Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Providing All China Energy Need with Geothermal and Other Renewables

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Keywords: China's energy demand, geothermal energy, clean energy, fossil energy, feasibility study

ABSTRACT

Fossil energy is great in terms of cost, convenience, infrastructure, and other issues. However it has many problems such as the limitation of resources and the emission of greenhouse gas that causes serious pollutions. For example, the heavy smog encircled a large area of China in recent years. Hundreds of flights have been cancelled and highways have been closed when that happened. Climate change, environment disaster, pollution, and energy insecurity may be among the greatest problems of the current world. Solving these harms requires essential changes in the present energy infrastructure. In this paper, we have analyzed and discussed the feasibility of providing all China's energy need for all of the purposes, including space heating/cooling, electricity, transportation, and others from geothermal, wind, and solar energies (GWS). The geothermal resource in 3.0-10.0 km deep hot dry rock in mainland China is about 2.5×10^{25} J in total, which is equivalent to 8.60×10^{8} million tons of standard coal. If only 2% is explored and utilized, the energy is equivalent to about 5300 times as much as the total annual energy consumption in China in 2010. The annular solar resource is equivalent to hundreds of times of the total annual energy consumption in China. This shows that it is possible to provide China's all energy need with GWS, considering wind energy and other renewables as a plus. The barriers to the all renewable plan might be primarily social and political, not technological or economic. The absolute energy cost in a GWS world may be greater than that today but the effective energy cost (after considering the increased costs of medical treatments, environmental recreation, and water treatments caused by pollution and disasters because of consuming fossil energy) of a GWS world could be less. We also predicted the growth rates of the renewables in China and found that GWS could meet all the energy need of China in 2055 or so.

1. INTRODUCTION

Energy security is an overarching and strategic issue, which is closely related to the national economy and social development. In face of the new changes in the world energy supply and international energy development, a revolution should be promoted in the energy production and consumption field to ensure national energy security.

The resources of oil, natural gas and other fossil energy resources in China are not abundant. The long period of high or violent fluctuations in the international crude oil price has greatly affected economic development and people's lives. The fossil energy causes the increasing greenhouse effect as a result of increasing concentration of CO_2 in the atmosphere. It threatens the living environment of human beings. The outline of the national program for medium-long term scientific and technological development of China (2006-2020) clearly states that low-cost large-scale development and utilization of renewable energy, including geothermal energy, is a priority theme.

In recent years, China has led the world in investment in new and clean energy, with the focus on wind, solar and nuclear energy. Geothermal energy, as a stable, safe, clean and renewable energy with low development cost and huge reserves, has also developed rapidly in recent years and may become a kind of base load. After a long period of development, China has become the world's biggest energy producer, consumer and importer of oil and gas. Comprehensive development of the energy supplied system including coal, electric power, petroleum, natural gas, renewable energy and clean energy was formed, promoting the increasingly improved technology and equipment level.

According to the data in the China energy statistical yearbook 2015 (national bureau of statistics, 2015), China is now still highly dependent on coal, oil, natural gas, and other fossil energy. Petroleum accounts for 18.3% of the total domestic energy consumption, about 787m tons of standard coal. Natural gas accounts for 5.9% of China's total energy consumption, about 254 million tons of standard coal, and the share of fossil energy consumption has exceeded 85% of the total annual consumption. At the same time, air pollution and haze caused by coal burning have a serious impact on human health, moreover, the greenhouse effect such as climate warming caused by large CO_2 emissions is becoming increasingly serious. All these indicate that the search for alternative clean energy is imminent.

At the same time, it should be noted that although big progress has been made in China's energy production and consumption, many challenges still exist. For example, high external dependency and energy demand of oil and gas, the low energy utilization efficiency compared to developed countries, the energy supply constraints, harsh damage to the ecological environment, and lack of advanced energy development technology.

It can be seen from the above analysis and discussion that the problems facing mankind include greenhouse effect, environmental disaster, environmental pollution and energy security. There is no doubt that one of the important measures to solve these problems is to change the types and ways of using the current energy sources, including improving energy utilization efficiency. To this end, based on the actual situation of clean energy (GWS) resources and current energy consumption level in China, this paper analyzes the feasibility of providing all of China’s energy need with clean energy GWS (geothermal energy, wind energy, solar energy).

2. ENERGY AND ENVIRONMENTAL ISSUES IN CHINA

2.1 Environmental Issues

After winning the bid for the 2008 Olympics in 2002, Beijing began counting the number of days in 2003 when air quality was above moderate as part of its commitment to a green Olympics. From 2003 to 2008, the number of clean air days in Beijing increased from 224 (61.4%) to 274 (75.1%). However, after reaching a peak of 286 days (78.4%) in 2010 and 2011, the number of days with good and moderate air quality dropped to 176 days in 2013, accounting for only 48.6% of the whole year. When the haze is severe, some famous landmarks almost disappear from people's eyes, as shown in the picture below (see Fig. 1).

Figure 1: The 246-meter-high "Nail Tower" of the famous landmark Beijing Olympic Sports Park hidden in the air (the left is a picture when there is no smog)

Haze is not limited to Beijing. Shenyang, which has won the first place in China by vigorously developing ground source heat pumps, created a miracle of 332 days (90.1%) of good air days in 2011, but was also overwhelmed by the haze in 2013. The city of Nanjing in eastern Jiangsu province of China has announced an unprecedented suspension of primary and middle school classes due to haze, which has also hit coastal cities such as Weihai in Shandong province and Ningbo in Zhejiang province.

Data from relevant researchers show (Shang, 2015) that there are four major regions with the most serious haze pollution in China. (1) Southern China: mainly in the pearl river delta region; (2) Southwest China: Sichuan basin; (3) Northern China- Beijing: Tianjin and Hebei; (4) Yangtze river delta region: mainly including Shanghai, Zhejiang and Jiangsu.

PM10 is a particulate that is 10 microns in size. PM2.5 is 2.5 microns in size, or roughly a quarter of the size of PM10. They are the particle pollutants of the atmosphere. According to the air quality statistics of the first quarter in 2017 (Ministry of Environmental Protection of the People's Republic of China, 2017), the average concentration range of PM2.5 average is 25-164 µg/m^3 in China's 74 cities, with an average of 66 µg/ m^3 , increasing by 4.8% year-on-year. The average quarterly concentration range of PM10 is from 44-219 µg/ m^3, with an average of 101 µg/m3, decreasing by 1.9% year-on-year. The average concentration range of SO_2 was 6-114 µg/ m^3, with an average of 25 µg/ m^3 , decreasing by16.7% year-on-year. The average concentration range of NO_2 was 13-75 µg/ m^3, with an average of 47 µg/ m^3, increasing by 6.8% year on year.

In 2016, 84 out of 338 cities (hereinafter referred to as 338 cities) met the environmental air quality standards, accounting for 24.9 percent of the total. 254 cities did not satisfy the environmental air quality standards, accounting for 75.1% (see Fig. 2).

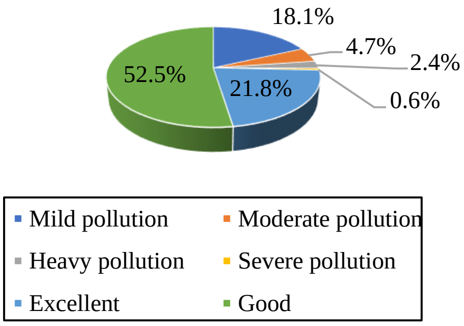

Figure 2: Environmental air quality grade ratio of 338 cities in China in 2016 (Ministry of Environmental Protection of the People's Republic of China, 2016)

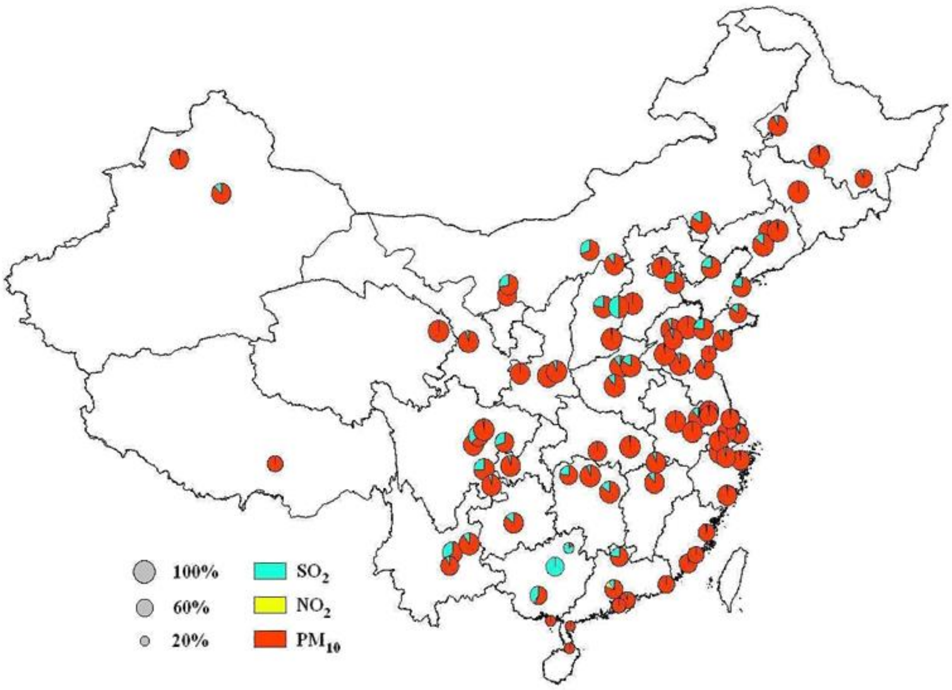

Figure 3: Proportion of primary pollutants in 86 key cities of China in 2007 (Hao, 2009)

Proportion of primary pollutants in 86 key cities in 2007 is shown in Fig. 3. China is the world's most seriously disrupted area when considering fine particle pollution, where PM2.5 concentrations reach 60-90 μg/m^3. Especially, the concentrations reach more than 100 μg/m^3 in some economic developed areas such as Yangtze river delta, the pearl river delta, Beijing-Tianjin-Hebei (Environ. Health. Perspect, 2010).

According to the ministry of urban air quality monthly report data (Ministry of Environmental Protection of the People's Republic of China, 2014-2016) (as shown in Fig. 4), PM2.5 and PM10 and SO_2, NO_2 concentration reached peak value every winter, the seasonal change of main pollutant concentration might be related to the winter heating in the north of China. Additionally, pollutants are hard to spread away in winter. Contrary to the high peak pollutant value in winter, the concentration of ozone reaches peak in summer every year due to the significantly more intense photochemical reactions and hot weather.

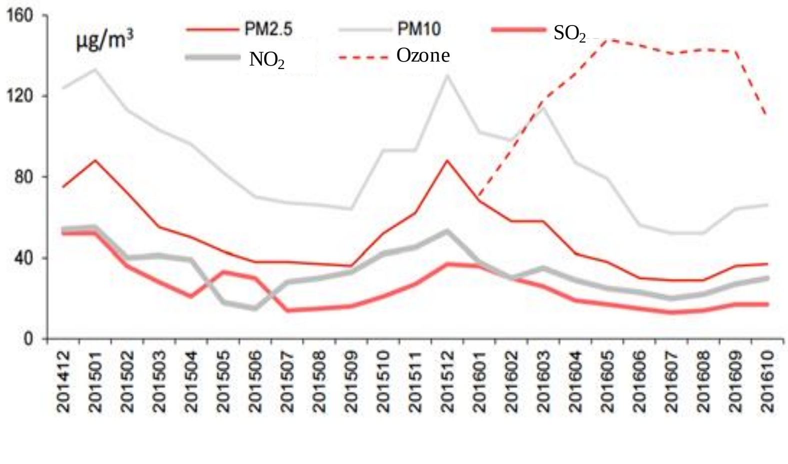

Figure 4: Trend of monthly average concentration of air pollutants in China (Ministry of Environmental Protection of the People's Republic of China, 2014-2016)

What causes such severe air and environmental pollution in China? Numerous studies have been done on this, the cause and mechanism are not unified. But the large amounts of burned coal in China, especially loose coal burned in suburban areas, definitely result in the pollution. As shown in Fig. 4, the actual annual consumption of coal burning in China reached 1.084 billion tons in 2002 (excluding equivalent conversion of other energy consumption), and reached 2.409 billion tons in 2012, increasing by 2.2 times in 10 years. As can be seen from the graph, the amount of good weather shows a negative relationship with the increase in coal consumption (see Fig. 5). The sudden drop in air quality in 2013 may result from climate change and rapidly increased air pollution in China.

