Trends and Status of Renewable Energy Power Generation in China

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Abstract. Energy is an essential and critical material foundation for economic development, contributing to the rapid growth of the economy and playing an integral role. In today's world, the revolution of energy resources is an imperative task. This is due to the continuous decline in the reserves of traditional energy resources worldwide, such as the urgent need for reserves of fossil energy resources, and the worsening global greenhouse effect and excessive greenhouse gas emissions. Therefore, energy resources need to undergo a restructuring, with the key focus on diversification, efficiency, and cleanliness. Currently, several countries, including China, are either planning or actively developing a low-carbon or even zero-carbon energy system. Furthermore, they are accelerating the revolution of energy consumption and production.China is becoming an essential contributor and guide to the transformation of the world's energy revolution, alongside the realization and improvement of this new energy system.Given this context, the inadequacies in China's ability to support renewable energy are identified by examining China's development objectives. The discussion covers the quantity of renewable power produced, the extent of its consumption and restrictions placed upon it. The present state of renewable energy development in China is viewed through a market-oriented approach. Additionally, the current state and future Development plans of renewable energy generation in China are assessed by considering the legal framework and policy instruments involved.

Keywords: renewable energy generation, generating capacity, photovoltaic, wind power.

1. Introduction

1.1. Background

The gross generating capacity of wind and photovoltaic power has been rapidly increasing worldwide, with a growth rate that changed from 0.2% in 2000 to 4.7% in 2022. In 2014, the total capacity of new energy power generation reached 892.1TWh, with 706.2TWh generated by wind power and 185.9TWh generated by photovoltaic (PV) power. In 2020, the share of wind power in electricity consumption will be 13.8% in China, 16.3 % in the United States and 22.2% on average in the European Union (Table 1).China currently ranks second in the entire world in terms of renewable energy generation.Despite being ranked second, China generates a significantly larger amount of wind and photovoltaic power than the United States.

Table 1. Comparison of the wind and photovoltaic power generation in the three countries in 2022.

	photovoltaic power (TWh)	Wind power (TWh)	Generation capacity (TWh)	Electricity consumption (TWh)	Wind and photovoltaic energy as a proportion of generation	Wind and photovoltaic energy as a proportion of consumption
China	4272.7	7626.7	884871.1	86372	13.4%	13.8%
United States	2041.1	4348.12	43016.47	39090.53	14.9%	16.3%
EU	203.15	419.59	2795.47	2809.41	22.3%	22.2%

In recent years, China's renewable energy sector has experienced significant growth.CINNO Research's statistics show that the investment in China's new energy projects, including Taiwan, reached 5.2 trillion RMB from January to June 2023. The emerging technology industry regards the new energy sector as a key area for investment.

China's renewable energy sector is progressing well in achieving the dual-carbon target, with stable growth in power generation capacity for installed capacity and electricity produced[1]. Renewable energy is increasingly dominating as China's main source of new installed power generation capacity. As a result, its role in ensuring energy supply and promoting clean, low carbon transformation is becoming more prominent. The new energy industry is anticipated to sustain steady growth during the next 3-5 years, and become a key growth engine for China's future economic development[2].

China's National Energy Administration (NEA) reported on 19th July 2023 that 109 million kilowatts of renewable energy had been newly installed in China from January to June, representing 77% of the country's new installations. Out of which, 78.42 million kilowatts added were from photovoltaic power, 22.99 million kilowatts from wind power, 5.36 million kilowatts from hydropower, and 1.76 million kilowatts from biomass power. Regarding photovoltaic power, there were 37.46 million kilowatts of centralized new installation, 40.963 million kilowatts of distributed new installation, and 21.522 million kilowatts of household PV new installation during the first six months. As of the end of June 2023, China has a cumulative installed capacity of 470 million kilowatts of PV[3].

At present, the domestic new energy industry capacity scale continues to expand, with the influx of many capital and cross-border players, the market competition is becoming increasingly fierce, which will promote further technological innovation and market segmentation; and from the international market, the world's countries and regions are also actively exploring the energy transition in the active development of the domestic enterprises to seek overseas orders at the same time, the overseas enterprises are also vigorously supporting the local new energy manufacturing industry, and through the setting of trade barriers and other ways of seeking energy independence, which will also give China's new energy globalization and development has brought certain challenges.

