average value of 80～90mW/m^2. Erdos Basin and Sichuan Basin in the center of China, the coastal basin in the south of China, the southern North China, northern Songliao Basin, northern Jiangsu, Bohai Bay Basin in the east of China, and Haier Basin in the north of China have average values of 55～80mW/m^2. Tarim Basin and Junggar Basin in Xinjiang, northern Sichuan Basin and Songliao Basin, and Sanjiang Basin have average values of 30～50 mW/m^2. These basins could be categorized as cool basin(Hu shengbiao, et al, 2001; Gong yuling, et al, 2003; Wang liangshu, et al, 2005;Duo ji, et al, 2003; Liao zhijie, et al, 1985).

In sedimentary basins of China, the temperature gradient ranges 1.5～4.0℃/m, and the average value is about 3.2℃/m. The temperature gradient is controlled by centrospheric thermal condition and thermal conductivity of geological media. Compared with, heat flow, temperature gradient is affected by the geotectonic structures and highly related to lithological structures. As a result, the temperature gradient and heat flow show different patterns. The highest value of temperature gradients in sedimentary basin range 3.0～4.0℃/m, are mainly found in Tengzhong (Yunnan), North Bay Basin, Xiamen, Shantou, most southern areas of North China Plain, the southmost tip of Bohai and Tianjin, Hailaer Basin, the west of Tsaidam Basin and Songliao Basin. These regions account for 1/10 of all the sedimentary basins of the world. most regions in sedimentary basin have the value range of 2.0～3.0℃/m. Other regions with the value less than 2.0℃/m mainly cover parts of Tarim Basin, Junggar Nasin, and the northwestern part of Sichuan Basin.

3. POTENTIALS OF GEOTHERMAL RESOURCES IN CHINA

3.1 Assessment methodology of the potentials of geothermal resources

Reservoir heat capacity method is used for the hydrothermal geothermal resources assessment. For the sedimentary basin-type geothermal resources, the areas of heat reservoir is determined as formations shallower than 4000m, whose temperature is,higher than 25℃, water yield is over 20m3/h per well, and average temperature gradient is over 2.5℃/100m in caprock. The border line between local thermal fields and geothermal abnormal areas, the contours of geothermal reservoir temperature and thickness are digitalized,to calculate the area of each sub-regions, and the geothermal reservoir thickness can be calculated according to sand thickness ratio. For apophysis mountain geothermal resources, the areas are calculated for individual geothermal formations in regions with enough geological survey data, such as Shanxi, Inner Mongolia, Shandong, Jiangsu, Zhejiang, Chongqing and Guizhou. In other provinces, the assessment of geothermal resources is conducted for every individual hot spring and geothermal well. If the volume of geothermal reservoirs can be encircled by the heat controlling fracture, the results could be determined by the geological and tectonic information . If the line of geothermal reservoir area is indistinct, the volume for the geothermal reservoir is assigned as one cubic kilo meter of every abnormal geothermal point(Muffler and Cataldi, 1978). For hydrothermal geothermal resources, the allowable exploitation can be based on the allowable exploitation of geothermal fluids with the condition of reinjection(Lin wenjing, et al, 2012, 2013). For the moderate- and low-temperature geothermal resources, assuming that the sedimentary basins-type geothermal resources are exploited for 100 years under the condition of reinjection, 15% geothermal reservoir is consumed, and then thermal balance is calculated. For apophysis mountain geothermal resources, the allowable exploitation of geothermal fluids is assigned as twice of the corresponding quantity calculated according to spring(well) fluid method. For the high temperature geothermal resources, the allowable exploitation is assigned as twice of the volume of geothermal fluids that have been determined by geological explorations.

