Bulletin of Chinese Academy of Sciences

Volume 35 | Issue 1 Article 10

January 2020

Spatial and Temporal Development Pattern and Environmentally-friendly Development Path of Electricity Industry in the Yellow River Basin

MA Shiping

Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; University of Chinese Academy of Sciences, Beijing 100049, China

See next page for additional authors

Recommended Citation

Shiping, MA and Wenzhong, ZHANG (2020) "Spatial and Temporal Development Pattern and Environmentally-friendly Development Path of Electricity Industry in the Yellow Rive *Bulletin of Chinese Academy of Sciences (Chinese Version)*: Vol. 35 : Iss. 1 , Article 10.
DOI: https://doi.org/10.16418/j.issn.1000-3045.20200107002
Available at: https://bulletinofcas.researchcommons.org/journal/vol35/iss1/10

This Article is brought to you for free and open access by Bulletin of Chinese Academy of Sciences (Chinese Version). It has been accepted for inclusion in Bulletin of Chinese Academy of Sciences (Chinese Version) by an authorized editor of Bulletin of Chinese Academy of Sciences (Chinese Version). For more information, please contact lcyang@cashq.ac.cn, yjwen@cashq.ac.cn.

Spatial and Temporal Development Pattern and Environmentally-friendly Development Path of Electricity Industry in the Yellow River Basin

Abstract

The electricity industry has a solid foundation and a long history in the Yellow River Basin owing to the large reserves of energy minerals, wind power, solar power, and hydropower. Giving full play to the positive socioeconomic benefits of power industry and controlling the negative environmental impact are of great significance to the ecological protection and high-quality development of the Yellow River Basin, which are also crucial to the safety of energy supply. Through the analysis of the micro data of 6000 kWand-above power plants, this study depicts the spatial and temporal development pattern of electricity industry in the Yellow River Basin from 2003 to 2017 in the perspectives of power plants construction, power production, and so on. The formation of the current pattern is mainly affected by both resource endowment and electricity demand. The existing problems of the electricity industry in this area are as following: little growing space for hydroelectricity, installed capacity surplus, and low efficiency of thermal-power and the insufficient consumption of wind and solar power. In order to realize the environmentally-friendly development of electricity industry, we should promote the clean and efficient utilization of thermal power, the integrated development of resource-based industries through electric power reform and institutional innovation, solve the problem of wind power consumption through the transformation of coalfired plants' flexibility and the complementary production of hydro and solar electricity, coordinate the contradictions during the development of wind and solar power, and promote the electricity technical advancement and the innovation of system mechanism to drive regional development.

Keywords

electricity industry; spatial and temporal development pattern; environment-friendly development; the Yellow River Basin

Authors

MA Shiping and ZHANG Wenzhong

Corresponding Author(s)

ZHANG Wenzhong [1,2*]

1 Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China

2 University of Chinese Academy of Sciences, Beijing 100049, China

ZHANG Wenzhong Professor of Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (CAS), Vice Chairman of Chinese Association of Development Strategy Studies, Director of Resource-based City Committee from China Society of Natural Resources, majoring in economic location theory and transformation of resource-based city.He has hosted and participated in more than 50 projects sponsored by the National Natural Science Foundation of China, CAS, the National Development and Reform Commission, etc., published more than 150 papers and more than 10 academic works.E-mail:zhangwz@igsnrr.ac.cn

This article is available in Bulletin of Chinese Academy of Sciences (Chinese Version):
https://bulletinofcas.researchcommons.org/journal/vol35/iss1/10

Citation: MA Shiping, ZHANG Wenzhong. Spatial and Temporal Development Pattern and Environmentally-friendly Development Path of Electricity Industry in the Yellow River Basin [J]. Bulletin of Chinese Academy of Sciences, 2020 (1): 86–98.

Spatial and Temporal Development Pattern and Environmentally-friendly Development Path of Electricity Industry in the Yellow River Basin

MA Shiping[1,2], ZHANG Wenzhong[1,2]

1. Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China;
2. University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: The electricity industry has a solid foundation and a long history in the Yellow River Basin owing to the large reserves of energy minerals, wind power, solar power, and hydropower. Giving full play to the positive socio-economic benefits of power industry and controlling the negative environmental impact are of great significance to the ecological protection and high-quality development of the Yellow River Basin, which are also crucial to the safety of energy supply. Through the analysis of the micro data of 6 000 kW-and-above power plants, this study depicts the spatial and temporal development pattern of electricity industry in the Yellow River Basin from 2003 to 2017 from the perspectives of power plants construction, power production, and so on. The formation of the current pattern is mainly affected by both resource endowment and electricity demand. The existing problems of the electricity industry in this area are as follows: little growing space for hydroelectricity, installed capacity surplus, and low efficiency of thermal power and the insufficient consumption of wind and solar power. In order to realize the environmentally-friendly development of electricity industry, we should promote the clean and efficient utilization of thermal power and the integrated development of resource-based industries through electric power reform and institutional innovation, solve the problem of wind power consumption through the transformation of coal-fired plants' flexibility and the complementary production of hydro and solar electricity, coordinate the contradictions during the development of wind and solar power, and promote the electricity technical advancement and the innovation of system mechanism to drive regional development. **DOI:** 10.16418/j.issn.1000-3045.20200107002-en

Keywords: electricity industry; spatial and temporal development pattern; environmentally-friendly development; the Yellow River Basin

Since the second industrial revolution, the electricity industry has played an extremely important role in economic development and is an important foundation for the development of modern industry and service industry. Many studies have confirmed that there is endogeneity between the production & consumption of electricity and economic growth, and the development level of the electricity industry can reflect the level of social and economic development to a certain extent [1–3]. With the continuous improvement of industrial electrification, digitization, and intellectualization, the modern economic development is more sensitive to electricity security, stability, and electricity cost. The high level of power supply guarantee capacity will become the comparative advantage of regional economic development. At the same time, the electricity industry also has good social benefits. According to the data of *China Population & Employment Statistics Yearbook*, the electricity, heat production, and supply industry absorbed 3.483 million urban employment population in 2017. The electricity industry plays a very good role in promoting the development of underdeveloped areas. At present, in poor rural areas with rich solar energy resources, the poverty alleviation project of photovoltaic power generation industry has become an important means and beneficial attempt to eliminate poverty precisely [4,5]. Meanwhile, the ecological and environmental problems associated with good economic and social benefits are also prominent, mainly reflected in the consumption of non-renewable resources and the pollution of atmospheric environment by thermal power generation, which is particularly serious in China. In 2017, the coal power accounted for about 65% of China's total power generation. Limited by China's energy mineral resources, the mode of thermal power generation dominated by coal-fired power generation will not change in the short term. Many studies show that the coal-fired power generation units are one of the main sources of carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_x), and inhalable particulates, which have a lot of negative effects on environmental health [6,7]. Therefore, it is very important to promote the high efficiency and environmentally-friendly development of electricity industry.