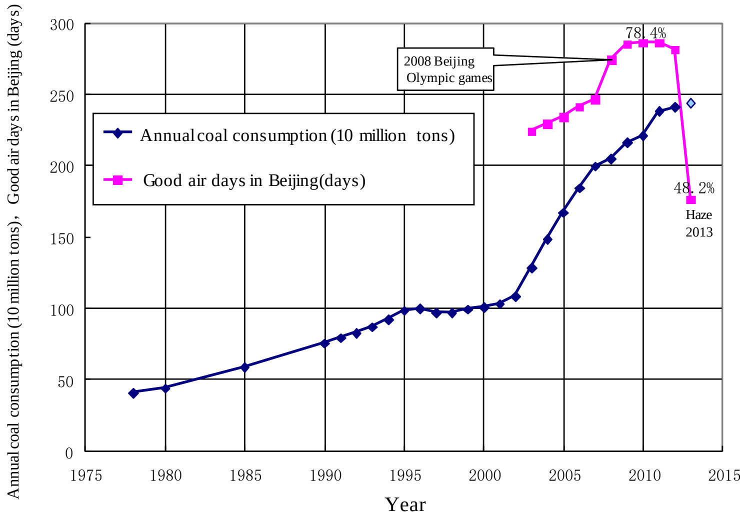

Figure 5: Severe haze caused by China's rapid coal burning

China's annual emissions of carbon dioxide are now about 10 billion tons, more than the sum of the United States and Europe, which almost offset the world's emission reductions in recent years. Therefore, China must accelerate the pace of replacing conventional fossil fuels with clean energy. To this end, the state council issued the air pollution prevention and control action plan in 2013, and Beijing also issued the clean air action plan for 2013-2017. Beijing added "building a clean energy system with electricity and natural gas as the main energy source, geothermal energy and solar energy as the auxiliary" in its energy cleaning strategy.

In recent years, haze has spread in many parts of China, often causing hundreds of flights to be cancelled and a large number of highways to be closed, which causes huge losses to the national economy as well as people's lives and property.

2.2 Serious Hazard to Public Health Contributed by Haze

The composition of haze is very complex, including hundreds of atmospheric chemical particles. What is bad for health is mainly aerosol particles less than 10 microns in diameter, such as mineral particles, sea salt, sulfate, nitrate, organic aerosol particles, fuel and car exhaust gas and so on. These particles are the carrier of metal, bacteria, viruses, which can enter the human body through the respiratory system. Exposure to such particles can affect both our lungs and heart. People with heart or lung diseases, children, and older adults are the most likely to be affected by particle pollution exposure.

2.3 Greenhouse Effect and Climate Change

Global warming is an environmental problem that all countries in the world are paying close attention to. Burning fossil fuels, deforestation, automobile exhaust, and the use of the modern refrigerator can produce greenhouse gases.

The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere. Radiatively active gases (i.e., greenhouse gases) in a planet's atmosphere radiate energy in all directions. Part of this radiation is directed towards the surface, warming it. The intensity of the downward radiation – that is, the strength of the greenhouse effect – will depend on the atmosphere's temperature and on the amount of greenhouse gases that the atmosphere contains (Gregory et al., 2007). Common greenhouse gases include CO_2, CH_4, nitrous oxide and fluorinated gases. The proportion of greenhouse gas components in 2014 and the global greenhouse gas emissions in 2017 are as follows (Fig. 6):

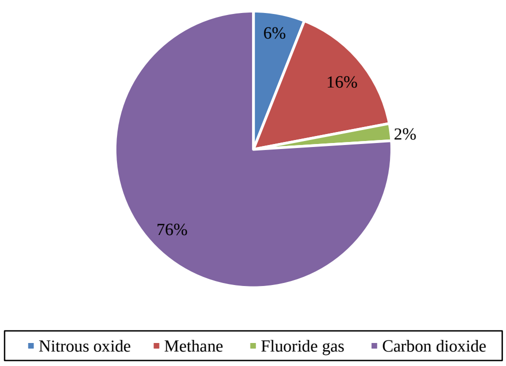

Figure 6: Composition and proportion of global greenhouse gases (IPCC, 2014)

The main component of greenhouse gases is carbon dioxide, followed by methane, nitrous oxide and fluoride gases (IPCC, 2014). Fig. 7 shows the change in the amount of greenhouse gases produced by burning fossil fuels from 2006 to 2016. Global carbon emissions from fossil fuels have increased significantly since 2009 and slowed down in recent years, peaking at 33,432 million tons in 2016. （BP Statistical Review World Energy, 2017)

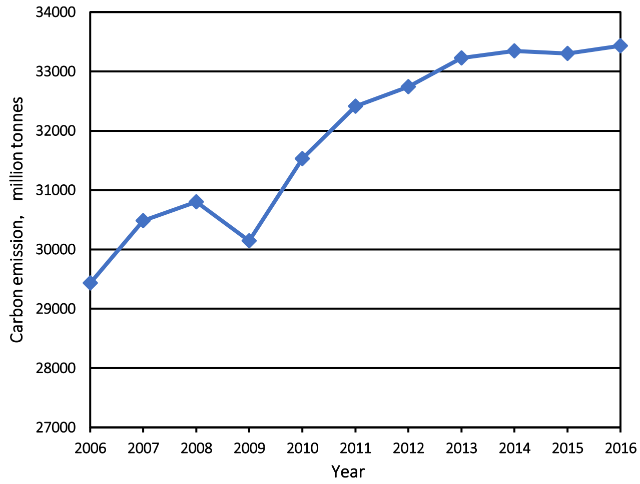

Figure 7: Global carbon emissions from 2006 to 2016 (BP Statistical Review World Energy, 2017).

China accounts for 30% of the world's carbon emissions, ranking first in the world. The carbon emission of the United States is only half of that of China, accounting for 15% (Boden et al., 2017). It can be seen that China relies heavily on fossil fuels such as coal, oil and natural gas and has a heavy task to reduce emissions (Fig. 8).

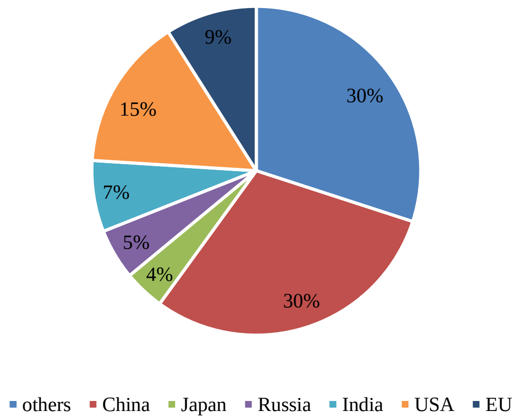

Figure 8: World carbon emissions (Boden et al., 2017)

2.4 Excessive External Dependence on Petroleum

It is particularly important to emphasize the external dependence of oil and natural gas. According to the 2017 domestic and foreign oil and gas industry development report released by the China academy of petroleum economics and technology, China's apparent oil consumption would exceed 600 million tons for the first time in 2018, with the external dependence approaching 70%. For the Chinese market, China's apparent oil consumption growth picked up in 2017, with growing speed at 5.9% to about 588 million tons. National crude oil production continued to decline to 192 million tons. China's net export of refined oil products has fallen off to 6.8 percent after five years of high growth, compared with an average of around 50 percent in the past five years. China's natural gas consumption has exceeded expectations, with periodic and regional gas supply shortages and soaring retail liquefied natural gas(LNG) prices.

2.5 Low Energy Utilization Efficiency

The difference in improvement rates before and after 2008 also highlights the impact of policy developments, particularly in China, where the influence of the 11th and 12th Five-Year Plans is seen via a 16% improvement in the efficiency effect since 2008(Fig. 9).

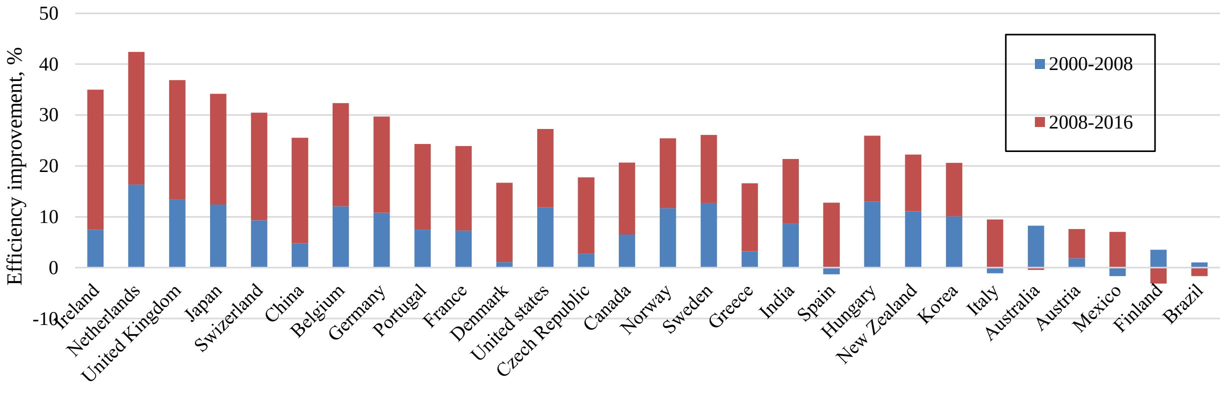

Figure 9: Percentage improvement in the efficiency effect for select countries, 2000-2016 （IEA, Energy Efficiency 2017）

However, compared with other countries, the percentage of energy savings in China is still not very high, which shows that China's energy efficiency or resource efficiency still has huge potential to improve (Fig.10).

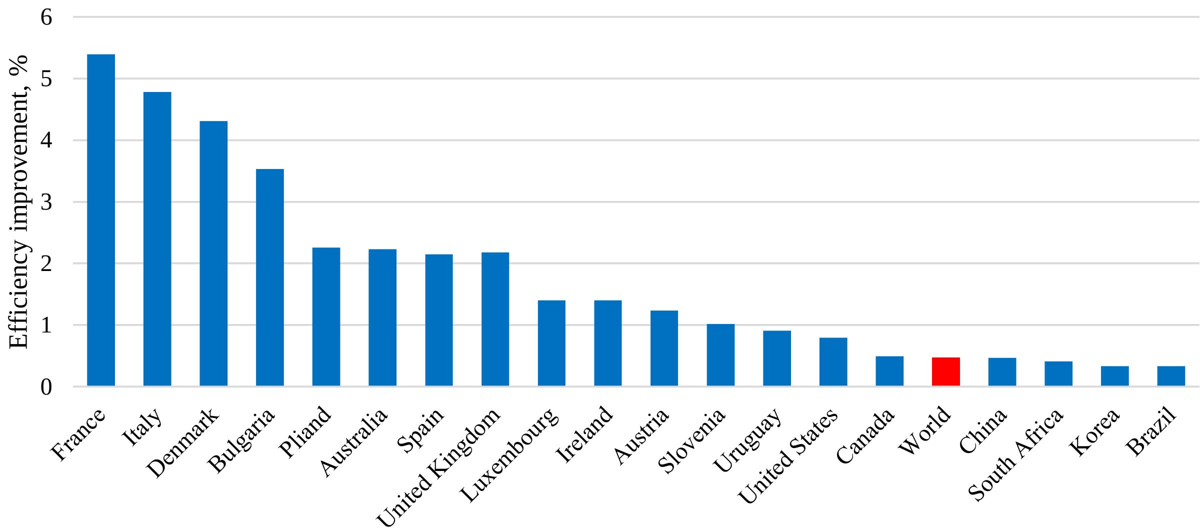

Figure 10: Energy savings in 2016 from utility obligations in operation since 2005, as a percentage of national final energy consumption （IEA, Energy Efficiency 2017）

3. BASIC SITUATION OF ENERGY CONSUMPTION IN CHINA

3.1 Energy Consumption Status in China

In 2015, China's primary energy consumption reached 4299.05 million tons of standard coal, with an increase of 1.5% over the previous year, accounting for 22.9% of the world's total energy consumption. China was the largest energy consumption country in the world. In the structure of China's primary energy consumption in 2015, coal, oil, natural gas, hydropower, nuclear power, wind, solar and other renewable energy sources accounted for 63.7%, 18.6%, 5.9%, 8.5%, 1.3%, 1.4%, 0.3% and 0.4%, respectively. The specific situation is shown in table 3 (National Bureau of Statistic, 2015).