For the shallow geothermal resources, the capacity and heat transfer rate of shallow geothermal formations shall be calculated separately on the basis of suitability zoning. On the basis of the suitability zoning of exploitation and utilization of shallow geothermal resources , the total heat transfer rate of ground-source heat pump system is obtained through the calculation results of both soil-source heat pump system and groundwater-source heat pump system . Specifically, for those regions where the soil-source heat pump system may be suitable or relatively suitable and the groundwater-source heat pump system is unsuitable, general heat transfer rate can be calculated according to the heat transfer rate of the soil-source heat pump system; for those regions where the soil-source heat pump system is unsuitable and the groundwater-source heat pump system may be suitable or relatively suitable, it should rely on the heat transfer rate of the groundwater-source heat pump system; for those regions where both the buried pipe ground-source heat pump system and the groundwater ground-source heat pump system may be suitable or relatively suitable at the same time, general heat transfer rate can be calculated on the basis of 2/3 of the heat transfer rate of the buried pipe ground-source heat pump system and 1/3 of the heat transfer rate of the groundwater ground-source heat pump system. Based on the calculated heat transfer rate, the local land utilization planning, and the heating and cooling peak clipping load, the area available for heating and cooling can be calculated to evaluate the potentials of shallow geothermal resources.

The reservoir of hot dry rock resources storage can be estimated through the volume method. Based on the temperature requirements for exploitation and utilization of hot dry rocks and the current drilling technologies, the calculation range can be set at 3~10km below the earth. The parameters for the estimation of hot dry rock resources include terrestrial heat flux, rock heat conductivity rate, rock heat generation rate, thickness of radioactive element concentration layer, ground surface temperature and deep ground temperature. If sedimentary contribution and basement contribution of deep ground temperature are calculated, it is necessary to obtain the data about the crust-mantle heat flow ratio(Lin wenjing, et al, 2012, 2013).

3.2 Potentials of geothermal resources in China

China boasts abundant geothermal resources. The annual allowable exploitation of hydrothermal geothermal resources can be converted into 1.865 million tons of standard coal, equaling 50% of the coal consumption in 2015. In 336 cities at the prefecture level and above, the annual allowable exploitation of shallow geothermal resources can be converted into 0.7 billion tons of standard coal. The prospective reservoir of hot dry rocks can be converted into 860 trillion tons of standard coal. The hot dry rock can be defined as national strategic energy due to the tremendous potentials.

3.2.1 Hydrothermal geothermal resources

China enjoys abundant hydrothermal geothermal resources, including 2334 hot springs and 5818 geothermal exploitation wells. The hydrothermal geothermal resources can be converted into 1250 billion tons of standard coal, indicating an annual allowable exploitation of 1.865 billion tons of standard coal. There are high-temperature geothermal resources (≥150℃), but the moderate -temperature geothermal resources（90℃-150℃）and low-temperature geothermal resources（<90℃）play a dominant role. The moderate- and low-temperature hydrothermal resources can be converted into 1230 billion tons of standard coal, and the annual allowable exploitation can be converted into 1.85 billion tons of standard coal, indicating the power generation of 1.5 million kW. Hydrothermal high-temperature geothermal resources can be converted into 1.41 billion tons of standard coal, and the annual allowable exploitation can be converted into 18 million tons of standard coal, equaling the power generation of 8.46 million kW.

Table 1:Evaluation table of geothermal resources in China

Cities	Reserve of geothermal resources		Heat of hydrothermal fluid available for exploitation in case of recharge	
	Reserve of geothermal resources（kJ）	Standard coal（t）	Heat of hydrothermal fluid available for exploitation in case of recharge（kJ/a）	Standard coal（t/a）
Beijing	9.94E+16	3.39E+09	1.23E+15	4.21E+07
Tianjin	8.98E+17	3.07E+10	1.48E+15	5.06E+07
Hebei	3.06E+18	1.04E+11	4.63E+15	1.58E+08
Shandong	2.03E+18	6.93E+10	3.39E+15	1.16E+08
Henan	7.73E+18	2.64E+11	1.30E+16	4.44E+08
Anhui	6.03E+16	2.06E+09	1.76E+14	6.01E+06
Jiangsu	6.91E+17	2.36E+10	9.55E+14	3.26E+07
Heilongjiang	1.24E+18	4.22E+10	2.01E+15	6.86E+07
Jilin	1.02E+17	3.48E+09	1.64E+14	5.61E+06
Liaoning	4.37E+16	1.49E+09	8.13E+13	2.77E+06
Sichuan	9.78E+18	3.34E+11	1.61E+16	5.50E+08
Hubei	2.56E+17	8.75E+09	3.77E+14	1.29E+07