The Yellow River Basin is rich in energy minerals, wind, light, and water energy and has a good foundation for the development of electricity industry. According to the planning and layout of the National Land Planning Outline

Received: 2020-1-10

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

(2016–2030), the Strategic Action Plan for Energy Development (2014–2020), and other documents, eight out of fourteen large key coal bases with hundred million tons in China are located in or around the Yellow River Basin, and the coal reserves in the basin account for more than half of the total national reserves. Six out of nine large key coal power bases with ten million kilowatts in China are located in the Yellow River Basin (in Ordos, northern Shanxi, central Shanxi, eastern Shanxi, northern Shaanxi, and eastern Ningxia respectively). In addition to coal power, the western Inner Mongolia is one of nine large modern wind power bases and supporting transmission project construction sites in China. More than half of China's nineteen leading photovoltaic power generation bases are located or close to the Yellow River Basin, while the hydropower bases in the upper and middle reaches of the Yellow River were listed as the thirteen largest hydropower bases in China as early as the 1980s. The electricity industry in the Yellow River Basin has a long history of development and its importance in the region and the whole country is self-evident.

On September 2019, the general secretary Xi Jinping delivered an important speech at the symposium on ecological protection and high-quality development of the Yellow River Basin and put forward new targets for the development of the Yellow River Basin in the new era. As an important energy enrichment area, whether the electricity industry can give full play to its economic and social benefits and strictly control the negative impact on ecological environment is of great significance to the ecological protection and high-quality development of the Yellow River Basin and is also related to the overall pattern of China's energy supply and security guarantee. Due to the limitation of research data and the influence of research purpose, the current research on electricity industry generally has the characteristics of large scale and coarse precision, and there are few studies on the power distribution, refined production pattern, and spatial and temporal evolution in a specific region. At present, the micro data of electricity industry is mainly used in the field of environmental research. A group of researchers have carried out research on thermal power emission pattern and simulation of emission reduction scheme based on the micro data of coal-fired power plants [8–10]. This paper will describe and sort out the spatial and temporal development pattern and mechanism of the electricity industry layout in the Yellow River Basin by using the micro data of different types of electricity industry, and put forward thoughts and suggestions on its environmentally-friendly and high-quality development path.

1 Data source and method

1.1 Research idea

Since there is no unified social and economic division of the Yellow River Basin, this paper takes the Yellow River Basin in China's natural geographical division as the research area. Its spatial scope comes from the resource and environment data cloud platform of the Resource and Environment Science and Data Center, Chinese Academy of Sciences, with an area of about 757,000 square kilometers, accounting for about 8% of China's total territorial area, involving 74 prefecture-level administrative units in Qinghai, Gansu, Ningxia, Inner Mongolia, Shaanxi, Shanxi, Henan, Shandong, and Sichuan. Based on different types of power plant data after geocoding, using the methods such as spatial visualization, descriptive statistical analysis, and spatial statistical kernel density analysis, combined with literature review and case analysis, this paper will explore the spatial and temporal development pattern of electricity industry in the Yellow River Basin and analyze the dynamic mechanism of its formation. On the basis of the development status of electricity industry in the Yellow River Basin and the overall development state of electricity industry, this paper will also discuss the environmentally-friendly development path of electricity industry in the Yellow River Basin in the future.

1.2 Main data source

The main data used in this paper come from the *Compilation of Statistics on the Electricity Industry* in 2003, 2010, and 2017 issued by China Electricity Council. The statistical data include the relevant data of electricity industry development of various provinces in China, as well as the name and technical and economic indexes of 6 000 kW-and-above power plants, such as installed capacity of power generation, generation capacity, utilization hours, and standard coal consumption of power supply. In the actual power production, the number of regular power plants with installed capacity less than 6 000 kW is very small. In 2017, the power generation capacity of 6 000 kW-and-above power plants accounted for about 98% of the total power generation in China. Therefore, the data can accurately reflect the pattern of power production. According to the needs of this study and the availability of data, the statistical data of 2003, 2010, and 2017 will be selected for analysis. In addition, according to the research needs, this study will also use some social and economic statistical data of prefecture-level cities in the Yellow River Basin for auxiliary analysis.

Due to the lack of spatial location information in micro data of power plants, before carrying out the research, the geocoding is firstly carried out for 6 000 kW-and-above power plants in China in the above three years by using the territorial and name field information to determine the spatial location of power plants. Due to the influence of data type and technology, there are some errors in the geocoding process. After manual correction of some data, 378, 510, and 1 937 power plants of 6 000 kW and above in the Yellow River Basin in 2003, 2010, and 2017 are finally screened out respectively. Their spatial distribution is shown in Figure 1.

