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News and Highlights

Carbon emission reduction: Contribution of geothermal energy and practice in China

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As a kind of natural energy from the earth’s interior, geothermal energy is characterized by large reserve, wide distribution, good stability, high utilization coefficient, and positive effects of energy-saving and emission-reduction. It is of great significance for promoting green and low-carbon energy transition, reducing greenhouse gas emission, and achieving global climate goals and sustainable economic development. Hence, it has been highly recognized and valued by lots of countries around the world, and has become one of the most important clean energy sources that countries are accelerating to develop and utilize.

The potential of the global geothermal energy resource is estimated to be 1.25×10^{27} J, equivalent to 4.27×10^{16} t of standard coal, among which the geothermal resource between 0 km and 5 km is 1.45×10^{26} J, equivalent to 4.95×10^{15} t of standard coal (China Geological Survey, 2018). According to the *Report on the Progress of Global Geothermal Power Generation released by World Geothermal Conference 2023*, as of the end of 2022, more than fifty countries worldwide were engaged in geothermal energy development and utilization. The total installed capacity for geothermal power generation worldwide grew up to 16260 MW in 2022 from 2110 MW in 1980, indicating a 6.7 times increase over 1980. Thirty-one countries had geothermal power plants in operation. The four leading countries for geothermal power generation in terms of installed capacity were the USA, Indonesia, Philippines and Turkey, among which the USA occupied the first place, with a total installed capacity of 3700 MW. The total global geothermal energy utilization in 2022 was 1476 PJ (410 TWh), indicating a 44 % increase over 2020. The global installed capacity of geothermal heating and cooling was equivalent to 173×10^{6} kWh, with a 60% increase over the number reported in 2020, among which the geothermal heating and cooling of buildings had the largest geothermal use worldwide and accounted for about 79% of the total. After that, the largest uses were medical treatment and entertainment, leisure tourism, agriculture and food processing. Iceland is the world’s most advanced country in terms of geothermal energy utilization. In the 1990s, Reykjavik, the capital of Iceland, had achieved 100% geothermal heating and become the world’s first heating “smoke-free city” (Adele M et al., 2023).

As a country with abundant geothermal resources, China accounts for about one-sixth of the global total (Fig. 1). Shallow geothermal resources are widely distributed, especially concentrated in the central and eastern areas (including Beijing City, Tianjin City, Hebei Province, Shandong Province, Jiangsu Province, Anhui Province, Henan Province, Shaanxi Province) and some northeastern areas. The annual exploitable amount in over 336 cities at or above the prefecture level is approximately equivalent to 700×10^{6} t of standard coal (Table 1). 80% of the land in these areas are suitable for utilizing shallow geothermal energy and could be able to provide a cooling area of 32.575×10^{9} m^{2} in summer and a heating area of 32.268×10^{9} m^{2} in winter for building . Hydrothermal geothermal resources are mainly distributed in twelve large and medium-sized sedimentary basins, such as the North China Plain, Songliao Plain, and Sichuan Plain. The geothermal resource is equivalent to 1.02×10^{12} t of standard coal and the annual exploitable amount is equivalent to 1.7×10^{9} t of standard coal (Table 2). Hydrothermal geothermal resources are relatively few in the uplift mountain areas. The high-temperature geothermal resources in the mainland are mainly distributed along the intensive hydrothermal activity zone, the southern Tibet-western Sichuan-western Yunnan region. The power generation potential of those high temperature resource is 7120 MW, accounting for 84.1% of the national total. The hot