Cities	Reserve of geothermal resources		Heat of hydrothermal fluid available for exploitation in case of recharge	
	Reserve of geothermal resources（kJ）	Standard coal（t）	Heat of hydrothermal fluid available for exploitation in case of recharge（kJ/a）	Standard coal（t/a）
Xinjiang	9.76E+17	3.33E+10	5.18E+13	1.77E+06
Shanxi	8.95E+17	3.05E+10	1.67E+15	5.69E+07
Shaanxi	1.43E+18	4.88E+10	2.43E+15	8.29E+07
Inner Mongolia	1.77E+18	6.04E+10	2.95E+15	1.01E+08
Qinghai	1.42E+17	4.86E+09	2.14E+14	7.32E+06
Gansu	4.11E+17	1.40E+10	7.19E+14	2.45E+07
Ningxia	9.37E+17	3.20E+10	1.43E+15	4.88E+07
Zhejiang	1.13E+17	3.87E+09	1.65E+14	5.64E+06
Jiangxi	8.18E+16	2.79E+09	1.40E+14	4.79E+06
Fujian	4.49E+16	1.53E+09	1.85E+13	6.30E+05
Hunan	1.05E+16	3.57E+08	1.09E+13	3.71E+05
Guangdong	2.52E+17	8.59E+09	2.27E+14	7.74E+06
Hainan	1.12E+17	3.81E+09	1.48E+14	5.05E+06
Guangxi	2.58E+17	8.81E+09	3.70E+14	1.26E+07
Chongqing	1.27E+18	4.33E+10	3.23E+13	1.10E+06
Shanghai	3.06E+15	1.04E+08	9.28E+12	3.17E+05
Guizhou	1.33E+18	4.55E+10	4.74E+13	1.62E+06
Yunnan	2.95E+17	1.01E+10	2.28E+14	7.80E+06
Tibet	2.74E+17	9.34E+09	1.76E+14	6.02E+06
Total	3.66E+19	1.25E+12	5.47E+16	1.865E+09

The moderate- and low-temperature hydrothermal resources are mainly distributed in 15 large and medium-sized sedimentary plains including the North China Plain, Hehuai Plain, Northern Jiangsu Plain, Songliao Plain, Lower Liaohe Plain, Fengwei Plain, and mountain faults. Specifically, the geothermal resources in mountain faults are usually of small size, but the geothermal resources in the plains and especially the large sedimentary plains are featured by satisfactory reservoir conditions, , considerable thickness and wide-spread distribution. The temperature of geothermal resources grows as the depth increases, indicating the largest potentials of geothermal resources development. In the 15 large and medium-sized sedimentary plains, geothermal resources can be converted into 1060 billion tons of standard coal, and the annual allowable exploitation can be converted into 1.7 billion tons of standard coal. In the Sichuan Basin, the allowable exploitation of geothermal resources is the highest, which can be converted into 544 million tons of standard coal, and next comes the North China Plain, where the allowable exploitation of geothermal resources can be converted into 422 million tons of standard coal, demonstrating the abundant moderate- and low-temperature geothermal resources in the sedimentary plains in Shandong and Hebei Province.