1.2. Developments of New Energy Power Generation in China

1.2.1 Photovoltaic power

According to 2016 statistics, China's photovoltaic power generation in 2016 totaled more than $315.3 billion. Since then, in 2017, the amount exceeded 350 billion yuan. In addition, in the scale of photovoltaic power generation to analysis, only in 2017, China has a total of 5306 kilowatts of new installations, and 130 million million cumulative power generation. In addition to this, the coverage of photovoltaic power generation in China has been increasing year by year, and photovoltaic power producers are able to produce 1182 million hours of electricity per year as well as a 78.5% increase. It can be found that China's photovoltaic energy industry is developing rapidly and has great potential for development. However, there are still some problems constraining the development of photovoltaic power generation in China.

The first issue is the imperfection of technical standards. China's entry into the field of photovoltaic power generation technology came relatively late[4]. The current grid-connected power stations are still in an experimental grid state, which is prone to the generation of harmonics and imbalance in three-phase current. Additionally, output power uncertainty can lead to voltage fluctuations in the grid, causing flicker. Therefore, it is necessary to adhere to certain grid-connected technology standards. The recommended national standards for the "photovoltaic system grid-connected technical requirements" and the national standards for the "photovoltaic power station access to the power system technical provisions" were both released in 2005 but have since become outdated. In 2009, the China’s State Grid Corporation issued the "photovoltaic power station access to the grid technical provisions" for trial implementation. However, the standard for photovoltaic power station

classification is too broad and lacks targeted refinement in the provisions. A kilowatt-level small-scale rooftop grid-connected photovoltaic power generation system may be an important development direction for China's distributed power generation in the future. However, the current standard lacks relevant provisions on access to 220v residential voltage technical requirements.

The second issue is the lack of harmonization of market management practices[4].Foreign prices for photovoltaic power generation equipment are significantly higher than those charged domestically. However, in an effort to reduce costs, some bidding project owners tend to buy low-priced equipment, resulting in the issue of substandard products in the Chinese market. Despite China's continuous development in science and technology, the country still lacks a comprehensive testing and certification management approach for photovoltaic products, despite having the means to test products and connect them to the grid.

1.2.2 Wind power

China, as a large country with significant wind energy potential, has experienced rapid growth in wind power generation in recent years due to the increased support from its government and society. The wind power industry in China plays a vital role in adjusting the country's energy consumption structure, developing a low-carbon economy, and serving as a crucial foundation for low-carbon industries[5]. For instance, the 13th Five-Year Plan for wind power development highlights the need to optimize the layout of wind power generation, strengthen its development in China's central and southeastern regions, and enhance the construction of its offshore wind power generation infrastructure. Furthermore, with the advancement of technology, the cost advantage of wind power generation will become more evident in the future. Therefore, China's new energy industry has broad prospects for development, and wind power generation is expected to be China's primary source of clean and renewable energy.

From the analysis of the current situation, at present, low wind speed and large capacity are still the main way of generating electricity for China's wind power industry[5]. In addition, with the maturity of China's wind power generation technology, wind power enterprises and industries have increased the number of large-capacity generator sets[6]. For example, since 2011, large-capacity wind turbines have been added to the power generation layout planning of the wind energy industry, for example, in 2011, the number of large-capacity generator sets of 2500-3000kW accounted for less than 4% of the total number of generator sets of more than 3,000kW accounted for less than 3% of the total number of generator sets of more than 3,000kW. Since then, according to 2017 statistics, the number of large capacity generator sets of 2,500-3,000kW accounted for more than 14%, while the total number of generator sets of more than 3,000 kW reached 8%. Finally, in terms of wind turbine production, China has become the world's largest wind turbine production base. By the end of 2020, 90% of the world's complete wind turbines will be supplied by the top 15 manufacturers, and it is worth noting that eight of them are Chinese companies.

1.2.3 Other renewable energy power generation

Hydropower is the largest source of clean energy in China and plays a key role in the new energy industry[7]. According to the "China Low Carbon Development Report", the growth rate of China's hydropower generation reached 6.2 per cent and 6.5 per cent in 2016 and 2017, respectively, during the "12th Five-Year Plan" period. Since then, according to the "13th Five-Year Plan for Hydropower" issued by the National Energy Administration, it is planned that China will achieve 5.6TWh of hydropower generation during the 13th Five-Year Plan period to meet the energy needs of different regions of China, which, when converted into standard coal, can reduce the combustion of about 1.68 billion tonnes of standard coal and reduce carbon emissions by more than 3.5 billion tonnes, thus improving environmental protection. Environmental protection.