Table 1. China's Total Energy Consumption and Its Consumption Structure (2015) (National Bureau of Statistics, 2015)

Total energy consumption (billion tons of standard coal)	Proportion of total energy consumption (%)					
	Coal	Oil	Natural gas	Primary electricity and other energy sources	hydropower	nuclear power
4.299	6.37	1.83	0.59	1.21	0.8	0.12

In 2015, China's coal consumption was 2.738 billion standard tons coal (BP Statistical Review World Energy, 2016), 1.5% lower than the previous year, accounting for 50.0% of the world's total coal consumption, ranking first in the world. The coal output of that year was 1827.0×10^6t equivalent of petroleum, accounting for 47.7% of the world's total output, making China the world's largest coal producer. Oil consumption was equivalent to78.67 million tons of standard coal, with an increase of 6.3% over the previous year, accounting for 12.9% of the world's total oil consumption, ranking second only after the United States. The consumption of natural gas was equivalent to 253.64 million tons of standard coal, with an increase of 4.7% compared to the last year, accounting for 5.7% of the world's total consumption, making China the world's third largest natural gas consumer. Natural gas production was $1{,}380 \times 10^8 m^3$, ranking sixth in the world. The consumption of primary power and other energy resources was 5208.505 million tons of standard coal, including 343.92million tons of standard coal for hydropower, with an increase of 5.0% over the previous year, accounting for 28.9% of the world's consumption. Nuclear power consumes 51,588,600 tons of standard coal, with an increase of 28.9% over the previous year, accounting for 6.6% of the world's total consumption, ranking fourth in the world (see Fig.11).

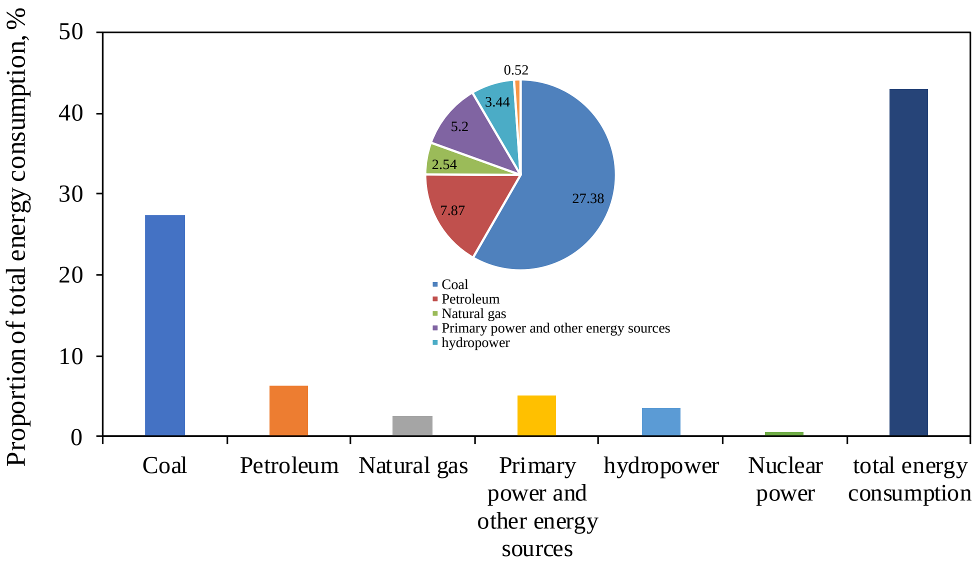

Figure 11: China's consumption of different types of energy in 2015(Zhou, 2016)

From the chart below (Fig.12), it can be seen that fossil energy such as coal, oil and natural gas is still the main type of energy consumption, with coal accounting for 63.7%, oil for 18.3%, natural gas for 5.9%, while primary electricity and other energy only accounts for 12.1% (National Bureau of Statistics, 2015). It can be seen that China is still heavily dependent on fossil energy at this stage, and it is difficult to change the energy consumption structure in a short period of time. At the same time, the current energy structure in China is difficult to shift.

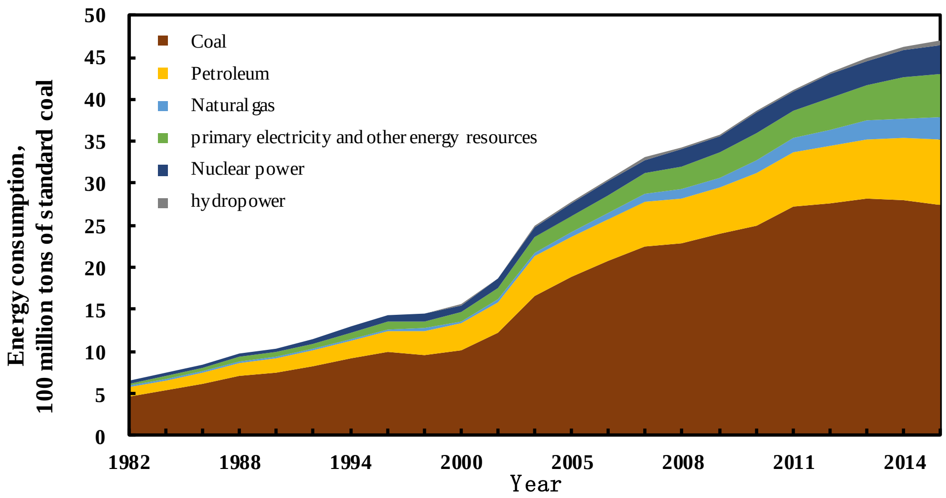

Figure 12: China's energy consumption from 1980 to 2015 (National Bureau of Statistics, 2015)

3.2 China's Future Energy Consumption Forecast

Assume that China's annual average GDP growth rates in 2011-2015, 2015-2020, 2020-2025 and 2025-2030 are 8%, 7%, 6% and 5% respectively. Assuming the two modes that the energy consumption per unit of GDP (*Ai*) from 2011 to 2030 will decline by 16% and 20% every 5 years, according to the formula *A= Ai *GDP*, where *A*-estimated annual energy consumption; *Ai*- energy consumption per unit of GDP (USD) in the i_{th} year, in per ton standard coal/ 1,000 USD; GDP-the total GDP (US dollars) in the i_{th} year, in 1,000 US dollars (see Table 2).

Table 2. Forecast of China's Energy Consumption in 2030 (Energy Consumption Per GDP Method) (Han et al., 2012)

Year	Mode I: *Ai* decreased by 16% every 5 years					Mode II: *Ai* decreased by 16% every 20 years				
	Energy intensity /t standard coal • USD1,000^{-1}	GDP annual growth rate/%	GDP /trillion USD	energy consumption/billion tons of standard coal	Coal consumption/billion tons of standard coal	Energy intensity /t standard coal • USD1,000^{-1}	GDP annual growth rate/%	GDP /trillion USD	energy consumption/billion tons of standard coal	Coal consumption/billion tons of standard coal
2015	4.53	8	9.36	42.4	31.8	4.31	8	9.36	40.34	30.26
2020	3.81	7	13.13	50.03	37.52	3.45	7	13.13	45.30	33.97
2025	3.20	6	17.56	56.19	42.14	2.76	6	17.56	48.67	36.35
2030	2.68	5	22.42	60.08	45.06	2.20	5	22.42	49.32	36.99

It can be seen from Table 2 that although the annual increase is decreasing, the annual energy consumption is increasing as time goes on. It is estimated that the annual energy consumption will reach 4.932 billion tons of standard coal in 2030.

Relevant data on predicting China's energy pattern in the future can be found in the international energy outlook 2013 (see Fig. 13)

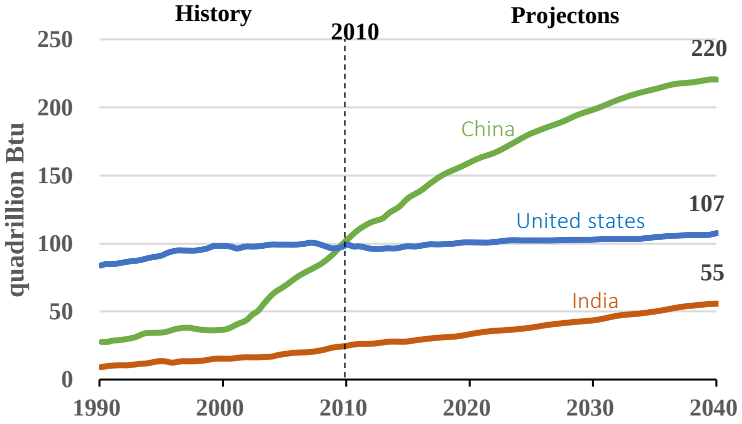

Figure 13: China's energy consumption forecast in 20 years (EIA, 2013)

China has recently become the world's largest energy consumer and is expected to consume more than twice as much energy as the United States by 2040.

4. CURRENT SITUATION OF CLEAN ENERGY RESOURCES IN CHINA

4.1 Geothermal Resources in China

In terms of shallow geothermal energy resources, hydrothermal geothermal resources and dry-hot rock resources, China's geothermal resources are richly and widely distributed.

The amount of shallow geothermal energy resources in major cities of China is 1.46×10^{19}J, equivalent to 4.97×10^{8} tons/year of standard coal. The development and utilization of geothermal resource can reduce the coal consumption of 8.29×10^{8} tons/year. If the utilization rate of shallow geothermal energy is 35%, the amount of coal consumption reduced is 2.90×10^{8} tons/year (Duoji et al., 2017).

The total geothermal resource reserves of hydrothermal medium-low temperature geothermal resources are 4.01×10^{22}J (equivalent to 1.37×10^{12}t of standard coal), with recoverable amount of geothermal fluid of 2.39×10^{10} m^3/a and recoverable heat of geothermal fluid of 4.77×10^{18}J/a (equivalent to 1.63×10^{8}t/a of standard coal). The total thermal energy of hydrothermal high-temperature geothermal resources is 4.13×10^{20}J, and the 30-year electricity generation potential is 8459.24MW/30a (Duoji et al., 2017).

The dry-hot rock resources at the depth of 3-10km are 2.52×10^{25}J, equivalent to 8.60×10^{14} tons of standard coal. If the development and utilization rate of dry-hot rock is 2%, the recoverable resources are 5.04×10^{23} Joules, equivalent to 1.72×10^{13} tons of standard coal, equivalent to 4000 times of the current annual energy consumption in China (Table 15). It can be seen that the potential of dry-hot rock resources is huge, and the research on the development and utilization technology of dry-hot rock resources is of great significance (Duoji et al., 2017).

Considering shallow and hydrothermal geothermal resources, if the shallow geothermal energy is 1.74×10^{8}tce, the hydrothermal geothermal energy is 1.72×10^{8}tce, the dry hot rock resource is 1.72×10^{13}tce, and the annual coal consumption is 27.38×10^{8}tce.

$$W_r = 1.74\times10^{8}+1.72\times10^{8}+1.72\times10^{13}=1.72\times10^{13}\ (\text{tce}) \quad (1)$$

$$n_1 = \frac{Q_G}{Q_E} = \frac{1.72\times10^{13}}{42.99\times10^{8}} = 4000 \quad (2)$$

$$n_2 = \frac{Q_G}{Q_C} = \frac{1.72\times10^{13}}{27.38\times10^{8}} = 6282 \quad (3)$$

where Q_G, Geothermal resources, tce; Q_E, Total annual energy consumption, tce; Q_C— Annual total coal energy consumption, tce; n_1 ,Years substituting total energy consumption, year; n_2 , Years substituting total coal energy consumption, year

From the above results, it can be concluded that China's geothermal resources have considerable reserves at present, and the current annual coal consumption is $27.38*10^{9}$ tons of standard coal. According to the current geothermal utilization technology, it can be used for 6282 years for normal activities if all the coal is replaced by geothermal energy. With continuous progress of science and technology, the utilization efficiency of geothermal energy will become higher and higher, and the energy consumption will become lower and lower. Therefore, the amount of available geothermal resources will be more considerable, and the problems of large energy consumption and serious pollution caused by the rapid development of today's society will be better solved.

4.2 China's Solar Energy Resources

4.2.1 Distribution of Solar Energy Resources in China

Areas with most abundant solar energy resources in China include most of Qinghai, central and western Tibet, western Gansu, western inner Mongolia, eastern Xinjiang and parts of western Sichuan, with an annual total radiation of over 1750 kWh/m^2 and graded as A; North China, most of Xinjiang, most of central and eastern Gansu, Ningxia, northern Shaanxi, southern and eastern Qinghai, eastern Tibet, western Sichuan, most of Yunnan, Hainan and other places are 1400-1750 kwh/m^2, which are areas rich in solar energy resources, graded as B; Most of the northeast, southern North China, Huanghuai, Jianghuai, Jianghan, Jiangnan and southern China are 1050-1400 kWh/m^2, graded C; while eastern Sichuan, Chongqing, central and eastern Guizhou, central and western Hunan and western Hubei are less than 1050 kWh/ m^2, graded as D (see Table 3 and Fig. 14).