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

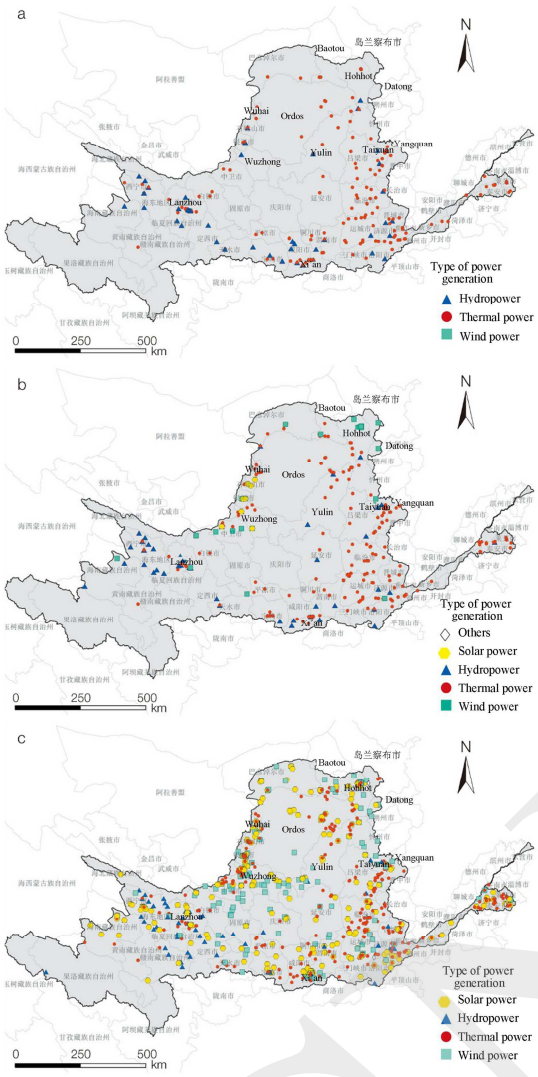

Figure 1 Distribution of 6 000 kW-and-above power plants in the Yellow River Basin

(a) 2003; (b) 2010; (c) 2017

2 Spatial and temporal development pattern of electricity industry

2.1 Spatial and temporal evolution of distribution pattern of installed capacity

On the whole, the proportion of the total installed capacity in the Yellow River Basin in China has a small change, accounting for 15.5% of the total installed capacity in China in 2017.

(1) In terms of power generation type. ① The installed capacity of thermal power occupies a dominant position in the basin, and the installed capacity increases rapidly. In 2017, the total installed capacity of thermal power in the basin expanded to about 6 times that in 2003. ② The hydropower construction has slowed down obviously in recent years. Due to the influence of factors such as earlier hydropower development in the Yellow River Basin, especially in the upper reaches of the Yellow River Basin, and the basic saturation of hydropower resource development, the gap between the installed capacity of hydropower and thermal power has rapidly widened. In 2017, the proportion of total installed capacity of hydropower in the basin in the national installed capacity of hydropower decreased to 7.1%. ③ Although the wind power and solar power are limited by the scale of single installed capacity and the total installed capacity is not high, their development scale and speed take the lead in China. From 2003 to 2017, the proportion of total installed capacity of wind power in the basin in the national installed capacity of wind power increased from 4.1% to 20.1%. The total installed capacity of solar power and other power plants accounted for 38.8% of China's total installed capacity in 2010 and fell to 24.8% in 2017. The growth of wind power and solar power made up for the impact of the slow development of hydropower on the installed structure. The installed capacity ratio of renewable energy power generation to fossil energy power generation in the basin was maintained at about 3:7 for a long time.

(2) In terms of spatial distribution. The distributions of thermal power and hydropower plants in the Yellow River Basin are relatively concentrated. The thermal power plants are mainly concentrated in the middle and lower reaches of the Yellow River Basin, and the hydropower plants are concentrated in the upper reaches of the Yellow River and the northern main stream area (Figure 1). The wind power and solar power plants spread rapidly in space, with obvious dispersive distribution characteristics.

(3) In terms of regional distribution. In recent years, the growth of installed capacity of thermal power in the Yellow River Basin is mainly attributed to Shanxi, Shaanxi, Inner Mongolia, and Ningxia. Among them, the rapid increase in the installed capacity of thermal power in Inner Mongolia makes it surpass Shaanxi and become the main contribution area of installed capacity of thermal power second only to Shanxi (Figure 2a). There are great differences among provinces in the growth of installed capacity of hydropower. The increment is mainly reflected in Qinghai and Gansu, and the overall growth momentum is weak since 2010–2017 (Figure 2b). The early installed increment of wind power mainly appears in Inner Mongolia, and the later increment mainly appears in Ningxia, Henan, and Qinghai. The wind power growth in Shandong is almost zero (Figure 2c). The growth of installed capacity of solar power is the latest, which starts after 2010, and the main growth appears in Ningxia, Inner Mongolia, and Qinghai (Figure 2d).

2.2 Change of power production pattern and power supply structure

The power production pattern in the Yellow River Basin is similar to the installed capacity pattern. Solar power has a prominent leading position in the whole country. In 2010, the

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

solar power in the basin accounted for 24.7% of the national solar power (Table 2), and the proportion reached 30.3% in 2017. The wind power generation also grew rapidly, accounting for 19.0% of the national wind power generation in 2017. The hydropower generation grew slowly and showed a downward trend over the years, and its proportion in the national hydropower generation also decreased from 23.0% in 2003 to 5.7% in 2017. Although the scale of renewable energy power generation and its proportion in the whole country have increased significantly, the situation that the thermal power generation is dominant has not changed. In the power generation structure of the Yellow River Basin, the contribution of thermal power to the total power generation increased from 77.2% in 2003 to 83.9% in 2017, higher than the contribution rate of thermal power in the national power supply structure (72.3%). Although the regulation effect of wind power and photoelectricity on the structure appeared in the installed capacity, due to the low power generation efficiency, the growth of wind power and solar power in the Yellow River Basin was difficult to make up for the gap caused by the sluggish hydropower generation, and the cleaning effect of power generation sources was still unsatisfactory.