The maturity of the technology for the development and application of nuclear power in China has led to the rapid development of nuclear power in China, which is already leading the world in the scale of nuclear power construction[7]. For example, in 2017 alone, China's total nuclear power generation increased by 17% year on year, exceeding the previous average growth rate of 15%, and

all nuclear power generation accounted for about 11% of total power generation. From the perspective of future development trend, China's nuclear power generation still has more room for development and is an effective means to promote China's green development and combat environmental pollution. At the same time, the safety of nuclear power generation is also an important factor limiting the scale of nuclear power generation in China.From a practical point of view, the increase in the total installed capacity of the nuclear power industry has further promoted the development of China's new energy industry. However, from an overall perspective, the capacity utilization rate of the generating units in China's nuclear power industry is not high. According to statistics, the hourly capacity utilization rate of the nuclear power industry started to decline in 2013. In 2014, the capacity utilization rate of the country's nuclear power industry was only 83.3%. And in 2016, it dropped to 79.55 %. This is mainly due to the fact that power generation in the country is seasonal, resulting in ineffective utilization of the nuclear power industry's generating units in the early stages. In addition, due to safety issues in the nuclear power industry, it is necessary to maintain the nuclear power units at regular intervals, which results in a lower actual utilization rate of the nuclear power units. Under these circumstances, China has made appropriate policy adjustments, so that by 2020, the power generation of China's nuclear power industry will reach 8,937.2 hours of utilization, with an average utilization rate of 85.32%.

2. Status quo

2.1. Market situation

2.1.1 Power generation

According to statistics published by the National Bureau of Statistics of the People's Republic of China (NBSP), the Electric Power Industry Information Agency (EPIIA), the State Grid Corporation (SGC) and the China Southern Power Grid Company Limited (CSG) (2020), China's installed renewable energy generation capacity reached 9.34TWh by the end of 2020, and the amount of electricity generated by renewable energy was as high as 221,48TWh[8]. In recent years, China's renewable energy has developed rapidly (Figure 4). The installed capacity of China's nuclear power operation has continued to grow, and nuclear power generation has continued to increase.In 2020, China's nuclear power generation capacity of 1,200TWh, an increase of 5.02% over 2019(Figure 1).During the "12th Five-Year Plan" period (2010-2015), China's wind power grid-connected installed capacity grew at an average annual rate of 34.6%, ranking first in the world for four consecutive years(Figure 2). In 2015, China's grid-connected photovoltaic power capacity was 165 times higher than in 2010". During the "13th Five-Year Plan" period (2016-2020), China's photovoltaic power generation reached 729.1TWh, an increase of 78.79% compared to the "12th Five-Year Plan"(Figure 3). The development target for wind power in the "14th Five-Year Plan" period (2021-2025) is about 3.3TWh, and the power generation capacity of wind and photovoltaic power will double on the basis of 2020; more than 80% of the new electricity consumption of the whole society will come from renewable energy.Table 2 and Table 3 demonstrates the achievement of non-hydro renewable energy power generation targets in China's 13th Five-Year Plan by province.