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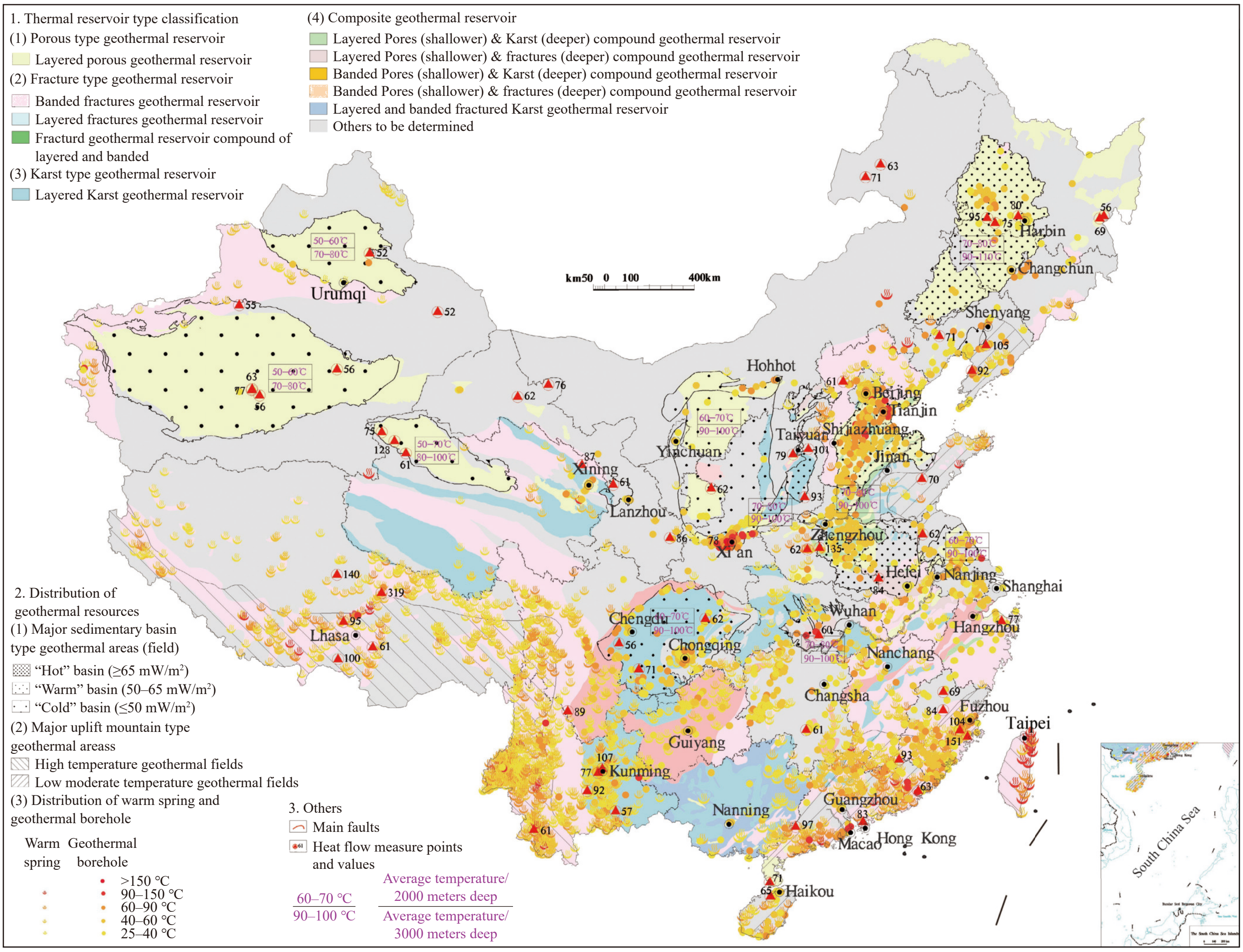

Fig. 1. Distribution of geothermal resources in China (after Wang GL et al., 2018).

Table 1. Potential of shallow geothermal energy in 336 cities above the prefecture level in China (after China Geological Survey, 2023).