Table 3. Abundance Level of Solar Energy Resources (China Meteorological Administration Wind Energy and Solar Energy Resources Center, 2014)

Energy abundance	Grade	Grading threshold (kWh/m^2)
Very abundant	A	≥1750
abundant	B	1400～1750
good	C	1050～1400
general	D	<1050

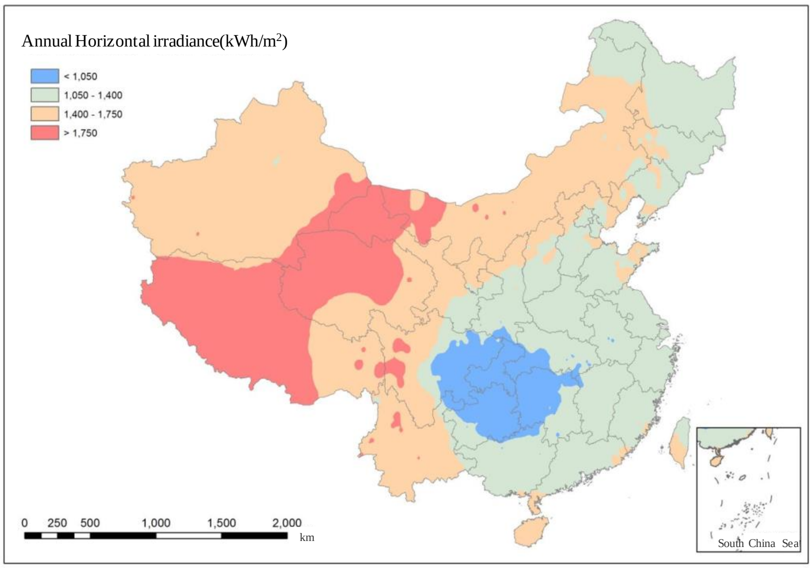

Figure 14: Distribution map of annual total radiation at horizontal level (2014) in China(Wind and Solar Energy Resource Center, China Meteorological Administration, 2014)

4.2.2 China's Solar Energy Resources and Their Substitution for Coal and Total Energy Consumption

In 2016, the average annual total radiation level of land surface in China was 1478.2 kW h/m^2. In recent 10 years, the annual radiation level has decreased slightly, by about 22.5 kW h/m^2 compared with the average from 2004 to 2013, which is 1.5% lower (China Meteorological Administration Wind Energy and Solar Energy Resource Center, 2016).

According to the above solar energy resources data, the replacement degree of solar energy resources to coal and total energy consumption is evaluated (China has a land area of 9634057 square kilometers).

$$Q_s = 1478.2 \times 9634057 \times 10^6 = 1.42 \times 10^{16} KWh = 1.74 \times 10^{12} tce \tag{4}$$

$$n_1 = \frac{Q_s}{Q_E} = \frac{1.74\times10^{12}}{42.99\times10^8} = 404.75 \tag{5}$$

$$n_2 = \frac{Q_s}{Q_C} = \frac{1.74\times10^{12}}{27.38\times10^8} = 635.50 \tag{6}$$

Where Q_S, total solar radiation, tce; Q_E , energy-total annual energy consumption, tce; Q_C, total annual coal energy consumption, tce; n_1, years substituting total energy consumption, year; n_2, years substituting total coal energy consumption, year

4.3 China's Wind Energy Resources

4.3.1 Distribution of Wind Energy Resources in China

The wind speed at a height of 70m over land in 2016 shows that China’s average annual wind speed is about 5.7m/s. Areas larger than 6.0m/s are mainly distributed in the mountainous areas of the northeast, north China, inner Mongolia, Ningxia, northern Shaanxi, Gansu, eastern and northern Xinjiang, Qinghai-Tibet plateau, western Sichuan, Yunnan-Guizhou plateau and Guangxi, among which the average annual wind speed in central and eastern inner Mongolia, northern and eastern Xinjiang, western Gansu and most of Qinghai-Tibet plateau reaches 7.0m/s, and some areas even reach above 8.0m/s. The area where the annual average wind speed is more than 5.0m/s is further expanded, including most of Shandong, eastern, southern, central and southwestern mountain areas where the average wind speed can reach more than 5.0m/s (China Meteorological Administration Wind Energy and Solar Energy Resource Center, 2016).

China’s annual average wind power density is 238.7W/m^2. The areas with high wind power density are mainly distributed in three northern regions, the eastern coastal regions, the Qinghai-Tibet Plateau, the Yunnan-Guizhou Plateau and the southern China ridge regions. The areas with annual average wind power density of 300W/m^2 are distributed in the Sanbei region, the Qinghai-Tibet plateau and the ridge region of Yunnan-Guizhou. The areas with an annual average wind power density of 200W/m^2 are widely distributed, including east China, coastal and central regions (China Meteorological Administration Wind Energy and Solar Energy Resource Center, 2016).

4.3.2 China's Wind Energy Resources and Their Substitution for Coal and Total Energy Consumption

According to the statistics and calculation of wind energy data from China’s national meteorological stations, about 2% of the solar radiation energy is converted into wind energy on the earth's surface. Wind energy is a part of the natural energy on the earth. The estimation of wind energy potential in China is as follows: the theoretical exploitable total amount of wind energy (R) is 3.226 billion kilowatts in the country, and the actual exploitable amount (r) is estimated by l/10 of the total amount. Considering that the actual swept area of the wind wheel is 0.785 times the square area of the calculated airflow (the area of the wind wheel with a diameter of

1 meter is $0.5^2*\pi$=0.785 (square meters)), the actual exploitable amount is *r*=0.785*R*/10=253 (billion kilowatts) (China Meteorological Administration Wind Energy and Solar Energy Resource Center, 2016).

$$Q_W = W_W \times t = 2.53 \times 10^8 \times 365 \times 24 = 2.22 \times 10^{12} KWh = 2.73 \times 10^8 tce \quad (7)$$

$$n_1 = \frac{Q_W}{Q_E} = \frac{2.73\times10^8}{42.99\times10^8} = 0.06 \quad (8)$$

$$n_2 = \frac{Q_W}{Q_E} = \frac{2.73\times10^8}{27.38\times10^8} = 0.10 \quad (9)$$

Where Q_W, total annual wind energy radiation, tce; Q_E, total annual energy consumption, tce; Q_C, total annual coal energy consumption, tce; n_1, years substituting total energy consumption, year; n_2 -years substituting total coal energy consumption, year

5. CURRENT UTILIZATION OF GWS ENERGY IN CHINA

5.1 Geothermal energy

China, with a long history of development and utilization of geothermal resources dating back to more than 2000 years, is one of the earliest countries employing geothermal resources in the world. Since the 1990s, under the impetus of the demand of the market economy, the development and utilization of geothermal resources developed more quickly (Home R N and Li K, 2012). At present, China has invested in the exploration and development of geothermal resources, including electricity generation, heating, medical treatment, bathing, recreation and fitness, aquaculture, agricultural greenhouse cultivation and irrigation, etc.

Geothermal resources can be divided into shallow geothermal resources, hydrothermal geothermal resources and dry hot rocks according to the heat flow transfer mechanism. Hydrothermal geothermal resources can be classified into three types (i.e., high, medium and low temperature geothermal) according to the temperature range, which are mainly used for electricity generation and direct utilization. Among them, the high temperature geothermal above 150℃ is mainly used for electricity generation, and the hot water left after electricity generation can be used step by step in multiple ways. The low-temperature geothermal at 90-150℃ is mainly used for direct utilization, and it is mostly used in industry, agriculture, forestry, animal husbandry, sideline fishery and other aspects. The shallow geothermal resources below 25℃ can be used for heating and cooling with the ground source and water source heat pump, providing energy convenience for life. China has high, medium and low temperature geothermal resources, among which medium and low temperature geothermal resources are dominated in China (Shibaki, 2003).

At present, a few areas, such as Yangbajing in Tibet and Bazhou in Hebei, have developed geothermal resources on a tiered basis for electricity generation, heating and greenhouse planting. The exploitation of geothermal resources is growing at an annual rate of nearly 10%, but the proportion of geothermal resources in the overall energy structure is still small, less than 0.5%. Therefore, great efforts should be made to meet the growing energy demand.

China's geothermal power potential reached 6.7 million kilowatts, only less than Indonesia (16 million kilowatts) and the United States (12 million kilowatts), but the actual electricity generation is far less than the two countries. At present, the total amount of geothermal water that can be developed and used annually is estimated to be about 7 billion cubic meters, equivalent to the annual calorific value of more than 50 million tons of standard coal. In China, 18.0% of geothermal water is used for heating, 65.2% for medical bathing, recreation and fitness, and 9.1% for planting and breeding. The others accounted for 7.7%. Although geothermal energy still accounts for a small proportion in the energy structure, the utilization of geothermal resources can reduce the use of conventional energy and relieve environmental pollution. It is of great potential for development and utilization (Lund and Boyd, 2016).

5.1.1 High Temperature Geothermal Power

There are nearly 100 hot spring regions with high temperature hydrothermal systems (above 150℃) in China, which are mainly distributed in the tropics of Tibet, Yunnan and Taiwan. South Tibet, west Yunnan, west Sichuan and north Taiwan are the most promising areas for the development and utilization of high temperature geothermal energy resources in China.

In the 1970s, China utilized medium and low temperature geothermal resources to establish geothermal electricity generation test stations in Fengshun, Guangdong province, Huailai, Hebei province, Yichun, Jiangxi province, Xiangzhou, Guangxi province, Ningxiang, Hunan province, Zhaoyuan, Shandong province and Gaixian, Liaoning province. Due to the low temperature, the economic benefits are not optimistic, except for Guangdong Dengwu geothermal power station. It is still generating electricity, while the others have been discontinued.

In the late 1970s, China began to make use of high-temperature geothermal resources to generate electricity. Commercial geothermal power stations were built successively in Yangbajing, Langjiu and Naqu, Tibet, with a total installed capacity of 28.18 MW. Among them, the installed capacity of Yangbajing geothermal power station is 25.18MW.

5.1.2 Direct utilization of medium and low temperature geothermal energy

At present, the direct utilization of geothermal water in China (Duo et al., 2017) includes: 32.86% in heating, 32.48% in medical bathing and recreation, 2.57% in breeding, 18.02% in planting, 0.45% in industrial utilization, and 13.63% in others. In 2013, direct utilization of geothermal water accounted for 1.21×10^{17}J of annual energy use (see Fig. 15).

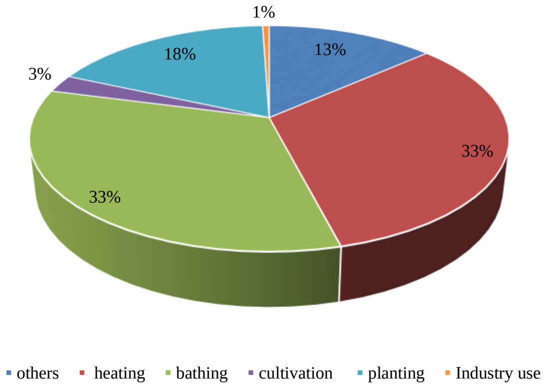

Figure 15: Direct utilization of medium and low temperature geothermal energy in China (Duoji, 2017)

Development and utilization of geothermal district heating in Xiongxian, Hebei province, meets the requirements of more than 90% of the county's heating. It is the first "smokeless city" in north China. To realize the sustainable development and protect the geothermal resources, the tail water after heating was reinjected at the same time. In February 2014, the Xiongxian model was planned to expand to 10-20 cities throughout China.

Xiongxian geothermal development is operated by Sinopec Star Co., Ltd, a state-owned enterprise that has been vigorously engaged in geothermal renewable energy industry in recent years. It has made geothermal heating of 22 million m^2 in more than 30 counties and cities nationwide, becoming the largest leading enterprise in the national geothermal industry. Another private enterprise, Sichuan Kangsheng geothermal development company, has made geothermal heating of 10 million square meters in more than 10 counties and cities across the country.

In some hot spring areas in China, especially in the north, the use of geothermal heating has also achieved good results. For example, Anbo hot spring in Liaoning province can save 223,800 USD per year by using geothermal heating.

The North China petroleum administration bureau has built three demonstration projects, using oil-free hot water heating in Renqiu and Liulu, realizing the aspiration of using oil-free hot water for production and life for many years. After thermal deoiling replaces liquid, the heating problem of the local oil field base was solved, saving millions of USD in fuel and electricity costs every year.