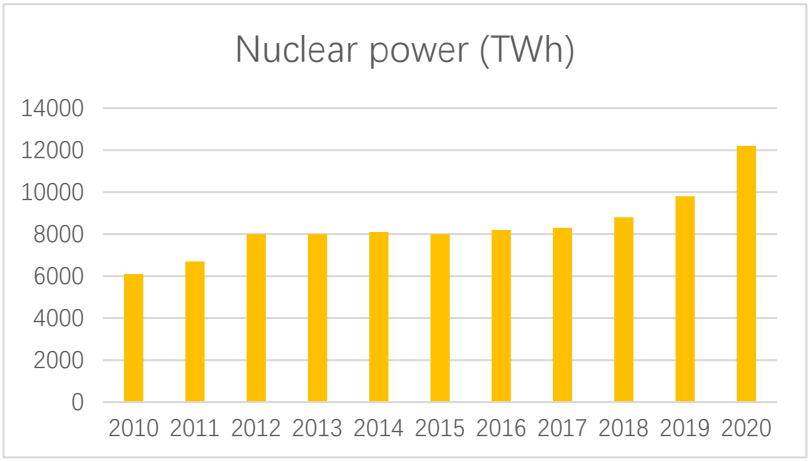


Fig. 1 Generation capacity of nuclear power

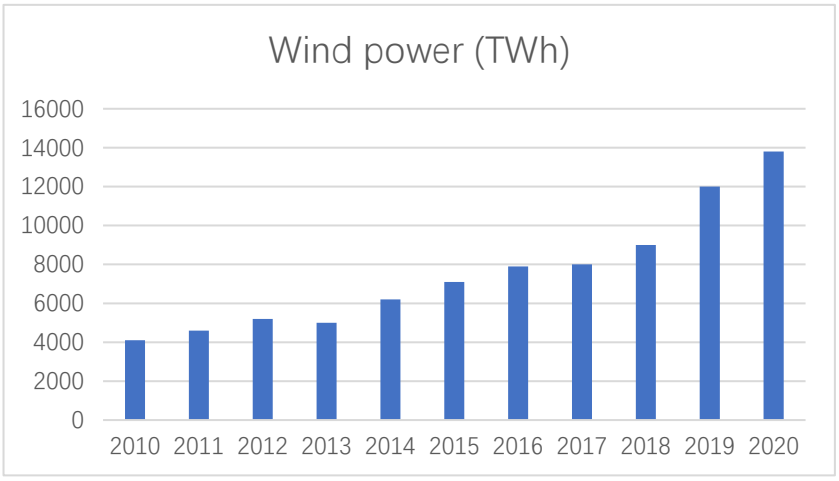


Fig. 2 Generation capacity of wind power

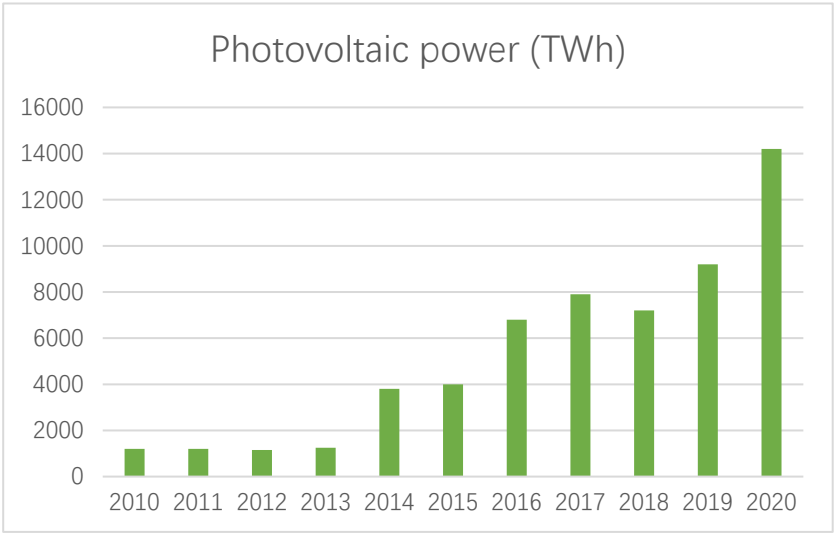


Fig. 3 Generation capacity of photovoltaic power

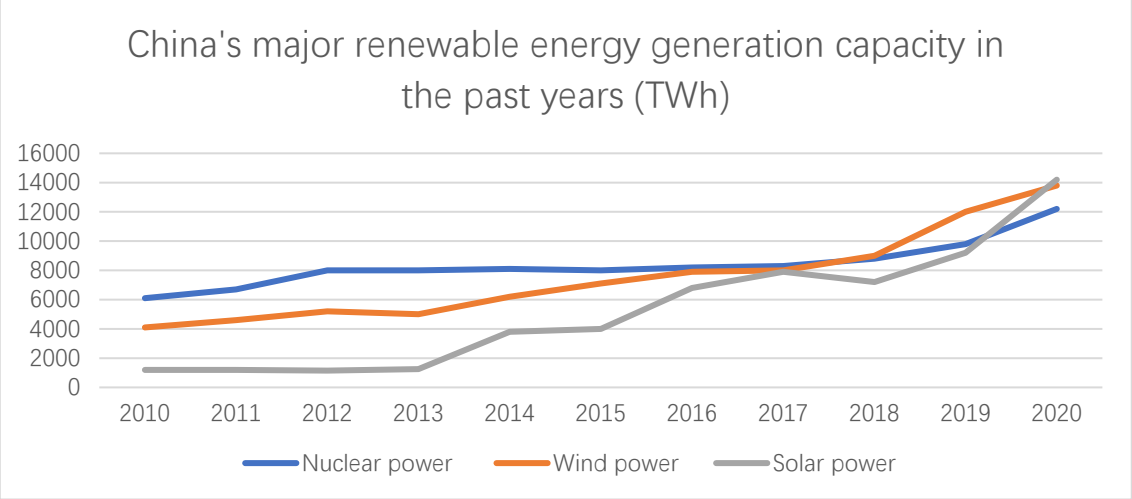


Fig. 4 China's major renewable energy generation capacity in the past years (TWh)

Table 2. Achievement rate of China's provincial wind power generation targets

kW/h	2019	2015	2020	Completion rate
Beijing	19	20	65	-2.2%
Tianjin	60	32.3	116	33.1%
Hebei	1639	1022	2080	58.3%
Shanxi	1251	669	1600	62.5%
Inner Mongolia	3007	2425	4500	28.0%
Liaoning	832	639	900	73.9%
Jilin	557	444.4	875	26.1%
Heilongjiang	611	503	900	27.2%
Shanghai	81	61	140	25.3%
Jiangsu	1041	412	1000	107.0%
Zhejiang	160	104	300	28.6%
Anhui	274	135	260	111.2%
Fujian	376	176	500	61.7%
Jiangxi	286	102	402	61.3%
Shandong	1354	721.5	14000	93.2%
Henan	794	120	600	140.4%
Hubei	405	135	500	74.0%
Hunan	427	165	600	60.2%
Guangdong	443	246	800	35.6%
Guangxi	287	40.85	340.85	82.1%
Hainan	29	30.9	65	-5.6%
Chongqin	64	23	50	151.9%
Sichuan	324	73.4	600	47.6%
Guizhou	457	323	600	48.4%
Yunnan	863	614	1200	42.5%
Tibet	1	1	20	0.0%
Shaanxi	532	114	550	95.9%
Gansu	1297	1252	1400	30.4%
Qinghai	462	47	710	62.6%
Ningxia	1116	822	1100	105.8%
Xinjiang	1956	1691	1800	243.1%

Table 3 Achievement rate of China's provincial photovoltaic power generation targets

kW/h	2019	2015	2020	Completion rate