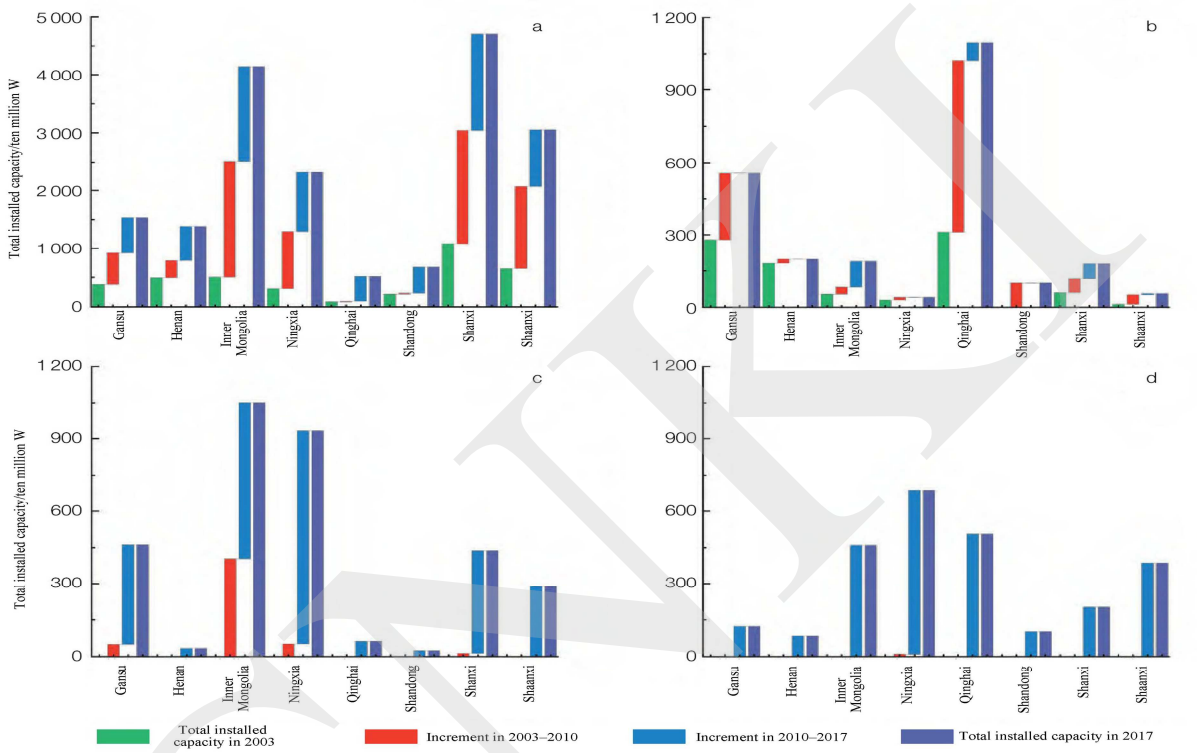

Figure 2 Installed capacity growth in different regions of the Yellow River Basin from 2003 to 2017

(a) Thermal power; (b) Hydropower; (c) Wind power; (d) Solar power. The name of the province or autonomous region refers to the area at the intersection of the Yellow River Basin and the spatial scope of the region (the same below). Since the electricity industry of Sichuan mainly relies on the development of hydropower resources in the Yangtze River Basin, it is not included in the statistics.

Table 1 Statistics of total installed capacity of 6 000 kW-and-above power plants in the Yellow River Basin

	2003		2010		2017	
	Total installed capacity (ten thousand kW)	Proportion in China	Total installed capacity (ten thousand kW)	Proportion in China	Total installed capacity (ten thousand kW)	Proportion in China
Thermal power	3138.7	11.1%	10961.2	15.6%	18466.9	16.8%
Hydropower	1528.4	19.3%	2170.3	11.4%	2208.8	7.1%
Wind power	2.2	4.1%	516.8	17.5%	3288.8	20.1%
Solar power and others	—	—	9.0	38.8%	2551.6	24.8%
Total	4669.3	12.6%	13657.3	14.6%	26516.1	15.5%

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

Table 2 Statistics of power generation of 6 000 kW-and-above power plants in the Yellow River Basin

	2003		2010		2017	
	Total power generation (one hundred million kW·h)	Proportion in China	Total power generation (one hundred million kW·h)	Proportion in China	Total power generation (one hundred million kW·h)	Proportion in China
Thermal power	1 875.9	12.0%	4 871.9	14.3%	7 855.4	17.3%
Hydropower	554.7	23.0%	650.1	10.6%	617.0	5.7%
Wind power	0.3	3.5%	90.1	18.2%	577.7	19.0%
Solar power and others	—	—	0.6	24.7%	312.0	30.3%
Total	2 430.9	13.1%	5 612.7	13.5%	9 362.1	14.9%

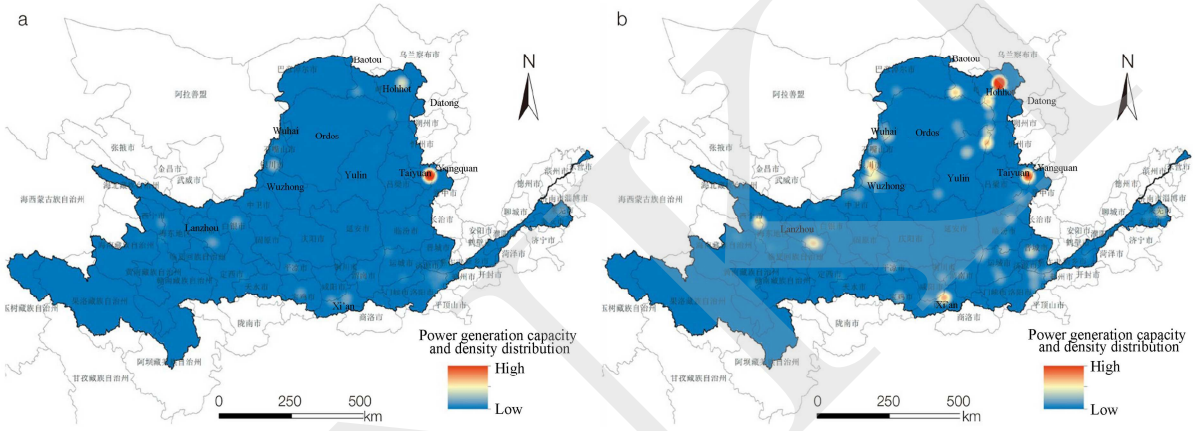

Figure 3 Power generation capacity and density distribution of 6 000 kW-and-above power plants in the Yellow River basin

(a) 2003; (b) 2017.