The growth and emission reduction of in northern China caused by geothermal heating are shown in Table 4 (Duoji et al., 2017).

Table 4. China's Geothermal Heating and increase in equivalent energy amount by energy-saving and emission-reduction (Duoji, 2017)

Year	1990	1999	2009	2014
Geothermal heating area (m^2)	1900000	8000000	30200000	60320000
Geothermal water supply for domestic hot water (households)	10000	200000	400000	600000
Substituting standard coal (1,000 tons)	38	233	449	1211
Carbon dioxide emission reduction (1,000 tons)	90	556	1072	2888

The cost of geothermal heating can be reduced by 30% compared with boiler heating under the same conditions. In 2000, geothermal heating accounted for 35% and geothermal tourism for 42% in the direct geothermal utilization, which are two main utilization ways in the world.

5.2 Utilization of Solar Energy and Wind Energy

The basic ways of solar energy utilization can be divided into four categories: photothermal utilization, photoelectric utilization, photochemical utilization and photobiological utilization. The first two kinds (i.e., photothermal utilization, photoelectric utilization) are more commonly used in China.

5.2.1 Solar Electricity generation

Large-scale utilization of solar energy is for electricity generation in the future. There are two main ways to make the use of solar power: (1) light - heat - electricity conversion. That is to use the heat generated by solar radiation to generate electricity. Generally, solar collectors are used to convert the heat energy absorbed into working medium steam, which drives the gas turbine to drive the generator to generate electricity. The former process is light-heat conversion, and the latter process is heat-electricity conversion, which is of high cost and low efficiency. (2) photoelectric conversion. Its basic principle is to use the photovoltaic effect to directly convert solar radiation energy into electricity, its basic devices are solar cells, such as the photovoltaic street lamp, the photovoltaic power station, and spacecraft power supply.

China is one of the countries rich in solar energy resources. The annual sunshine hours than 2000 hours in more than 2/3 of the country area, and the annual radiation amount is more than 5000MJ/m². According to statistical data analysis, the annual solar radiation received by China's land area is $3.3\times10^3\sim8.4\times10^3$MJ/m², equivalent to 2.4× 10.4 billion tons of standard coal reserves (Figs 16 and 17).

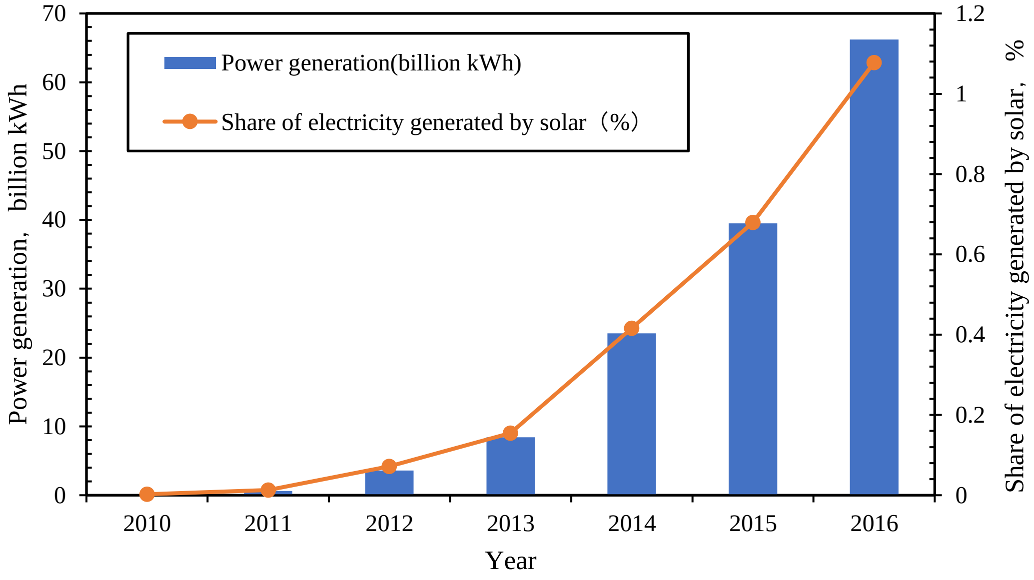

Figure 16: Changes in solar electricity generation from 2010 to 2016 and its share in China's annual total electricity generation (National Bureau of Statistics, 2000-2015; China Electric Power Enterprise Federation 2012-2015)

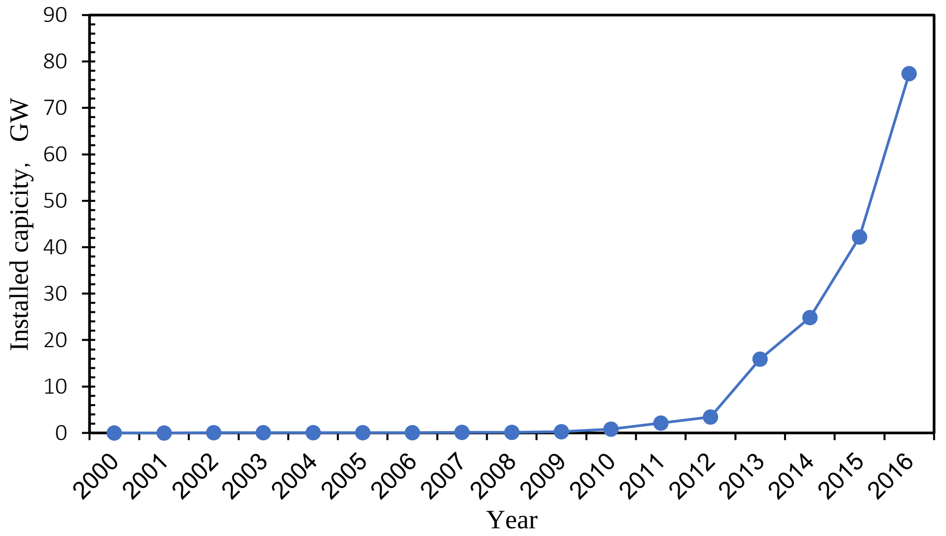

Figure 17: Cumulative installed solar energy capacity from 2000 to 2016 in China (CPVS, 2013)

Since 2010, China's solar power industry has made great progress. In terms of the total share of annual electricity generation, from almost 0 in 2010 to 1.08% in 2016, it has made a great breakthrough. Since 2012, the installed capacity has increased exponentially and reached 77420MW in 2016.

5.2.2 Solar Thermal Utilization Technology

Solar thermal energy (STE) is a form of energy and a technology for harnessing solar energy to generate thermal energy or electrical energy for use in industry, and in the residential and commercial sectors. Solar thermal panels are referred to by a number of different names such as Solar Water Heater, Solar Hot Water Panel, Solar Hot Water Collector, Solar Thermal Panel or Solar Thermal Collector. These terms all describe the same generic device. Solar water heaters work by absorbing sunlight and converting it into usable heat. A simple analogy is to think about a dark colored object sitting in the summer sun. Over time it can become very hot from absorbing the sunlight. Solar water heaters work in the same way by using materials that are specially designed to maximize the efficiency of that absorption. High quality absorber coatings are able to absorb up to 95% of the energy in sunlight throughout the full spectral range (PV only absorbs a portion of the spectrum). Standard coal conversed by solar thermal utilization technology and its proportion in the total energy consumption in 2010-2016 are shown in Fig.18.

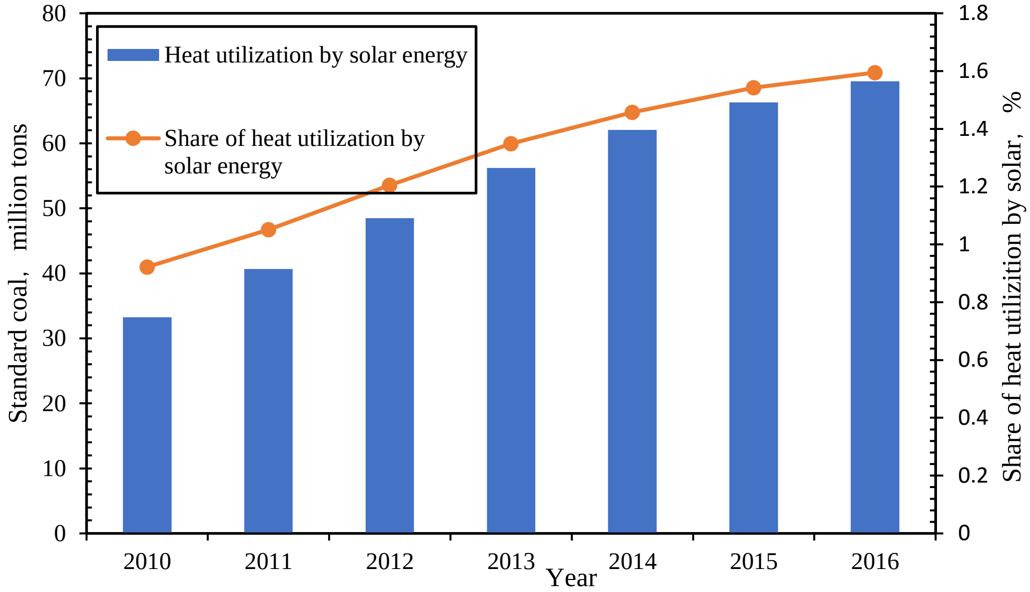

Figure 18: Standard coal conversed by solar thermal utilization technology and its proportion in the total energy consumption from 2010 to2016 in China(China Electric Power Enterprise Federation, 2012-2015; Zhang, 2016)

5.2.3 Wind Electricity generation

Wind power is a renewable energy with large resource potential and mature technology. In recent years, global fossil resources have become increasingly severe, and climate change has become increasingly obvious. Wind power has received more and more attention from all countries in the world, and achieved rapid development with the joint efforts of each country.

China is rich in wind energy resources that can be developed and utilized. The total reserves of wind energy resources at a height of 10m are 3.226 billion kW, among which the actual reserves of wind energy resources that can be developed and utilized are 253 million kW. Southeast coastal and nearby islands, northern Xinjiang, Inner Mongolia, northern Gansu and other areas are rich in wind energy resources. Driven by national policies and measures, China's wind power industry has shifted from extensive quantitative expansion to a new stage of steady and sustainable growth with improving quality and a reducing cost after ten years of development.

Since 2010, the country's wind power industry has seen rapid development. Its share in China’s annual total electricity generation increased from 0.74% to 3.92% from 2009 to 2016, with an eight-year continued steady growth. It reached 168739 MW in 2016 (Figs.19 and 20).

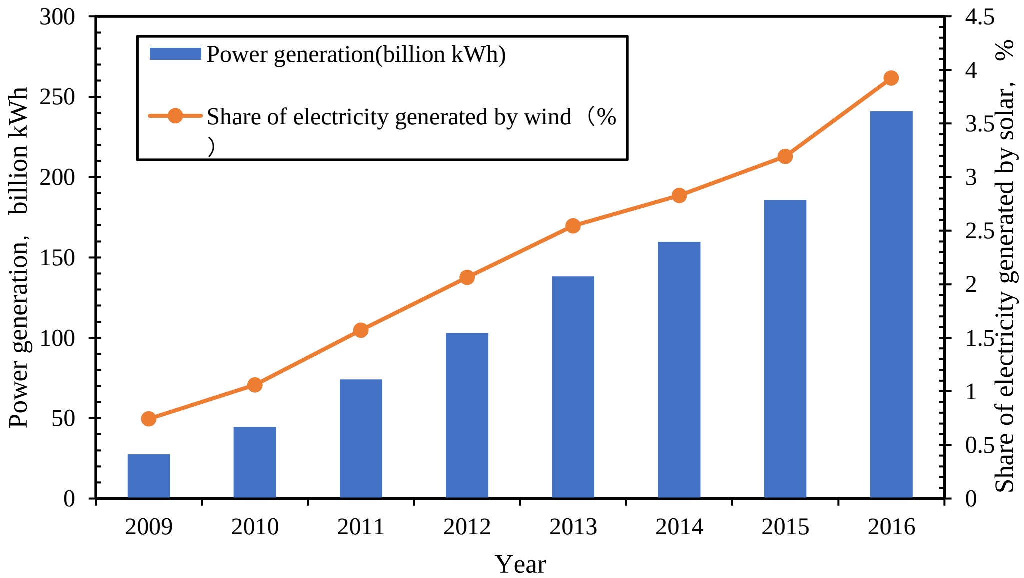

Figure 19: Change of wind energy electricity generation from 2009 to 2016 and its share in China’s annual total electricity generation (National Bureau of Statistics, 2016)