Table 2:Evaluation table of moderate- and low-temperature geothermal resources of main sedimentary basins

Name of basin	Reserve of geothermal resources	Heat of hydrothermal fluid available for exploitation in case of recharge

	Reserve of geothermal resources（kJ）	Standard coal（t）	Heat of hydrothermal fluid available for exploitation in case of recharge（kJ/a）	Standard coal（t/a）
North China Plain	7.23E+18	2.47E+11	1.24E+16	4.22E+08
Hehuai Plain	5.33E+18	1.82E+11	9.02E+15	3.08E+08
Northern Jiangsu Plain	6.75E+17	2.30E+10	9.20E+14	3.14E+07
Songliao Plain	1.24E+18	4.22E+10	2.01E+15	6.87E+07
Lower Liaohe Plain	3.95E+16	1.35E+09	7.52E+13	2.56E+06
Fengwei Basin	2.20E+18	7.49E+10	3.86E+15	1.32E+08
Erdos Basin	1.48E+18	5.03E+10	2.68E+15	9.15E+07
Sichuan Basin	9.62E+18	3.28E+11	1.59E+16	5.44E+08
Jianghan Basin	2.49E+17	8.51E+09	3.64E+14	1.24E+07
Hetao Basin	6.61E+17	2.25E+10	9.59E+14	3.27E+07
Yinchuan Plain	9.37E+17	3.20E+10	1.43E+15	4.88E+07
Xining Basin	1.34E+17	4.57E+09	2.09E+14	7.12E+06
Junggar Basin	4.78E+17	1.63E+10	-	-
Tarim Basin	4.83E+17	1.65E+10	-	-
Tsaidam Basin	3.04E+17	1.04E+10	-	-
Total	3.11E+19	1.06E+12	4.98E+16	1.70E+09

The high-temperature geothermal resources are distributed along the Southern Tibet-Western Sichuan-Western Yunnan region with intensive hydrothermal activities, indicating the power generation of 7.12 million kW, 84.1% of the national total. There are 139 hydrothermal zones exceeding 150℃, including 34 in Southern Tibet, 56 in Western Sichuan and 49 in Western Yunnan. The possible generation of high-temperature hydrothermal resources in the coastal areas of Southeast China can reach 7.12 million kW, 8.27% of the national total. There are 14 hydrothermal zones exceeding 150℃ in this area. The high-temperature hydrothermal system is also found in the Guanzhong Basin, Xinjiang Taxkorgan region and Changbai Mountain region in Jilin Province. As a crucial renewable energy, it's of importance to fully develop high-temperature geothermal resources, promote electricity generation by high-temperature geothermal resources in the Southwestern part of China, and build a multipurpose and complementary power development pattern, which can meet the demand of the national energy restructuring polices.

Table 3: Evaluation table of moderate- and low-temperature geothermal resources in the main hydrothermal activity zones of apophysis mountains

Main hydrothermal activity zones	Geothermal resources		Allowable exploitation of hydrothermal fluid（m^3/a）	Heat of hydrothermal fluid available for exploitation	
	Reserve of geothermal resources（kJ）	Standard coal（t）		Heat of hydrothermal fluid available for exploitation（kJ/a）	Standard coal（t/a）
Southern Tibet——Western Sichuan——Western Yunnan	3.16E+17	1.08E+10	2.26E+08	3.61E+13	1.23E+06
Coastal areas in Southeast China	1.71E+17	5.85E+09	2.04E+08	3.22E+13	1.10E+06
Jiaoliao Peninsular	2.69E+14	9.18E+06	5.37E+06	1.27E+12	4.34E+04

Main hydrothermal activity zones	Geothermal resources		Allowable exploitation of hydrothermal fluid（m^3/a）	Heat of hydrothermal fluid available for exploitation	
	Reserve of geothermal resources（kJ）	Standard coal（t）		Heat of hydrothermal fluid available for exploitation（kJ/a）	Standard coal（t/a）
Taiwan			3.78E+07	9.40E+12	3.21E+05
Total	4.88E+17	1.67E+10	4.73E+08	7.90E+13	2.70E+06