The spatial pattern of power production in the Yellow River Basin has gradually evolved from single center to dual center and even to multiple centers (Figure 3). In 2003, the total power generation of power plants in Taiyuan City exceeded 50 billion kW·h, accounting for about 23% of the total power generation in the whole basin, far higher than that of other prefecture-level cities. By 2017, the total power generation of power plants in Hohhot City exceeded 100 billion kW·h, accounting for about 12.4% of the total power generation in the whole basin. The total power generation of Taiyuan City increased little compared with that in 2003, and its proportion in total power generation of the whole basin decreased to about 5.5%. In addition, the cities such as Wuzhong, Yulin, Lanzhou, Xi'an, and Ordos had the power generation capacity of nearly 50 billion kW·h.

2.3 Characteristics of economic and technical indexes of power generation

The development level of the electricity industry is not only related to the total installed capacity and total power generation but also associated with the efficiency and technical level of power production. The economic and technical indexes such as utilization hours of power generation equipment, scale of installed capacity, and coal consumption of coal-fired units directly reflect the development quality of the electricity industry, which is very important for optimizing the layout of the electricity industry and promoting its the environmentally-friendly and clean development.

2.3.1 Utilization hours of power generation equipment

The utilization hours of power generation equipment refer to the ratio of annual power generation to installed capacity of the equipment. Fewer utilization hours indicate lower utilization rate of equipment, and there are problems such as excess installed capacity or equipment abandonment. The utilization rate of thermal power equipment in the Yellow River Basin is seriously low. In 2017, the utilization hours were only 3 270 hours, significantly lower than the average level (4 219 hours) in China (Figure 4). The thermal power equipment was mainly composed of coal power units. Generally speaking, the coal power units usually took 5 500 hours as the planned utilization hours. If the actual utilization hours were less than 5 000 hours, it can be considered that there was

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

excess installed capacity. In recent years, the total installed capacity of coal power units in China has increased rapidly. The problem of excess installed capacity of coal power is quite serious, especially in the Yellow River Basin. In addition to the reason that the installed capacity of thermal power equipment grew too fast, due to the high penetration rate of renewable energy in the Yellow River Basin, the installed reserve demand of thermal power was also high when the renewable energy was installed and connected to the grid. In addition, there were many thermal power units in the self-provided power plants of industrial enterprises in the region, which would reduce the overall efficiency of thermal power equipment [11,12]. The utilization rate of hydropower units in the Yellow River Basin was relatively high, with 3871 utilization hours in 2017, higher than the national average level. The utilization hours of wind power and solar power were significantly lower than those of hydropower and thermal power due to their poor stability and frequent abandonment. Compared with the national average level, the utilization rate of wind power equipment in the Yellow River Basin was low, but the utilization rate of solar power equipment was slightly higher than the national average level.

In terms of regions, the utilization hours of power generation equipment decreased significantly in the main areas of installed capacity growth of thermal power. From 2003 to 2017, the average annual utilization hours of thermal power generation equipment in Shanxi and Shaanxi decreased by 2 294 and 1 572 hours respectively, and the problem of excess installed capacity of thermal power was quite prominent. The utilization hours of thermal power equipment in Qinghai and Gansu which were the main contribution areas of installed capacity growth of renewable energy have also decreased significantly, which is related to the installed reserve demand of thermal power when the renewable energy was installed and connected to the grid. Meanwhile, due to the high proportion of wind power and solar power equipment and its low utilization rate, the total utilization hours of power generation equipment in Ningxia, Qinghai, and Gansu were significantly lower than those in other provinces.

2.3.2 Installed scale of thermal power plants

Thermal power, especially the coal-fired power plants, occupied a dominant position in the Yellow River Basin. Therefore, the high-quality development of thermal power, especially the coal-fired power plants, played a decisive role in the high-quality development of electricity industry in the whole basin. An important influencing factor of the high-quality development of thermal power was the scale of thermal power units. The overall installed scale of thermal power in the Yellow River Basin was relatively small. Among the 692 thermal power plants in 2017, only 175 power plants had an installed capacity of no less than 300 000 kW (Figure 5). This is mainly due to the existence of a large number of self-provided power plants of enterprises in the basin, which have small overall installed capacity. Especially in Shandong, Shanxi, Gansu, and some other provinces, the proportion of thermal power plants with installed capacity less than 100,000 kW accounted for more than 70%, and the news reports on the chaotic development of self-provided power plants were frequent. The research showed that the coefficients of different scales of thermal power units and the emission of CO_2, SO_2, NO_x, and fine particulate matter ($PM_{2.5}$) during power generation with the power generation were different. The lower scale of thermal power units would generate more emissions. The large thermal power units were often more advanced in technology and designed according to stricter emission standards with higher operation efficiency, thus more conducive to energy conservation and emission reduction [13]. Too low installed scale of thermal power directly led to low thermal power operation efficiency and low cleanliness in the basin, which poses a great challenge to the future governance and development of thermal power in the Yellow River Basin.

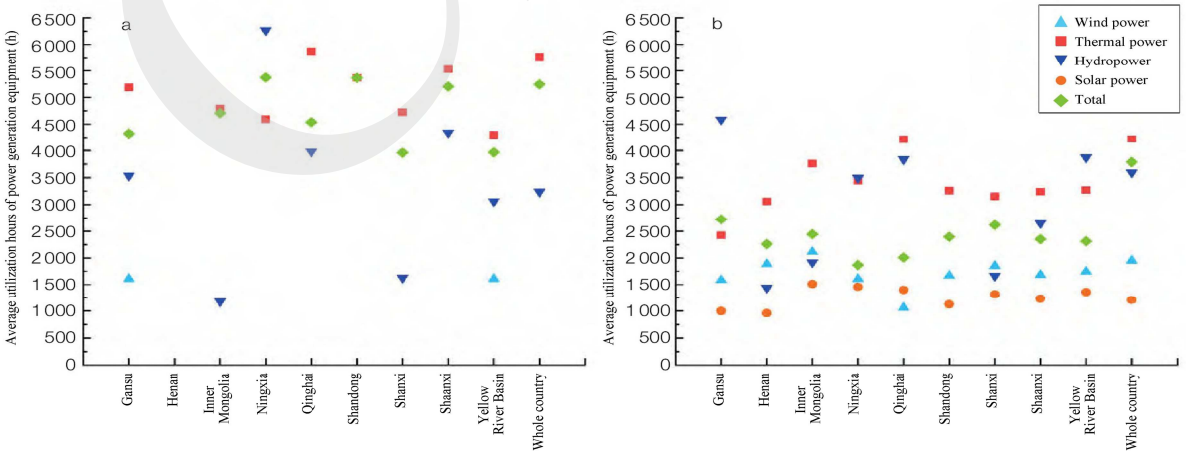

Figure 4 Average annual utilization hours of power generation equipment in the Yellow River Basin

(a) 2003; (b) 2017. The micro data of Henan power plants in 2003 are lack of utilization hour information of power generation equipment.