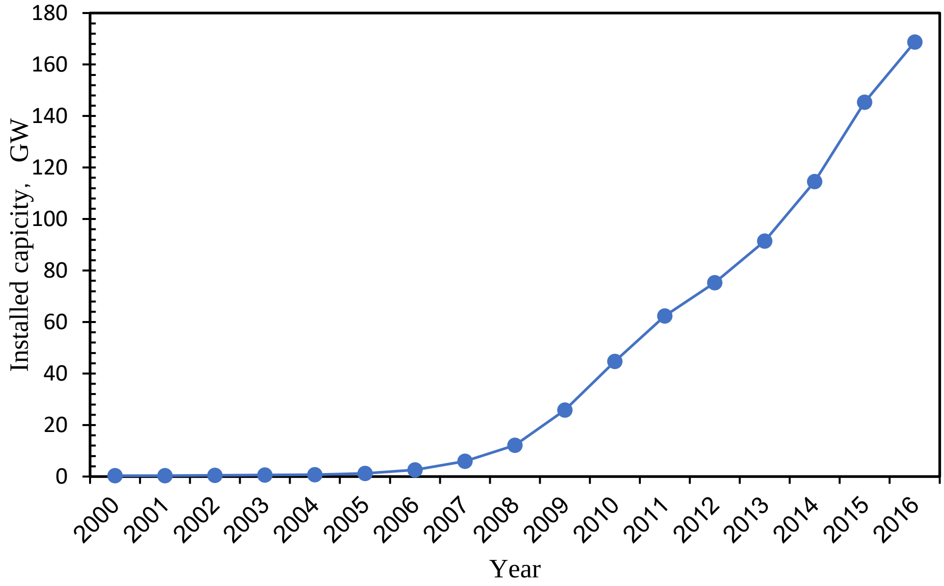

Figure 20: Cumulative wind energy generation from 2000 to 2016 in China (National Bureau of Statistics, 2016)

6. COST OF CLEAN ENERGY

6.1 Electricity generation Costs

Although geothermal power is a capital-intensive industry with a large initial investment and a long payback period, almost all costs are included in the initial investment. Once completed, the maintenance cost is very low, which highlights one of the advantages of geothermal power. Costs of electricity generation by various clean energy sources are shown in Table 5. operation and maintenance

Table 5. Costs of electricity generation by various clean energy sources (EIA, 2017)

Technology	Scale (MW)	Base overnight cost in 2016 (USD/kW)	Project Contingency Factor	Technological optimism Factor	Total overnight cost in 2016 (USD/kW)	Variable O&M (USD/kW)	Fixed O&M (USD/kW)
Biomass	50	3540	1.07	1	3790	5.49	110.34
Geothermal	50	2586	1.05	1	2715	0	117.95
Hydropower	500	2220	1.1	1	2442	2.66	14.93
Wind	100	1576	1.07	1	1686	0	46.71
Solar thermal	100	3908	1.07	1	4182	0	70.26
Photovoltaic	150	2169	1.05	1	2277	0	21.66

Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2017 listed that the initial investment and construction cost of geothermal power station in the early stage is 2,586 $/kW, while the production and maintenance cost in the later stage is 117.95$/kW. The total investment cost is significantly lower than that of biomass energy and solar energy. Compared with solar energy and hydroelectricity generation, geothermal electricity generation has the advantages of continuity, stability and little interference from external factors. If it can be well promoted and utilized, its development prospect will be bright.

6.2 Direct Utilization Cost of Geothermal Energy

Compared with other heating methods, the direct utilization cost of geothermal energy is relatively low. According to preliminary estimation, at the current technical level, the direct utilization cost of geothermal energy is equivalent to 0.03 - 0.06 USD/kWh, which is certainly competitive. At such low cost, the available amount of current geothermal resources in the country is equivalent to 1440 $\times10^4$kW of installed capacity and 864 × 10^8 kWh/a of electricity generation (see Table 6).

Table 6. Energy and Investment Costs of Direct Heating Using Renewable Energy (Liu, 2014)

Projects	Current energy costs / [dollars·(kW·h)$^{-1}$]	Estimated future energy costs / [dollars·(kW·h)$^{-1}$]	gross investment / (dollars·kW^{-1})
Biomass energy (including ethanol)	1～5	1～5	250～750
Geothermal energy	0.5～5	0.5～5	200～2000
Wind energy	5～13	3～10	1100～1700
Solar energy	3～20	2～10	500～1700

According to the calculation of existing practical projects, the initial investment of ground heat pump system is about 45- 72USD/m^2. Compared with the conventional single heating mode, the initial investment of the ground source heat pump system is higher, but it provides multiple functions of heating, air conditioning and daily hot water, while the traditional central heating is basically a single heating function. Using ground source heat pump system as air-conditioning system can greatly reduce its operating cost. When the ground source heat pump system is used for heating, the operation cost can be reduced by 25% - 50% compared with the traditional central air conditioning system according to different regions, climates, resources and environments.

7. POTENTIAL COST REDUCTION BY CLEAN ENERGY UTILIZATION

7.1 Air Pollution Control Cost

338 cities in China have all carried out monitoring of air quality since 2015. Monitoring results show that 73 cities have reached the standard of ambient air quality, accounting for 21.6%. Air quality in 265 cities were worse than the standard, accounting for 78.4%. Analysis of the proportion of standard days shows that the proportion of standard days in 338 cities ranges from 19.2% to 100%, with an average of 76.7%. The average number of days worse than the standard is 23.3%, including 15.9% of light pollution, 4.2% of moderate pollution, 2.5% of heavy pollution and 0.7% of sever pollution (Ministry of Environmental Protection of the People's Republic of China, 2014-2016).

Since 2000, the investment in China's air pollution control has shown an overall growth trend. From 2001 to 2007, the investment has increased year by year with an average annual growth rate of more than 25%. From 2008 to 2010, the overall scale of investment in industrial pollution control has decreased, and the investment in air pollution control has also decreased. In 2013, the total investment in China's air pollution control was about 4.38 billion USD, up 13.89% from last year. The total investment in air pollution control in 2014 was about 5.04 billion USD.

7.2 Health Loss Caused by Fossil Fuel Combustion

According to a report released by the World Bank, air pollution has become the fourth most significant factor in the early death of human beings. One in ten people died of air pollution, which caused hundreds of billions of dollars in economic losses to the world.

Meanwhile, according to the report, outdoor air pollution caused 2.9 million deaths in 2013. Considering indoor air pollution caused by cooking with fossil fuels such as coal, the death toll rose to 5.5 million. Cardiovascular diseases, lung cancer, chronic lung diseases and respiratory diseases caused by air pollution result in 6 times the number of deaths than malaria. About 87% of the world's population is more or less threatened by air pollution.

The loss of human life causes heavy economic losses. According to the calculation of the World Bank, the global economic losses from pollution-related deaths reached 225 billion US dollars in 2013 (about 0.224 trillion USD) (The World Bank,2016). If considering the economic losses of air pollution that destroys comfortable life, the total figure is as high as 5.11 trillion US dollars.

The economic loss caused by the pollution of PM2.5 particles in the air is 134.29 (159.5-1238.1) billion USD, accounting for 2.16% (1.72%-2.58%) of the Beijing- Tianjin-Hebei's GDP in 2013. In terms of the single economic loss of various health problems, the economic loss caused by chronic bronchitis accounts for 78.5% of the total loss (i.e., 15.72 billion USD). It was the largest loss, followed by premature death, causing a 17.8% of the total economic loss (i.e., 0.58 billion USD). The two health losses accounted for 96.3% of the total loss in 2013 (Lv et al., 2016).

Due to the different pollution statuses, population densities and economic development levels of these cities, the residents' health losses caused by atmospheric particulate pollution are different in different cities. Beijing, Tianjin, Shijiazhuang, Handan, Baoding and Tangshan are the cities with the most serious losses, with total losses exceeding 1.3 billion USD, namely 45.52, 29.19, 23.76, 19.55, 19.42, 1.56 billion USD respectively. Zhangjiakou and Chengde still have the lowest economic losses, which are 5.96 billion USD and 12.69 billion USD respectively. Judging from the ratio of losses to the GDP of each city, Xingtai suffered the greatest loss, accounting for 5.53% of the city's GDP in 2013, followed by Baoding and Hengshui, accounting for 4.86% and 4.33% (Lv et al., 2016).

In general, the air pollution caused by the burning of fossil fuels and the human health problems will cause certain losses to GDP, increase the cost of energy use, and, more importantly, seriously affect people's life happiness index. More attention should be paid to this issue.

8. CHINA'S CLEAN ENERGY TARGET AND FEASIBILITY OF SUBSTITUTING FOSSIL ENERGY

According to mygridgb.co.uk's data, as shown in Fig. 21 below, the share of Britain's energy consumption for electricity generation by source was coal at 43.2% (318 billion kilowatt hours), natural gas at 26.1%, nuclear power at 20.8%, wind power at 4%, large hydro at 1%, biomass at 7%, and imports at 4.3% in 2012. Five years later in 2017, electricity consumption has decreased (274TWh), the share of coal has dropped to 7.1%, while that of natural gas has soared to 41.6%, nuclear power to 22.9%, wind power to 11.6%, biomass to electricity to 5%, photovoltaic to 3.6%, hydro to 1.4%, imports to 6.8%. This fully shows that the ratio of electricity production from coal sources can drop very rapidly, and may even to zero.

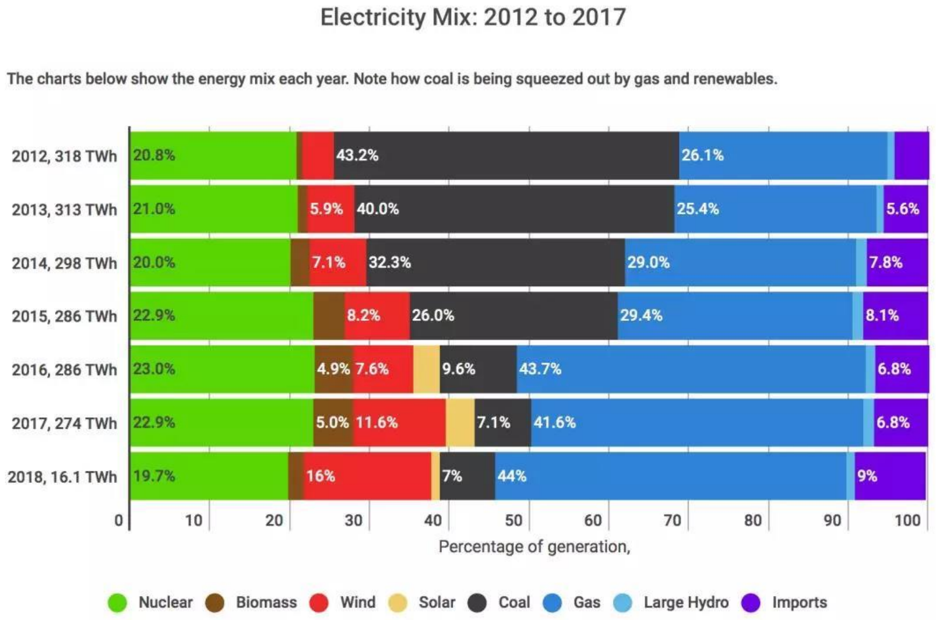

Figure 21: The electricity mix from2012 to2017 in Britain

By 2040, China's total installed capacity is expected to reach 31.45 million kilowatts. The installed capacity of coal electricity generation will reach 3.45 million kilowatts, accounting for 47% (Fig. 22) (APEC, 2016). The energy structure will be shifted away from current coal-fired power plants by two major drivers (i.e., environmental issues and drop in renewable energy cost). In the future, China's newly increased non-fossil fuel production capacity is estimated to be 9.7 million kilowatts, accounting for 74% of that in the entire APEC region. Obviously, China plays an important role in determining the energy structure as well as in the development and deployment of renewable energy of APEC. It is estimated that by 2040, clean energy sources including geothermal, solar and wind energy can substitute about 596mtce or 559bcm of natural gas (Fig. 23).