3.2.2 Shallow geothermal resources

The heat capacity of shallow geothermal resources in 336 cities is 1.11×10^{17} kJ/℃, and the annual allowable exploitation can be converted into 700 million tons of standard coal. The shallow geothermal resources can replace the standard coal of 1.17 billion tons each year, thus reducing the coal consumption by 410 million tons each year. When it comes to the modes of shallow geothermal resources utilization, the suitable area of soil-source heat pump system constitutes 29% of the total evaluation areas, and the relatively suitable area accounts for 53%; the suitable area of groundwater-source heat pump system constitutes 11% of the total evaluation areas and the relatively suitable area accounts for 27%.The regions suitable for the groundwater-source heat system are mainly distributed in the plains and basin of the eastern part of China and those areas with satisfactory water yield. The regions unsuitable for the groundwater-source heat system are mainly located in the water shortage areas and some hot or cold regions in the western part of China due to its high costs and difficulty for construction. Those factors that affect the exploitation and utilization of shallow geothermal resources are taken into consideration. The regions where shallow geothermal resource can be effectively exploited and utilized mainly include the provinces in the middle and eastern part of China, such as Beijing, Tianjin, Hebei, Shandong, Henan, Liaoning, Shanghai, Hubei, Hunan, Jiangsu, Zhejiang, Jiangxi and Anhui.

The heat conversion rate of shallow geothermal resources refers to heat exchange quantity of shallow rocks and groundwater within the unit time. For the groundwater-source heat pump system in 336 cities at the prefecture level and above, the heat transfer rate is 7.49×10^{8}kW in summer and 3.68×10^{8}kW in winter; for the soil-source heat pump system, the heat transfer rate is 2.69×10^{9}kW in summer and 1.91×10^{9}kW in winter. For the ground-source heat pump system, the general heat transfer rate is 3.14×10^{9}kW in summer and 2.10×10^{9}kW in winter.

Table 4: Summary of the calculation of heat capacity and heat transfer rate of shallow geothermal resources (land-use coefficient)

Cities	Evaluation areas (km^2)	Shallow geothermal capacity at the depth of 200m (kJ/°C)	Heat transfer rate of groundwater ground-source heat pump system（KW）		Total heat transfer rate of buried pipe heat pump system（kW）		Heat transfer rate of ground-source heat pump system（kW）	
			Cooling in summer	Heating in winter	Cooling in summer	Heating in winter	Cooling in summer	Heating in winter
Qinghai	624	3.97E+13	2.68E+06	7.23E+05	7.65E+05	6.73E+05	3.45E+06	1.40E+06
Tibet	514	1.85E+14		1.05E+06		2.70E+05		1.19E+06
Heilongjiang	2203	9.27E+14	6.56E+06	2.07E+06	1.51E+07	5.86E+06	1.54E+07	5.66E+06
Inner Mongolia	2601	1.07E+15	8.99E+06	4.49E+06	2.04E+08	8.39E+07	1.39E+08	5.76E+07
Xinjiang	2201	4.13E+16	2.54E+07	1.44E+07	2.53E+07	1.45E+07	3.55E+07	2.03E+07
Jilin	2985	1.37E+15	1.23E+06	5.31E+05	6.31E+07	2.35E+07	5.94E+07	2.24E+07
Liaoning	9377	4.76E+15	5.48E+07	3.32E+07	8.78E+07	5.00E+07	1.34E+08	7.90E+07
Ningxia	1587	6.96E+14	3.73E+06	1.87E+06	2.50E+07	5.81E+06	2.15E+07	6.91E+06
Gansu	2130	3.41E+14	2.86E+07	1.43E+07	4.87E+07	1.90E+07	4.44E+07	1.73E+07
Beijing	6130	1.94E+15	1.47E+07	7.35E+06	7.17E+07	3.59E+07	8.64E+07	4.33E+07