Beijing	51	16.5	116.5	34.5%
Tianjin	143	12.5	80	193.3%
Hebei	1474	280	1500	97.9%
Shanxi	1088	113	1200	89.7%
Inner Mongolia	1081	469	1500	59.4%
Liaoning	343	16	250	139.7%
Jilin	274	6.7	393.3	69.1%
Heilongjiang	274	6.7	600	45.5%
Shanghai	109	29	80	156.9%
Jiangsu	1486	422	1000	184.1%
Zhejiang	1339	220	800	192.9%
Anhui	1254	130	800	167.8%
Fujian	160	15	90	205.3%
Jiangxi	630	102	402	176.0%
Shandong	1619	132.7	1000	171.4%
Henan	1054	50	500	223.1%
Hubei	621	49	350	190.0%
Hunan	344	38	200	188.9%
Guangdong	610	85	600	101.9%
Guangxi	135	9.65	100	138.7%
Hainan	140	27.34	125	115.4%
Chongqin	65	0	Unknown	
Sichuan	188	36.4	250	71.0%
Guizhou	510	3	200	257.4%
Yunnan	375	117	310	133.7%
Tibet	110	17	100	112.0%
Shaanxi	939	72	700	138.1%
Gansu	908	610	1100	60.8%
Qinghai	1101	564	2400	29.2%
Ningxia	918	309	1000	88.1%
Xinjiang	1080	529	Unknown	

The wind power generation of the country is on the verge of achieving the total target of the 13th Five-Year Plan in 2019, while the self-imposed wind power development targets of provinces show an average completion rate of only 61%.(Table 2)

Despite the absence of PV targets for Xinjiang and Chongqing, the combined development goals for other provinces were 61% higher than those for the entire country. The national development target was exceeded in 2019 by 86%. The majority of provinces have achieved their own regional targets, with only Qinghai, Beijing, and Heilongjiang failing to reach their actual targets(Table 3).