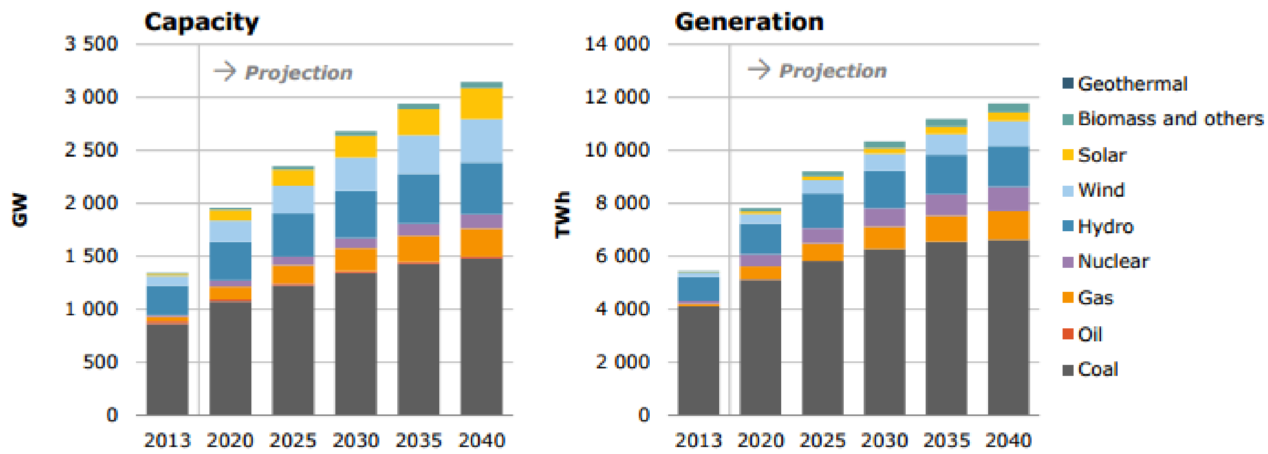

Figure 22: Forecast of different types of energy installed capacity and generation capacity in China from 2020 to 2040

Renewable energy sources include geothermal energy, solar energy and wind energy. The total amount of electricity generation will reach 3,241 kilowatt-hours by 2030 and 4,183 kilowatt-hours by 2040 in China (accounting for 36% of the total electricity generation).

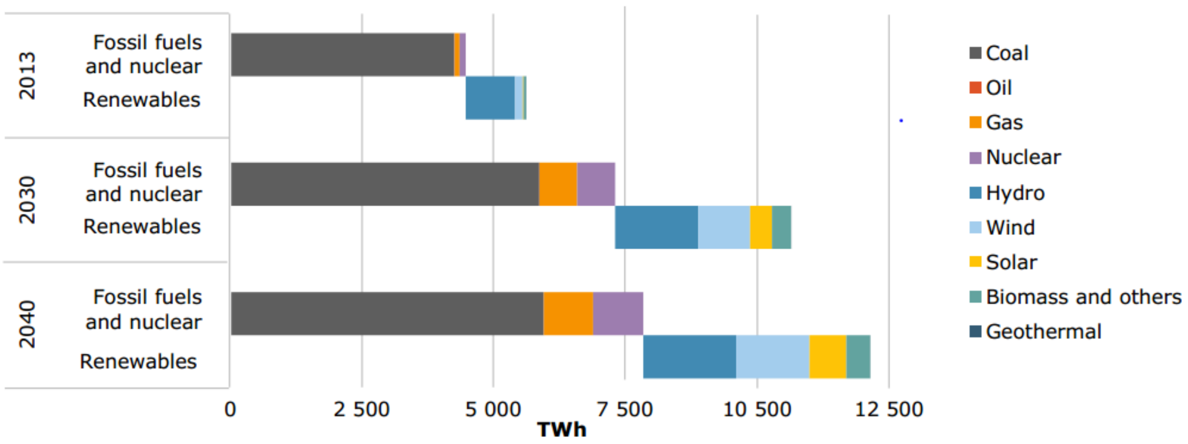

Figure 23: Composition of China's future electricity generation structure

At present, intense research has been done on clean energy sources in the world. Jacobson et al. (2011,2015) took the United States as the background and obtained the feasibility of the WWS new energy model.

Based on the current development speed of electricity generation by different energy sources, their installed capacity and electricity generation in the future are predicted, where C is the installed capacity in gigawatt, E is the electricity generation in gigawatt -year, S is coal consumption for geothermal heating in t/(gigawatt -year) and y is the year.

Forecast model of installed capacity generated by photovoltaic power;

$$C = 0.0092 \times e^{0.5339y} \quad (10)$$

Forecast model of photovoltaic electricity generation;

$$E=0.1515 \times e^{0.5252y} \quad (11)$$

Prediction model of wind energy generating capacity;

$$C = 3.4061 \times e^{0.2507y} \quad (12)$$

$$E = 24.371 \times e^{0.2964y} \quad (13)$$

Forecast model of installed capacity of geothermal energy electricity generation;

$$C = 0.000006 \times e^{0.5339y} \quad (14)$$

Forecast model of geothermal energy electricity generation;

$$E=6 \times 10^{-8} \times e^{0.7372y} \quad (15)$$

Prediction model of coal generating capacity

$$C = 355.44 \times e^{0.0576y} \quad (16)$$

Prediction model of coal electricity generation output;

$$E = 22704 \times e^{0.00577y} \quad (17)$$

Prediction model of coal consumption for geothermal heating

$$S = 0.0016e^{0.1965y} \quad (18)$$

The installed capacity of photovoltaic electricity generation, wind electricity generation and geothermal electricity generation is expected to surpass that of coal electricity generation in 2040. The installed capacity of solar electricity generation and wind electricity generation is expected to exceed that of coal in 2024 and in 2027 respectively. In recent years, China has gradually increased its efforts to invest in geothermal energy development. However, due to its late start, the installed capacity of geothermal electricity generation will exceed that of coal in 2042 in terms of the current development speed of solar energy (Fig. 24). In the future, the electricity generation scale by solar and wind energy will still be larger than geothermal energy. Note that the actual reported data are marked in solid circles and the curve represents the estimated values in Figs. 24-30.

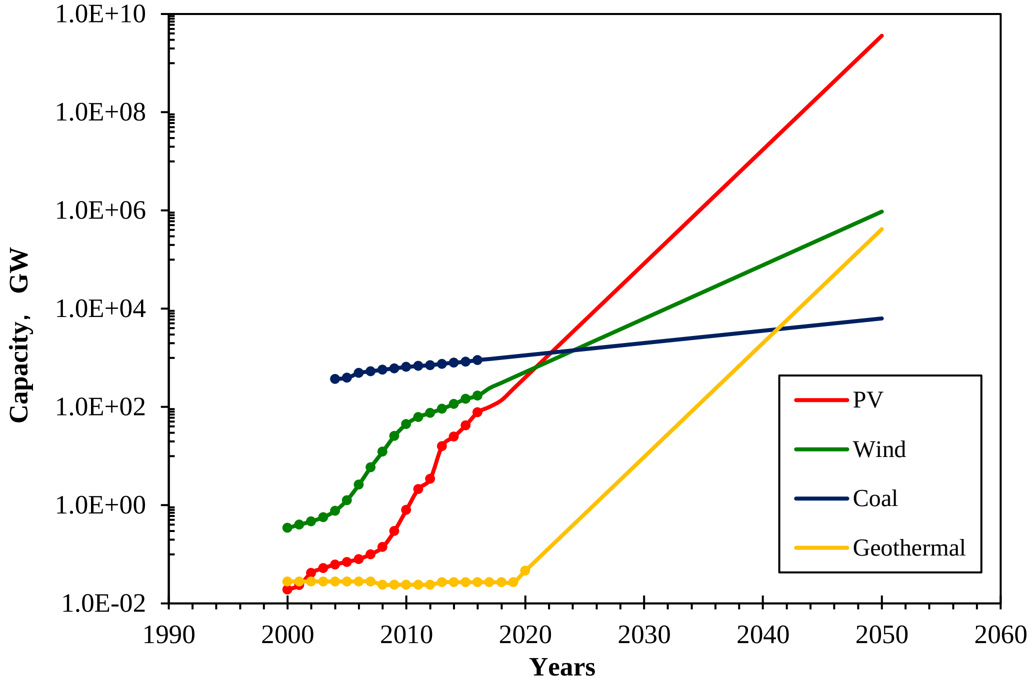

Figure 24: Installed capacity of different types of energy sources in China in the future

Based on the current development speed, electricity generation by solar, wind, and geothermal is expected to surpass that by coal in 2026, in 2030 and in the second half of the 21st century, respectively (Fig. 25).

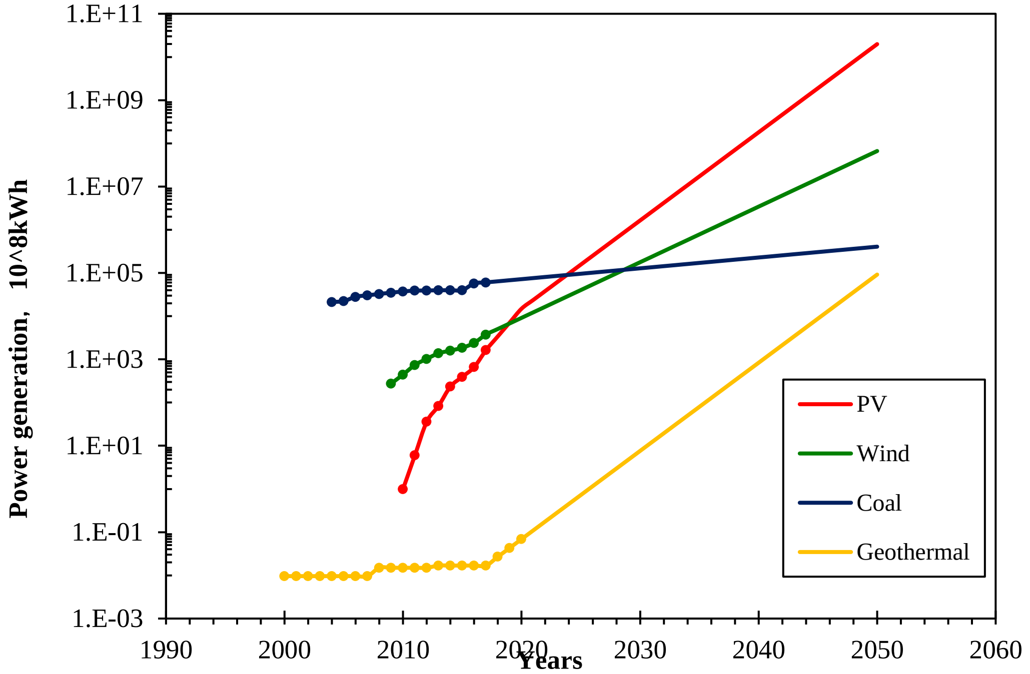

Figure 25: Energy generation by different types of energy in China

With the rapid development of clean energy in China, the total installed capacity and total electricity generation of clean energy (wind energy, solar energy and geothermal energy) can exceed those of coal electricity generation around 2025 (Figs. 26 and 27). According to the forecast results of China's future electricity demand, China's electricity demand will reach 117.50 billion kilowatt-hours by 2030 (Shan et al., 2015). Based on their predictions of China's electricity demand, the total electricity demand in China can be completely provided by clean energy (wind energy, solar energy and geothermal energy) around 2024 (Fig. 28).