Cities	Evaluation areas (km²)	Shallow geothermal capacity at the depth of 200m (kJ/°C)	Heat transfer rate of groundwater ground-source heat pump system（KW）		Total heat transfer rate of buried pipe heat pump system（kW）		Heat transfer rate of ground-source heat pump system（kW）	
			Cooling in summer	Heating in winter	Cooling in summer	Heating in winter	Cooling in summer	Heating in winter
Tianjin	11250	5.59E+15	8.03E+05	4.02E+05	1.01E+08	6.70E+07	1.01E+08	6.70E+07
Shanxi	5817	1.93E+15	1.44E+06	9.15E+05	7.00E+07	3.34E+07	5.10E+08	3.24E+07
Shaanxi	2615	1.15E+15	2.51E+07	1.26E+07	6.00E+07	3.96E+07	5.49E+07	3.21E+07
Henan	7785	3.95E+15	4.21E+08	2.13E+08	8.37E+07	7.01E+07	8.21E+07	6.80E+07
Shandong	7936	2.50E+15	6.86E+07	3.43E+07	1.17E+08	9.35E+07	1.17E+08	8.63E+07
Hebei	2460	8.78E+14	3.02E+06	1.58E+06	6.99E+07	4.35E+07	5.46E+07	3.43E+07
Yunnan	1083	4.90E+14	6.91E+05	3.45E+05	1.18E+07	1.18E+07	1.04E+07	1.02E+07
Guizhou	1414	6.79E+14	2.23E+06	1.11E+06	5.20E+07	3.42E+07	4.47E+07	2.93E+07
Jiangsu	26610	1.10E+16	1.22E+07	6.44E+06	2.72E+08	2.15E+08	2.21E+08	1.66E+08
Sichuan	3960	1.80E+15	7.33E+06	3.68E+06	4.20E+07	3.85E+07	4.17E+07	3.70E+07
Zhejiang	12914	6.88E+15	5.00E+06	2.50E+06	9.11E+07	6.32E+07	8.36E+07	5.80E+07
Hunan	17012	7.27E+15	2.17E+06	1.08E+06	1.72E+08	1.16E+08	1.55E+08	1.12E+08
Hubei	5606	3.04E+15	4.65E+06	2.33E+06	8.43E+07	7.02E+07	8.27E+07	6.76E+07
Anhui	11488	4.15E+15	6.15E+06	3.08E+06	2.74E+08	1.49E+08	2.69E+08	1.46E+08
Jiangxi	2584	9.93E+14	5.41E+06	2.70E+06	2.20E+08	2.38E+08	1.43E+08	1.15E+08
Shanghai	1980	9.94E+14	0.00E+00	0.00E+00	6.89E+07	6.99E+07	6.89E+07	6.99E+07
Chongqing	2432	3.81E+14	0.00E+00	0.00E+00	2.15E+08	2.33E+08	2.15E+08	2.33E+08
Fujian	3411	5.38E+14	5.96E+05	1.12E+06	1.18E+07	1.21E+07	1.03E+07	1.06E+07
Guangxi	2942	1.49E+15	3.59E+07	0.00E+00	9.68E+07	0.00E+00	7.60E+07	0.00E+00
Guangdong	6735	2.56E+15	4.07E+05	9.65E+05	3.56E+07	6.89E+07	2.57E+08	4.73E+08
Hainan	499	2.82E+14	2.58E+04	0.00E+00	2.52E+06	0.00E+00	2.47E+06	0.00E+00
Total	168885	1.11E+17	7.49E+08	3.68E+08	2.69E+09	1.91E+09	3.14E+09	2.10E+09

Currently, the shallow geothermal resources are mainly utilized for heating and cooling. The area that can be heated or cooled by the shallow geothermal resources per unit area is used to express the potentials of shallow geothermal resources. In 336 cities at the prefecture level and above, 80% of land areas are suitable for the utilization of shallow geothermal resources, and the area of buildings available for cooling in summer is $3.26\times10^{10}m^2$ and for heating in winter is $3.23\times10^{10}m^2$. Specifically, for the groundwater-source heat pump system, the area of buildings available for cooling in summer is $5.59\times10^{9}m^2$ and for heating in winter is $3.61\times10^{9}m^2$; for the soil-source heat pump system, the area of buildings available for cooling in summer is $3.56\times10^{10}m^2$ and for heating in winter is $3.75\times10^{10}m^2$.