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

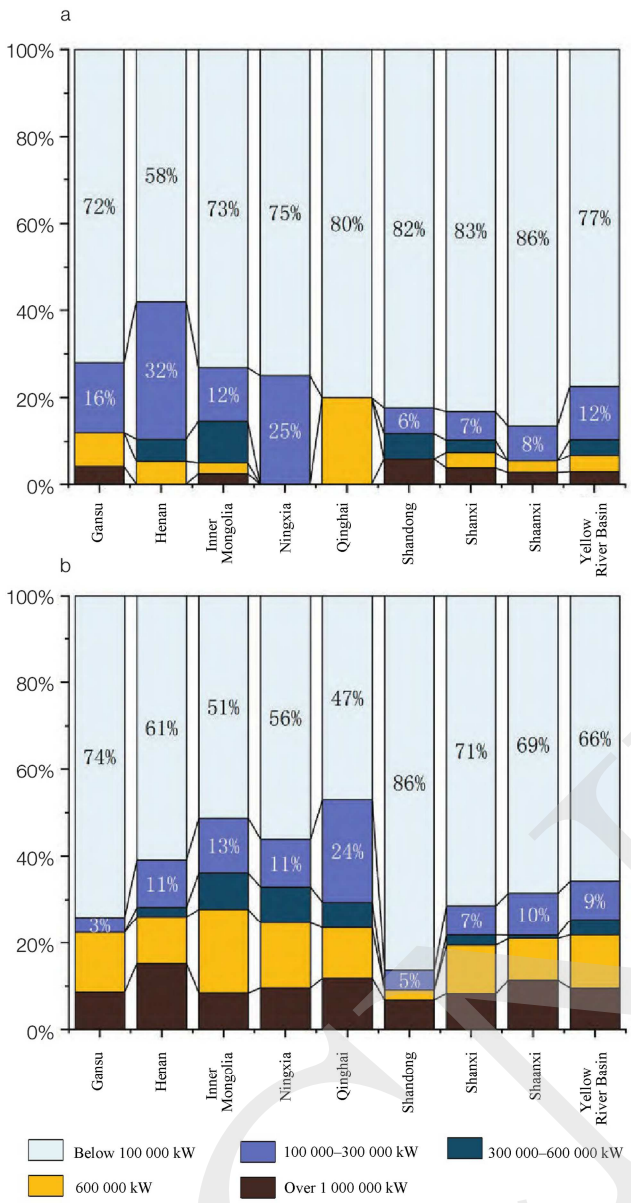

Figure 5 Scale structure of thermal power plants in the Yellow River Basin

2.3.3 Standard coal consumption of power supply of coal-fired power plants

The standard coal consumption of power supply refers to the average standard coal amount (gram) consumed by thermal power plants per kilowatt hour of electric energy production. Reducing the standard coal consumption of power supply will reduce the consumption of coal resources and the emission of pollutants such as SO_2 and NO_x [14]. From 2003 to 2017, although the standard coal consumption of power supply of coal-fired power plants in the Yellow River Basin decreased significantly overall, it was still higher than the national average level (Figure 6). In 2003, the median standard coal consumption of power supply of coal-fired power plants in the Yellow River Basin was 173 g/kW·h higher than the national average level. Only about 25% of coal-fired power plants in the basin had the standard coal consumption of power supply lower than the national average level in 2010 and 2017. From the perspective of spatial distribution, the standard coal consumption of power supply of coal-fired power plants of Shanxi, Shaanxi, and Inner Mongolia which were highly rich in coal resources was significantly higher than that of other provinces. The coal-fired power plants in the Yellow River Basin need further standardized management and technical upgrading.

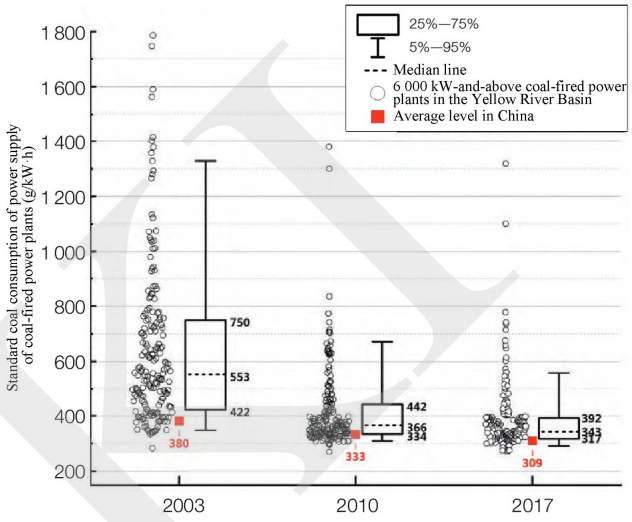

Figure 6 Standard coal consumption of power supply of 6 000 kW-and-above coal-fired power plants in the Yellow River Basin from 2003 to 2017

3 Influencing factors of spatial and temporal pattern of electricity industry

The formation of spatial and temporal development pattern of electricity industry in the Yellow River Basin was mainly affected by resource endowment and electricity demand. The renewable energy power generation was more sensitive to these two factors.

3.1 Resource endowment

The renewable energy power industry (hydropower, wind power, and solar power) is a typical resource-oriented industry. Its formation of spatial and temporal evolution pattern is closely related to the distribution of water energy, wind energy, and solar radiation energy in the Yellow River Basin.