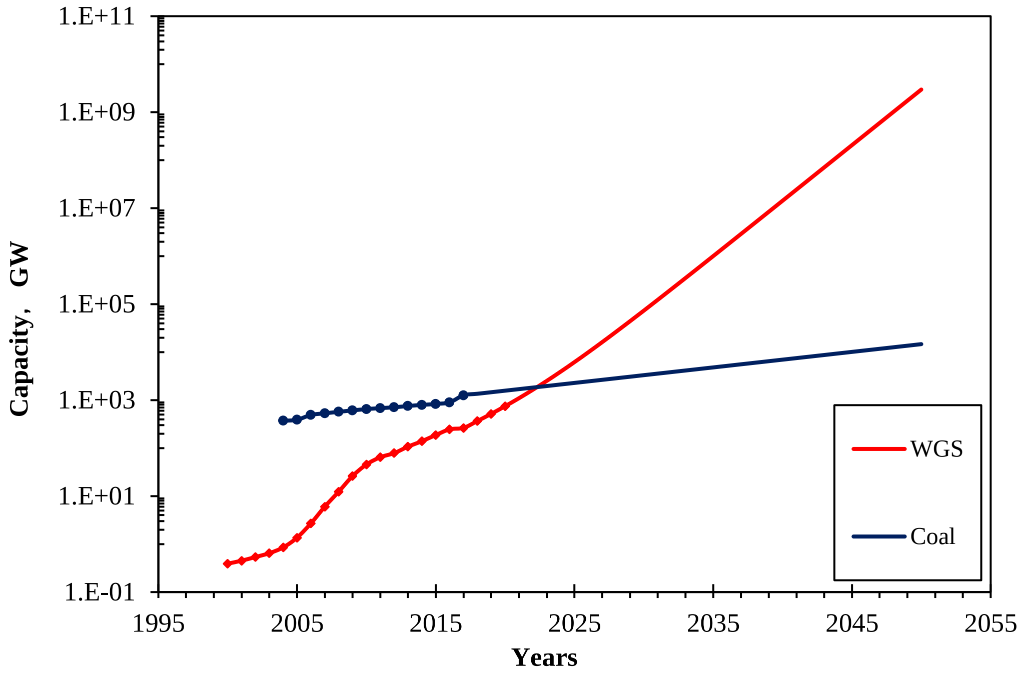

Figure 26: Comparison of China's future installed clean energy generation capacity and Installed coal generation Capacity

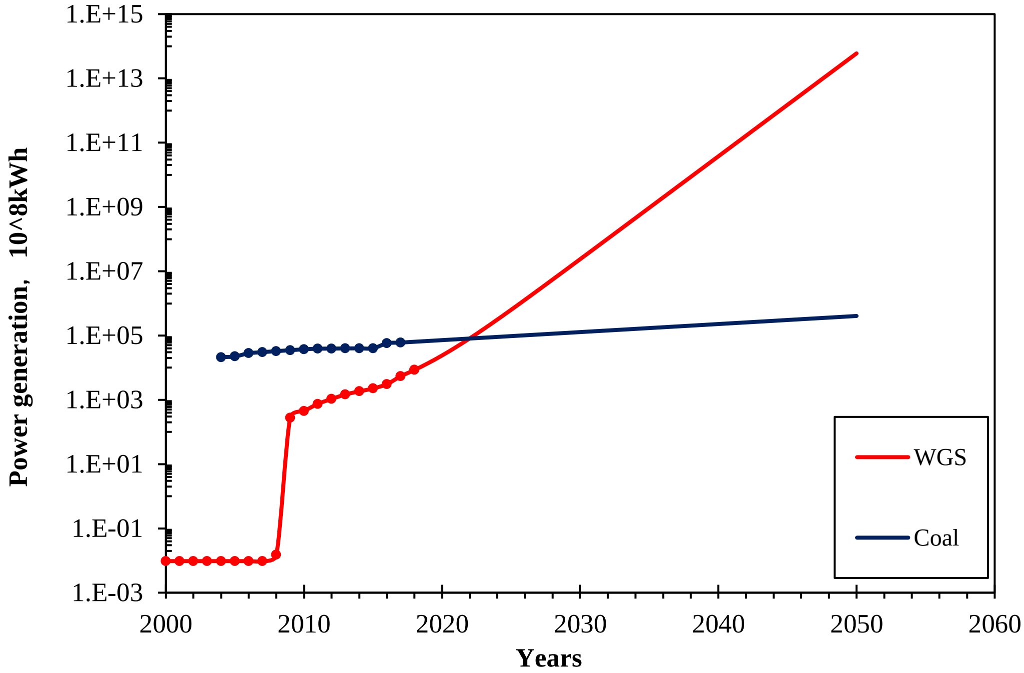

Figure 27: Comparison of future electricity generation by clean energy and coal in China

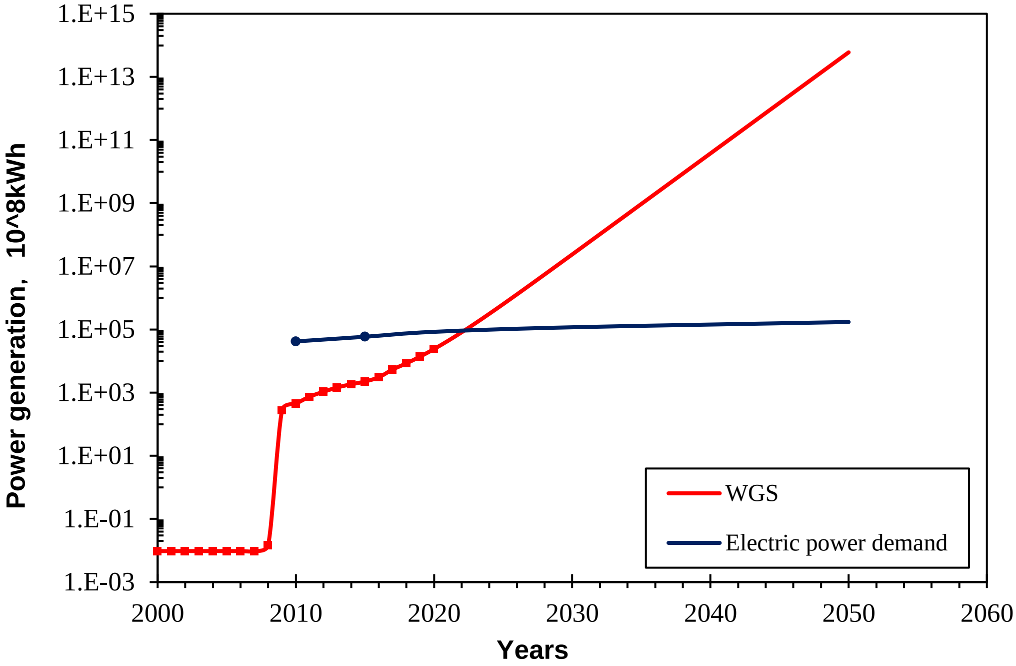

Figure 28: China's future demand for clean energy and electricity

The utilization of geothermal energy is expected to be rapidly developed in the second half of the 21st century. From the perspective of quantity, according to the forecast of China's electricity demand by Shan et al. (2015) and the forecast of China's total energy consumption by Shen et al. (2015), China's non-electricity energy demand can be completely supplied by geothermal energy in the second half of the 20th century with the current development trend(Fig. 29).

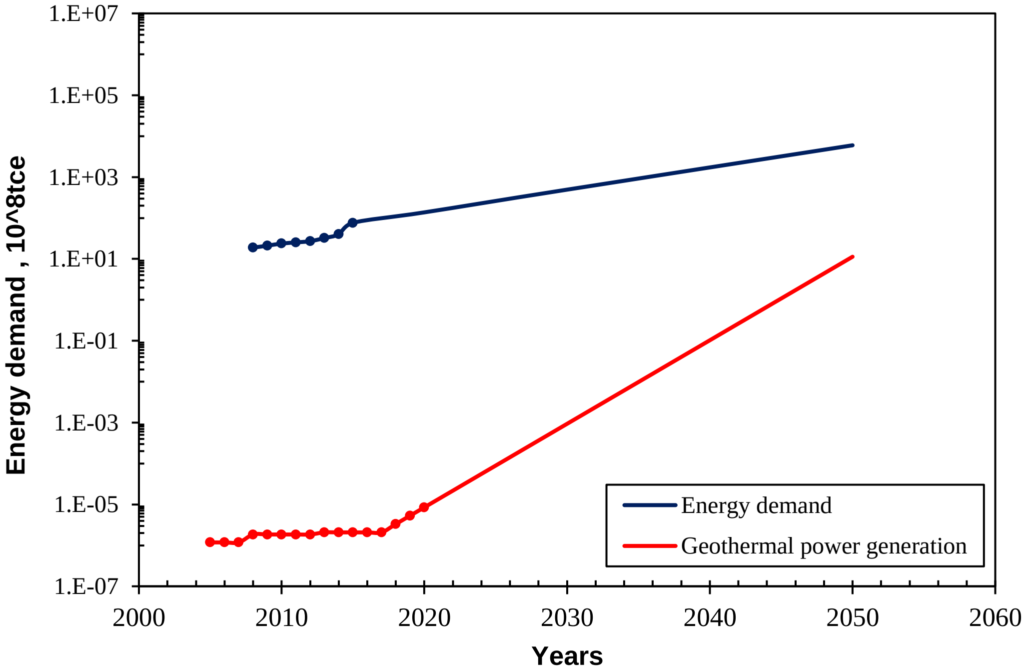

Figure 29: Geothermal energy utilization and non-electric energy demand in China

To clearly illustrate the great difference among different energy demands, a semi-log coordination was used. As can be seen from the prediction results (Fig. 30), it will still take quite a long time for China to depend entirely on geothermal energy (including geothermal electricity generation and geothermal heating). Geothermal electricity generation is developing more rapidly than geothermal heating. However, geothermal heating starts early and has a high base, whose utilization will be higher than that of geothermal electricity generation in the near future. Clean energy supply is expected to be realized with the combination of solar electricity generation, wind electricity generation, geothermal electricity generation and geothermal heating in 2026 (Fig. 30). Note that the utilization of geothermal energy is still relatively small compared with that of wind energy.

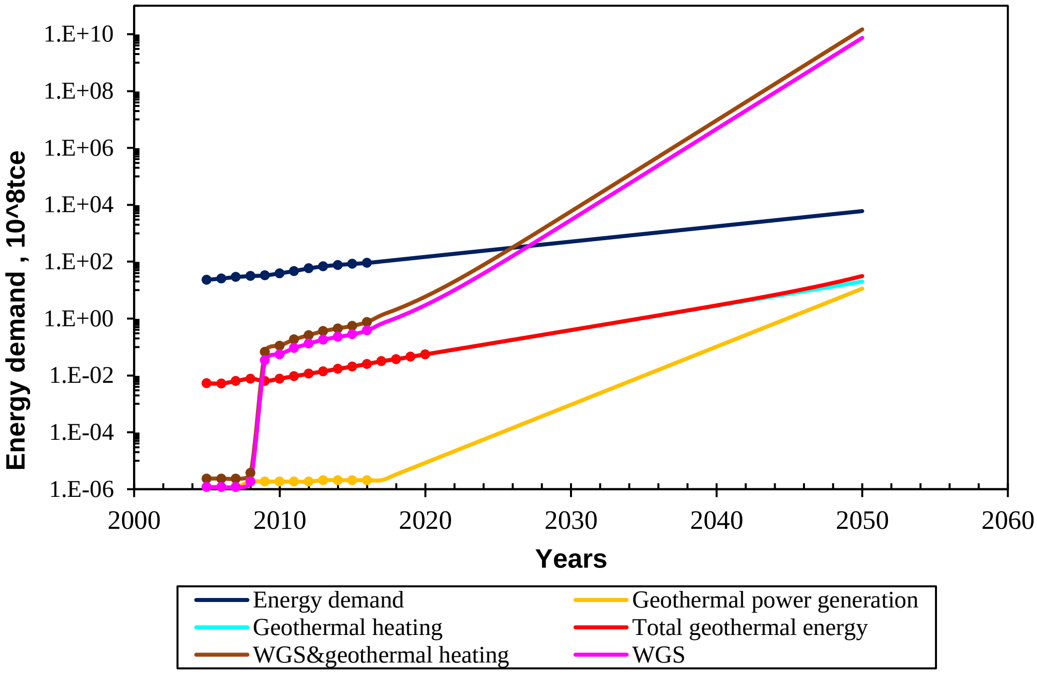

Figure 30: Energy utilization and total energy demand in China

9. CONCLUSIONS

(1) There is a large amount of geothermal resources in China. The geothermal resources of dry hot rocks with a depth of 3.0-10.0 kilometers in China are about 2.5×10^{25} J, which is equivalent to 860×10^{8} million tons of standard coal. If only 2% of the geothermal energy is explored and utilized, the figure is equivalent to 4,000 times of China's total energy consumption or 6,282 times of China's total coal consumption in 2015.

(2) The annual average solar irradiance in China is about 1478.2 kW h/m^2. The annual total energy is about 5.11×10^{22}J, which is 404 times of China's total annual energy consumption in 2015 and 635 times of China's total coal consumption in 2015.

(3) The exploitable amount of wind energy resources in China is 253 million kilowatts. The annual exploitable total energy is about 7.59×10^{18}J , which is equivalent to 0.06 times of China's total annual energy consumption or 0.1 times of China's total coal consumption in 2015.

(4) It is feasible to provide all China's energy needs with available resources of geothermal, wind and solar energy (GWS).

(5) In terms of money spent on exploration and well drilling, the cost of geothermal electricity generation will probably exceed 0.15USD/kWh. However, considering the levelized cost, except for the relatively high cost of solar electricity generation of 262.21 USD (MW h)$^{-1}$, the geothermal electricity generation of 78.91 USD (MW h)$^{-1}$ and wind electricity generation of 65.47 USD (MW h)$^{-1}$ are lowest in renewable resources, making them promising for development in the future. On the other hand, the effective energy cost may be less than that of fossil fuels after considering the issues of air pollution control and human health loss.

(6) According to relevant electricity generation data of geothermal, solar, and wind, as well as their respective proportion in China from 2010 through today, it can be seen that the current energy demand relies heavily on fossil energy, while the GWS energy only accounts for a small proportion. Efforts should be made for the widespread development and utilization of renewable resources, which requires continued support from the government and society.

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