Table 5: Summary of the calculation of potentials evaluation results of shallow geothermal resources

Cities	Heating and cooling area of groundwater ground-source heat pump system（m²）	Heating and cooling area of buried pipe heat pump system（m²）	Heating and cooling area of ground-source heat pump system（m²）

	Cooling in summer	Heating in winter	Cooling in summer	Heating in winter	Cooling in summer	Heating in winter
Qinghai	4.58E+07	9.20E+06	1.65E+07	9.64E+06	6.23E+07	1.88E+07
Tibet		1.76E+07		4.50E+06		2.00E+07
Heilongjiang	1.15E+08	2.59E+07	2.52E+08	7.32E+07	2.56E+08	9.01E+07
Inner Mongolia	1.38E+08	9.99E+07	3.13E+09	1.87E+09	2.15E+09	1.28E+09
Xinjiang	4.18E+08	2.34E+08	3.89E+08	2.23E+08	5.75E+08	3.30E+08
Jilin	1.54E+07	8.84E+06	7.89E+08	3.17E+08	7.43E+08	2.85E+08
Liaoning	6.36E+08	5.23E+08	1.02E+09	7.88E+08	1.55E+09	1.25E+09
Ningxia	5.40E+07	3.63E+07	4.08E+08	1.89E+08	3.12E+08	1.47E+08
Gansu	8.89E+08	3.94E+08	7.84E+08	2.76E+08	7.13E+08	2.48E+08
Beijing	2.72E+08	1.63E+08	1.33E+09	7.96E+08	1.60E+09	9.59E+08
Tianjin	1.01E+07	8.04E+06	1.26E+09	1.34E+09	1.26E+09	1.34E+09
Shanxi	3.16E+07	1.76E+07	1.20E+09	6.50E+08	1.13E+09	5.28E+08
Shaanxi	2.69E+08	1.87E+08	6.80E+08	6.11E+08	6.65E+08	5.41E+08
Henan	1.12E+09	8.46E+08	2.88E+09	3.51E+09	1.12E+09	1.30E+09
Shandong	9.79E+08	6.23E+08	1.67E+09	1.70E+09	2.58E+09	2.29E+09
Hebei	3.47E+07	2.60E+07	8.11E+08	7.58E+08	6.35E+08	5.99E+08
Yunnan	1.30E+07	7.70E+06	2.26E+08	2.35E+08	1.53E+08	1.80E+08
Guizhou	3.17E+07	2.22E+07	7.43E+08	6.84E+08	6.39E+08	5.86E+08
Jiangsu	9.29E+07	6.64E+07	2.85E+09	2.97E+09	2.31E+09	2.59E+09
Sichuan	9.16E+07	5.53E+07	5.22E+08	6.42E+08	5.17E+08	6.16E+08
Zhejiang	5.00E+07	3.57E+07	9.11E+08	1.03E+09	8.36E+08	8.29E+08
Hunan	3.17E+07	3.12E+07	2.51E+09	3.34E+09	2.28E+09	3.27E+09
Hubei	5.83E+07	3.99E+07	1.05E+09	1.20E+09	1.03E+09	1.16E+09
Anhui	8.77E+07	6.14E+07	3.79E+09	3.02E+09	3.72E+09	2.97E+09
Jiangxi	3.15E+07	2.10E+07	2.75E+09	3.97E+09	2.44E+09	2.56E+09
Shanghai	0.00E+00	0.00E+00	4.64E+08	1.45E+09	4.64E+08	1.45E+09
Chongqing	0.00E+00	0.00E+00	2.15E+09	3.89E+09	2.15E+09	3.89E+09
Fujian	7.45E+06	2.24E+07	1.47E+08	2.43E+08	1.28E+08	2.11E+08
Guangxi	5.74E+07	0.00E+00	2.83E+08	0.00E+00	3.35E+08	0.00E+00
Guangdong	5.81E+06	2.41E+07	5.08E+08	1.72E+09	1.98E+08	7.36E+08
Hainan	2.86E+05	0.00E+00	2.82E+07	0.00E+00	2.75E+07	0.00E+00
Total	5.59E+09	3.61E+09	3.56E+10	3.75E+10	3.26E+10	3.23E+10