At present, the hydropower development in the Yellow River Basin is stable for a long time. The increment space is very small and mainly limited by the reserves and development intensity of hydropower resources in the Yellow River. The results of the national review of hydropower resources show that China's hydropower resources are mainly concentrated in the Yangtze River Basin, the Yarlung Zangbo River Basin, and other river basins in Tibet. The theoretical reserves

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

of hydropower resources in the Yellow River Basin only account for 6.2% of the total amount of China. The hydropower resources are relatively limited [15,16], and the only hydropower resources are mainly concentrated in the upper reaches of the Yellow River and its northern main stream. According to the relevant report, except that the development degree of hydropower resources in Sichuan, Yunnan, and Tibet is 65.2%, 65.4%, and 1.4%, respectively, the average installed hydropower development degree in other provinces of China has reached 83.9%. Considering the technical and economic feasibility of hydropower development comprehensively, it is found that the newly added conventional hydropower in China will be mainly concentrated in Sichuan and Yunnan regions in the future, and the increment space in the Yellow River Basin is small [17].

The total installed capacity and power generation of wind power and solar power take the lead in China, mainly due to the good wind and light energy resources in the northwest of the Yellow River Basin as well as the rich land resources. According to the Annual Bulletin of China's Wind Energy and Solar Energy Resource in 2018 jointly issued by the Wind Energy and Solar Energy Resource Center of China Meteorological Administration and China Meteorological Service Association, the annual average wind speed of land at an altitude of 70 m in Inner Mongolia, Qinghai, Ningxia, and Gansu ranks 1, 6, 8, and 11, respectively among all provincial administrative units in China. The total annual horizontal radiation of northern Shanxi, western Inner Mongolia, Ningxia, Gansu, and Qinghai in the Yellow River Basin in 2018 is in the range of 1 400–1 750 kW·h per square meter. The solar energy resource in the above regions is higher than that in most parts of China except the Qinghai-Tibet Plateau. The good energy resource endowment and vast land resources ensure the rapid development of wind power and solar power in this region.

Compared with the other three types of power generation, the dependence of thermal power generation on resource endowment is weak, which is related to the great improvement of current transportation capacity of coal resources and the technology and cost issue of long-distance power transmission. However, in the Yellow River Basin, the installed thermal power and power generation still show strong resource dependence. Shanxi, Inner Mongolia, and Shaanxi are the main regions of installed capacity growth of thermal power. The cities such as Hohhot, Taiyuan, Wuzhong, Yulin, Lanzhou, Xi'an, and Ordos with annual power generation of more than 50 billion kW·h are or close to rich coal resource regions.

3.2 Electricity demand

Although there are abundant coal resources and renewable energy resources, the proportion of the total power generation of the Yellow River Basin in the overall level of China is not proportional to the proportion of its resource reserves. Moreover, thermal power, wind power, and solar power all have a serious phenomenon of excess installed capacity and equipment abandonment, which mainly results from the low power demand in the region. According to the estimate from the relevant data of *China City Statistical Yearbook*, the gross domestic product (GDP) of prefecture-level cities in the Yellow River Basin in 2017 accounted for about 15% of the whole country. The total power consumption of all prefecture-level cities was about 1 trillion kW·h, accounting for nearly 20% of the total national power consumption, which is basically equal to the total power generation in the basin. The regional economic development and the distribution of power consumption in the basin are also quite different. The northwest region is obviously low. In the case of low demand for electricity in the basin and the need for further development of power transmission capacity, the problem of excess installed capacity is highlighted.

Limited by the technology and cost, the low demand for electricity leads to insufficient local consumption capacity, which has an obvious impact on the power generation efficiency of renewable energy, resulting in frequent wind power and light power curtailment in the Yellow River Basin. In July 2016, the National Energy Administration launched the wind power investment monitoring and early warning mechanism. Gansu, Inner Mongolia, and Ningxia were included in the red early warning provinces of wind power investment detection due to the high wind power curtailment rate. According to the statistical data released by the National Energy Administration, in 2017, the wind power curtailment in Gansu and western Inner Mongolia reached 9.18 billion kW·h and 7.1 billion kW·h, respectively, with wind power curtailment rate of 33% and 17%, respectively. After strict regulation and control in Ningxia, the wind power curtailment rate has dropped to 5%. The five northwest provinces and western Inner Mongolia are the key regions of light power curtailment in China, and the light power curtailment accounts for more than 90% of the national total quantity [17]. According to the statistical data released by the National Energy Administration, in 2017, the light power curtailment of Gansu, Shaanxi, and western Inner Mongolia was 1.85 billion kW·h, 770 million kW·h, and 400 million kW·h, respectively, with the light power curtailment rate of 20%, 13%, and 11%, respectively.

4 Environmentally-friendly development path of electricity industry in the Yellow River Basin

4.1 Environmentally-friendly development path of thermal power industry

4.1.1 Promotion of cutting overcapacity of thermal power and improvement of clean and efficient utilization degree of thermal power

In 2015, the former Ministry of Environmental Protection, the National Energy Administration, and the National

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

Development and Reform Commission (NDRC) of China jointly issued the Work Plan for the Comprehensive Implementation of Ultra-low Emission and Energy-saving Transformation of Coal-fired Power Plants. In 2017, the National Energy Administration issued the Opinions on Promoting the Structural Reform of the Supply Side to Prevent and Resolve the Risk of Coal Power Overcapacity. In 2018, the NDRC issued the Special Governance Scheme for Standardized Construction and Operation of Coal-fired Self-provided Power Plants (Exposure Draft). Although the development of thermal power in the Yellow River Basin has a prominent advantage of coal resources and is absolutely dominant in power production and supply, the problems such as excess installed capacity of thermal power units, high coal consumption of power supply, low utilization hours, and numerous self-provided power plants are also very prominent. Under the dual pressure of policy regulation and ecological environment protection, the environmentally-friendly development of thermal power in the Yellow River Basin is full of challenges.