2.2. Issues of renewable energy generation

2.2.1 Wind power

1.Voltage deviation is a common issue in wind power generation systems. The theoretical deviation and the actual deviation can differ significantly, leading to insufficient level of power transmission [5]. Wind power grids may use grid-connected capacitors to regulate voltage. However, capacitors may also worsen the power resource transmission when they experience switching issues. This can seriously impact the overall transmission level of power resources. Since the output and composite effect of wind power units can change significantly during actual operation, pressure

deviation and fluctuation can introduce errors that degrade the efficiency of the power grid. Wind variations are the primary cause of voltage deviation and voltage fluctuation. Wind speed changes during wind power variation, leading to more visible voltage fluctuations during wind turbine start up and shutdown operations. In the operation process of the wind power generation power supply system, voltage deviation is a common problem. The theoretical deviation often differs significantly from the actual deviation and cannot guarantee the power transmission level fundamentally.

2.Although the wind power generation grid connection is in operation.Voltage regulation can be carried out with the help of grid-connected capacitor device compensation, the capacitor may get stuck in the switching process, leading to a significant adverse impact on the overall transmission level of electrical power resources. During actual operation, the output and compounding effect of the generating unit is always subject to change. Under the influence of pressure deviation and pressure fluctuation, the error during the operation of the power grid will also increase significantly. Wind variations mainly cause voltage deviation and voltage fluctuation. During changes in wind power, the wind speed varies, and voltage fluctuation is more noticeable during the start-up and shutdown of the wind turbine.

2.2.2 Photovoltaic power

1. The system voltage of the utility grid is impacted. Various natural factors such as sunshine, weather, season, and temperature cause unstable output power in photovoltaic power generation. When the output power varies greatly, it leads to voltage fluctuation and flicker on the system access point.

2. It generates harmonics. The photovoltaic module in the photovoltaic power generation system converts photovoltaic energy into DC energy, which is then converted into AC energy using an inverter[9]. During this conversion process, a large number of harmonics are produced. Real-time monitoring of harmonics is necessary in the grid. If it exceeds the national standards, the appropriate measures, such as adding filtering devices, must be taken.

3. The effect of reactive power. The power factor of photovoltaic power generation is generally high, around 0.98, with mostly active output. In order to adhere to the principle of reactive power compensation stratified zoning and balancing, photovoltaic power stations should be equipped with the requisite reactive power compensation mechanism to meet the grid's reactive power demand[9].

4. Photovoltaic power generation is linked to the grid through a power electronic inverter, which can easily cause a three-phase current imbalance[10].

5.When there is a line failure in the PV power generation system, it can readily impact the grid's relay protection as well as the reclosing action.

2.3. Energy abandonment

The western region of China is experiencing a high-speed growth in wind and photovoltaic power generation, making it a new energy power highland in the country. However, due to the limited capacity of local consumption, coupled with the lag in the construction of outgoing channels, some areas in the west are forced to "abandon wind and photovoltaic". During concentrated time of new energy power generation, some local thermal power units experience a peak capacity shortage, which affects the safe operation of the power grid[11].

Take the north-west of China as an example,A clean energy industry base has been established in Hainan and Qinghai Province, with approximately 12 million kilowatts of installed photovoltaic power generation. At least 4 billion kilowatt-hours of photovoltaic power are abandoned each year, costing nearly 900 million yuan in output value, despite the fact that the price of electricity in Qinghai is 'parity on the Internet'.

The situation of abandoned light and wind in provinces and regions such as Qinghai, Inner Mongolia, Shaanxi and Ningxia cannot be ignored. The reason for this abandonment is primarily due to the imperfect new energy consumption market mechanism, which poses numerous obstacles to cross-regional consumption. In the construction process of the northwestern regional power grid market system, most of the current trading mechanisms fail to achieve competitive transactions,

limiting the growth of trading power and fixing the transaction price. The market configuration of new energy has not yet been fully utilized.

Secondly, there is a significant contradiction between the relative excess capacity of new energy and the insufficient load on the consumption side. For example, during the 13th Five-Year period, the average annual growth rate of installed photovoltaic power generation in Hainan Province and Qinghai increased by 47%. However, the growth rate of energy consumption only increased by 6%. Although Ningxia is connected to the East China and North China power grids through two direct current channels, its power transmission potential could not be fully utilized in actual operation due to considerations such as system security and the acceptance capacity of the recipient provinces.

3. Policy tools

During the 13th Five-Year Plan period, the National Energy Administration (NEA) has taken a series of measures to increase the utilization rate of new energy generation[8].