Province	Number of cities assessed	Geothermal heat pump heating and cooling area/10^8 m^2		Standard coal equivalent to the annual exploitable heat energy /10^4 t
		Cooling in summer	Heating in winter	
Beijing	1	16.02	9.59	3972
Tianjin	1	12.58	13.41	3584.6
Hebei	11	6.35	5.99	1626.01
Shanxi	11	11.28	5.28	2801.52
Inner Mongolia	12	21.46	12.81	3222.74
Liaoning	14	15.49	12.47	3743.59
Jilin	9	7.43	2.85	865.76
Heilongjiang	13	2.56	0.9	313.74
Shanghai	1	4.64	14.5	5814.36
Jiangsu	13	23.06	25.91	4699.39
Zhejiang	11	8.36	8.29	1797.12
Anhui	16	37.25	29.75	6353.7
Fujian	9	1.28	2.11	2790.59
Jiangxi	11	24.39	25.63	1313.25
Shandong	17	25.81	22.87	3051.01
Henan	17	11.18	12.97	2632.64
Hubei	13	10.33	11.58	1290.06
Hunan	14	22.77	32.67	6314.65
Guangdong	21	1.98	7.36	1055.59
Guangxi	14	3.35	0	1277.4
Hainan	3	0.27	0	77.98

Table 1 (*Continued*)

Province	Number of cities assessed	Geothermal heat pump heating and cooling area/10^8 m^2		Standard coal equivalent to the annual exploitable heat energy /10^4 t
		Cooling in summer	Heating in winter	
Chongqing	1	21.54	38.89	675.17
Sichuan	20	5.17	6.16	1485.65
Guizhou	9	6.39	5.86	611.25
Yunnan	16	1.53	1.8	304.6
Xizang	7	0	0.2	25.47
Shaanxi	10	6.65	5.41	2762.52
Gansu	14	7.13	2.48	3693.6
Qinghai	8	0.62	0.19	52.35
Ningxia	5	3.12	1.47	574.8
Xinjiang	14	5.75	3.3	1609.44
Total	336	325.75	322.68	70393

Table 2. Potential of hydrothermal geothermal resources (after China Geological Survey, 2023).

Geothermal zoning		Medium-and low-temperature geothermal resources				High-temperature geothermal resources	
		Geothermal resources amount		Exploitable heat energy of geothermal fluid under the condition of reinjection		Thermal energyKJ	30-year power generation potential /MW
		Geothermal resources/kJ	Equivalent to standard coal/t	Exploitable heat energy/kJ/year	Equivalent to standard coal/t		
Sedimentary basin type	North China Plain	7.23×10^{18}	2.47×10^{11}	1.24×10^{16}	4.22×10^{8}		
	Hehuai Plain	5.33×10^{18}	1.82×10^{11}	9.02×10^{15}	3.08×10^{8}		
	Northern Jiangsu Plain	6.75×10^{17}	2.30×10^{10}	9.20×10^{14}	3.14×10^{7}		
	Songliao Plain	1.24×10^{18}	4.22×10^{10}	2.01×10^{15}	6.87×10^{7}		
	Lower Liaohe Plain	3.95×10^{16}	1.35×10^{9}	7.52×10^{13}	2.56×10^{6}		
	Fengwei Basin	2.20×10^{18}	7.49×10^{10}	3.86×10^{15}	1.32×10^{8}		
	Erdos Basin	1.48×10^{18}	5.03×10^{10}	2.68×10^{15}	9.15×10^{7}		
	Sichuan Basin	9.62×10^{18}	3.28×10^{11}	1.59×10^{16}	5.44×10^{8}		
	Jianghan Basin	2.49×10^{17}	8.51×10^{9}	3.64×10^{14}	1.24×10^{7}		
	Hetao Basin	6.61×10^{17}	2.25×10^{10}	9.59×10^{14}	3.27×10^{7}		
	Yinchuan Plain	9.37×10^{17}	3.20×10^{10}	1.43×10^{15}	4.88×10^{7}		
	Xining Basin	1.34×10^{17}	4.57×10^{9}	2.09×10^{14}	7.12×10^{6}		
	Total	2.198×10^{19}	1.02×10^{12}	4.98×10^{16}	1.70×10^{9}		
Uplift mountain type	Southern Tibet—Western Sichuan—Western Yunnan	3.16×10^{17}	1.08×10^{10}	7.22×10^{13}	2.46×10^{6}	3.37×10^{17}	7120
	Southeast coastal areas	1.71×10^{17}	5.85×10^{9}	6.44×10^{13}	2.20×10^{6}	3.56×10^{16}	700
	Jiaoliao Peninsular	2.69×10^{14}	9.18×10^{6}	2.54×10^{12}	8.68×10^{4}		
	Total	4.88×10^{17}	1.67×10^{10}	1.39×10^{14}	4.75×10^{6}	3.72×10^{17}	7820