3.2.3 Hot dry rock resources

The dry-hot rock is widely distributed and is the main direction of geothermal development in the future. The available dry-hot rock resources under the current technical and economic conditions are generally buried at a depth of 3~10 km. The preliminary estimation shows that the hot dry rock resources within the scope of 3～10 kilometers below the earth are 2.5×10^{25} J , and can be converted into 860 trillion tons of standard coal, 2% of which is 3500 times as much as the national total energy consumption in 2020. The dry-hot rock resource is the most potential strategic alternative energy, but it is difficult to develop.

Table 6: Dry hot rocks resources at the depth of 3-10km on Chinese mainland

Serial No.	Depth of calculation layer（km）	Reserve of dry hot rocks resources		Allowable exploitation of dry hot rocks resources（extracted by 2%）	
		Reserve （J）	Standard coal（t）	Reserve （J）	Standard coal（t）
1	3.0-4.0	1.9E+24	6.48E+13	3.8E+22	1.30E+12
2	4.0-5.0	2.5E+24	8.53E+13	5E+22	1.71E+12
3	5.0-6.0	3E+24	1.02E+14	6E+22	2.05E+12
4	6.0-7.0	3.6E+24	1.23E+14	7.2E+22	2.46E+12
5	7.0-8.0	4.2E+24	1.43E+14	8.4E+22	2.87E+12
6	8.0-9.0	4.7E+24	1.60E+14	9.4E+22	3.21E+12
7	9.0-10.0	5.3E+24	1.81E+14	1.06E+23	3.62E+12
3.0-10.0 Km		2.52E+25	8.60E+14	5.04E+23	1.72E+13

4. CONCLUSIONS

1. China enjoys very abundant geothermal resources, including 2334 hot springs and 5818 geothermal exploitation wells. The hydrothermal geothermal resources can be converted into 1250 billion tons of standard coal, indicating an annual allowable exploitation of 1.865 billion tons of standard coal. There are high-temperature geothermal resources (≥150℃), but the moderate -temperature geothermal resources（90℃-150℃）and low-temperature geothermal resources（<90℃）play a dominant role.The high-temperature geothermal resources are mainly found in Southern Tibet, Western Yunnan, Western Sichuan and Taiwan. The moderate- and low-temperature geothermal resources are mainly found in large sedimentary basins and mountain fractures.

2. The moderate- and low-temperature hydrothermal resources can be converted into 1230 billion tons of standard coal, and the annual allowable exploitation can be converted into 1.85 billion tons of standard coal, indicating the power generation of 1.5 million kW. Hydrothermal high-temperature geothermal resources can be converted into 1.41 billion tons of standard coal, and the annual allowable exploitation can be converted into 18 million tons of standard coal, equaling the power generation of 8.46 million kW.

3.The heat capacity of shallow geothermal resources in 336 cities is 1.11×10^{17} kJ/℃, and the annual allowable exploitation can be converted into 700 million tons of standard coal. For the ground-source heat pump system, the general heat transfer rate is 3.14×10^{9}kW in summer and 2.10×10^{9}kW in winter. And the area of buildings available for cooling in summer is 3.26×10^{10}m^2 and for heating in winter is 3.23×10^{10}m^2.

4.The dry-hot rock resources within 3~10 km underground are equivalent to 860 trillion tons of standard coal, which is about 3500 times of China's total energy consumption in 2020 based on 2% of the exploitable resources, with huge potential and broad development prospects.

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