Strengthen the regional resource mutual aid channel to eliminate surplus power in the sending provinces and reduce the use of coal power in the receiving provinces, thereby producing favourable effects on both the sending and receiving provinces. The person in charge of energy enterprises in the western region, together with local departments, should focus on breaking cross-provincial transmission barriers by broadening the transmission channels for new energy, particularly by promoting the construction of new DC transmission channel projects. Efforts should be made to increase the proportion of clean energy in the transmission channels and to further expand the use of the existing DC transmission channels for new energy, so as to increase the transmission of new energy from the western region to the central and eastern regions[12].

Under the policy, China's new energy consumption contradictions continued to ease in 2019 (Figure 5), with new energy power abandonment at 21.5TWh, down 35.2% year-on-year, and a utilization rate of 96.7 %, an increase of 2.5 percentage points year-on-year, achieving the new energy utilization rate of 95% a year ahead of schedule.

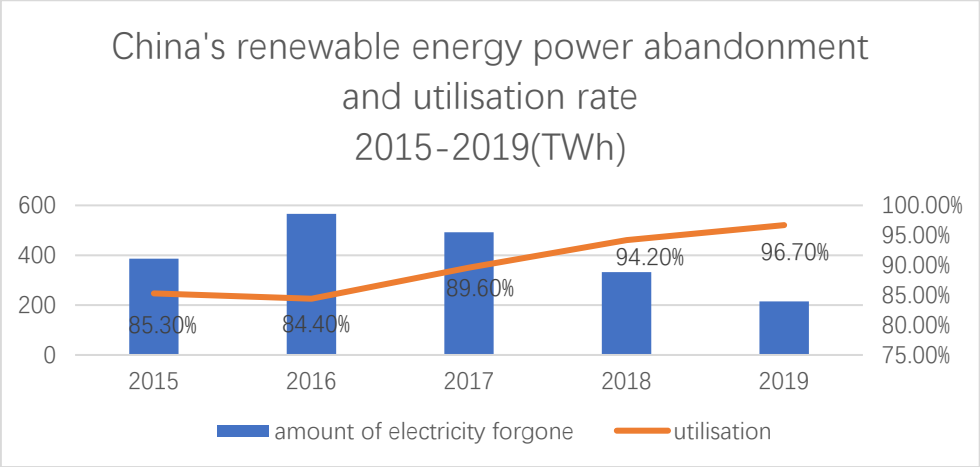


Fig. 5 China's new energy power abandonment and utilization rate in 13th Five-Year Plan period

4. Conclusion

In the near future, China will shift its focus towards renewable energy power generation, with an emphasis on addressing its existing challenges. This will involve making reasonable adjustments to the energy adjustment structure of society and continuously promoting the development of renewable energy power generation to advance the national renewable energy industry. When formulating and implementing the development plan for the renewable energy power generation industry and specific construction, it is necessary to consider the practicality of the situation. This plan must be linked with the overall economic situation of the country, carbon reduction tasks and other considerations.

Predictions related to electricity data associated with China's renewable energy must also be made within the medium and long-term developmental stages. This would serve as a scientific basis for the planning of renewable energy project development.

1.China is currently undergoing a transformation reform of its energy consumption structure, which has been effectively encouraging the development of renewable energy through the rise of the energy revolution. After considering the specific data on China's current energy consumption structure, comparing it to major industrial countries, and projecting the trend of its renewable energy resources, we have concluded that the decline in coal and renewable energy proportions in end-use energy consumption is closely related to China's process of high electrification. We also analyzed the current difficulties and problems faced in the development of renewable energy in China, which includes issues such as abandoned wind and sun, abandoned water, high generation power costs, serious reliance on subsidies and lack of mature market mechanism and operation mode. This analysis will guide the further development of renewable energy in China.

2.This paper examines the development trend and potential applications of renewable energy in China. It will forecast the future electricity data of renewable energy, and analyze the cost of renewable energy power generation as well as its market competitiveness compared to traditional coal power from an economic viewpoint. This paper will take representative renewable energy power projects in China and analyze them empirically using carbon trading data. The conclusions derived from this analysis are both practical and scientifically sound. However, due to the limitations of data scope and timeliness, and the time constraints while writing this paper, the conclusions obtained cannot fully represent the specific operation of renewable energy power projects in China. They require improvements in the future research process.

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