dry rock resource in China has huge potential and is considered to be the main direction for future geothermal exploration and development. It is estimated that the resource potential of the hot dry rock at a depth between 3 km and 10 km in the mainland is 2.5×10^{25} J, equivalent to 856×10^{12} t of standard coal (Table 3). Calculated on 2% of exploitable resources, the exploitable heat energy from hot dry rock is equivalent to 17.2×10^{12} t of standard coal (China Geological Survey, 2023).

China's direct utilization of geothermal energy has consistently ranked first in the world for many years. By the end of 2021, the installed capacity for geothermal direct utilization had been equivalent to 100.2 GW and the total annual energy use had exceeded 820 PJ. The heating (cooling) area exceeded 1.33×10^9 m^2. The hydrothermal geothermal heating (cooling) capacity reached 530×10^6 m^2, and the annual energy utilization was more than 320 PJ. The shallow geothermal heating (cooling) capacity reached 800×10^6 m^2, and the annual energy utilization was more than 390 PJ. As for leisure tourism, the annual utilization of hot springs in 72 regions that had been rated as the hometown of hot springs was 6665 MW, with an annual utilization amount exceeding 100 PJ. China's utilization of geothermal energy for agriculture had spread to over 20 provinces, with the total utilization capacity of more than 1108 MW and the annual amount of 12.559 PJ. During the initial development stage, geothermal power generation in China did not receive price subsidies similar to wind and solar power generation,

Table 3. Potential of hot dry rock resources at the depth of 3–10 km on Chinese mainland (after China Geological Survey, 2023).

Depth of calculation layer/km	Reserve of hot dry rock resources		Allowable exploitation of hot dry rock resources (extracted by 2%)	
	Reserve/J	Equivalent to standard coal/t	Reserve/J	Equivalent to standard coal/t
3–4	1.9×10^{24}	6.48×10^{13}	3.8×10^{22}	1.30×10^{12}
4.0–5	2.5×10^{24}	8.53×10^{13}	5×10^{22}	1.71×10^{12}
5–6	3×10^{24}	1.02×10^{14}	6×10^{22}	2.05×10^{12}
6–7	3.6×10^{24}	1.23×10^{14}	7.2×10^{22}	2.46×10^{12}
7–8	4.2×10^{24}	1.43×10^{14}	8.4×10^{22}	2.87×10^{12}
8–9	4.7×10^{24}	1.60×10^{14}	9.4×10^{22}	3.21×10^{12}
9–10	5.3×10^{24}	1.81×10^{14}	1.06×10^{23}	3.62×10^{12}
3–10	2.5×10^{25}	8.56×10^{14}	5.04×10^{23}	1.72×10^{13}

resulting in the relatively slower growth. As of the end of 2021, the total installed capacity of geothermal power generation in operation was only about 16 MW (Guo XS et al., 2023). In January 2024, the Future Space Deep Geothermal Innovation Consortium has been officially established .This innovation consortium, guided by the State-owned Assets Supervision and Administration Commission of the State Council and led by Sinopec, is formed in collaboration with 22 central enterprises, advantageous universities and research institutes. It is committed to promote the key technologies of geothermal energy exploration and evaluation, efficient development and comprehensive utilization.

According to the official targets set by National Energy Administration, by 2025, the heating (cooling) area of geothermal energy in China will increase by 50% and the installed capacity of geothermal power generation will double compared to 2020. By 2035, the heating (cooling) area and installed capacity will double compared to 2025. It is expected that geothermal energy will play a more and more important role in achieving China's carbon peak and carbon neutrality goals and contributing to the global sustainable development.

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