Based on the current situation of coal power overcapacity in the basin, the Yellow River Basin, especially Shanxi, Inner Mongolia, and Shaanxi, needs to strengthen coal power planning and construction, strictly control the investment of thermal power projects, especially coal power projects, and face the problem of low average annual utilization time of thermal power generation equipment. Meanwhile, it is necessary to shut down generator units with backward technology, substandard emission, and small scale, and standardize the management and regulation of self-provided power plants. According to the estimate from the research data, the total installed capacity of self-provided power plants in the Yellow River Basin is about 10–15 million kW, mainly in Shandong and Shanxi. The large number of self-provided power plants directly leads to a high proportion of small-scale thermal power units and the low utilization hours of power generation equipment in the basin. However, it must be noted that a large number of self-provided power plants have a specific historical background. The reform involves such thorny issues as the rising operating costs of enterprises and employment security, which need to be further properly solved. It is necessary to continue to promote the transformation to ultra-low emission of coal power, reduce the standard coal consumption of power supply, and promote the clean and efficient development of coal power. It is also necessary to give full play to the advantages of coal-bed methane resources in the basin, promote the development of gas generating electricity, and improve the cleanliness of thermal power.

4.1.2 Promotion of the reform of power transmission and distribution and exploration of the integrated development path of resource-based industries such as "joint operation of coal and power"

The strategic significance of good coal resource reserve and coal power base determines that the thermal power generation will still be dominant in a certain period of time in the future. In order to overcome the problem of the current low demand for electricity and the low thermal power production efficiency caused by insufficient delivery capacity, the construction across North China power grid and northwest power grid should be further strengthened, and the construction of trans-provincial and trans-regional power transmission channels and institutional innovation should be promoted. It is necessary to focus on solving the problem of lag in the construction of power transmission channels with the power grid of western Inner Mongolia and Shanxi as the sending end and Beijing-Tianjin-Hebei Region and Nanjing as the receiving end. The ultra-high-voltage long-distance power transmission should be further developed to promote the formation of west-east and north-south power transmission patterns in the North China power grid [17], so as to promote the further improvement of thermal power generation.

In order to give full play to the coal resource endowment in the basin, the pilot work of "joint operation of coal and power" can be carried out to explore the integrated development path of resource-based industries and promote the common progress of coal and power industries. For example, the construction of pithead power plants in coal producing areas and the coal–power composite production bases can reduce the unreasonable transportation and large-scale pollution caused by thermal power generation and promote the economic development in the basin. In recent years, the NDRC and the National Energy Administration have been committed to promoting the "joint operation of coal and power" to solve the long-standing contradiction of coal power development. In 2016, the NDRC issued the Guiding Opinions on the Development of Joint Operation of Coal and Power. In 2018, the NDRC and the National Energy Administration jointly issued the Supplementary Notice on Further Promoting the Joint Operation of Coal and Power for Industrial Upgrading. In October 2019, the NDRC and the National Energy Administration issued the Notice on Strengthening Policy Support to Further Promote Joint Operation of Coal and Power. The above all released a strong signal of reform.

4.2 Environmentally-friendly development path of renewable energy power generation industry

4.2.1 Solution of wind power and solar power consumption by means of "transformation of coal-fired plants' flexibility" and "complementary production of hydro and solar electricity"

The key to promoting the development of wind power and solar power is to solve the consumption of wind power and solar power and reduce the wind and light power curtailment rate. The main reasons for the frequent wind and light power curtailment are the mismatch between the growth rate of installed power generation equipment and that of load in the Yellow River Basin, the insufficient peak regulation capacity

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

of thermal power system based on cogeneration, and the low local consumption capacity while the power transmission capacity is insufficient [18]. The solution to wind and light power curtailment requires all kinds of power supply and all subjects to work together.

Compared with hydropower and other power generation modes, coal power has higher flexibility, so it becomes the main power source to provide regulation capacity for the power system. The promotion of the transformation of coal-fired plants' flexibility will help to improve the peak regulation capacity of the power system and ensure new energy consumption [17]. Since 2016, the National Energy Administration has selected 22 coal power projects nationwide to carry out flexible transformation pilot projects, and a total of four power plants in the Yellow River Basin have been included. Among them, Units 1 and 2 of Linhe Thermal Power Plant in northern Inner Mongolia have completed the transformation. Shanxi also pointed out in the 15 major measures proposed in the comprehensive reform pilot project of energy revolution in 2019 that it is necessary to speed up the pilot project of the transformation of coal power units' flexibility, make full use of the existing coal power capacity, and build "peak regulation bases in North China."

In the case of limited increment space, in recent years, the hydropower development in the Yellow River Basin mainly aims at optimization and improvement and has initiated the operation mechanism of "complementary production of hydro and solar electricity" to improve the utilization efficiency of renewable energy system. Due to the good objective complementarity between hydropower and solar energy resources, the complementary operation of photovoltaic power station with intermittent, volatility, and strong randomness and hydropower station with flexible operation, rapid start-up, and strong adaptability will promote the consumption of solar power [19]. At the beginning of 2013, relying on Longyangxia Hydropower Station, Huanghe Hydropower Development Co., Ltd. of State Power Investment Corporation Limited built an 850 MW Longyangxia photovoltaic power station with "complementary production of hydro and solar electricity" which is an operation mechanism developed for the first time. The successful operation of Longyangxia hydropower station has verified the rationality and effectiveness of this measure.

4.2.2 Rationalizing planning and investment construction, coordinating the resource endowment and local consumption in the main areas of wind power and solar power, and relieving the development contradiction of wind power, solar power, and thermal power

As mentioned above, although the northwest region of the Yellow River Basin has abundant wind and solar energy resources and vast land, which is suitable for the establishment of large-scale wind power and solar power generation facilities, it is also affected by the limitation of population and economic size and the low local consumption capacity. The location conditions have both advantages and disadvantages for the development of wind power and solar power. Meanwhile, the development of wind power and solar power also has a certain conflict with the development of thermal power. While the consumption of renewable energy power generation is guaranteed, the generation efficiency of thermal power units is affected. In the face of the contradiction of the development of wind power and solar power and the current declining trend of renewable energy power generation subsidies, planning should be strengthened in the future development of wind power and solar power, and investment and construction need to be rational. Moreover, the wind power and light power curtailment rates should be reduced, so as to form a positive interaction relationship of thermal power, wind power, and solar power.

4.3 Promotion of regional development by promoting power technology progress and mechanism innovation

The development of electricity industry is inseparable from the progress of related technologies, including energy storage technology, material technology, smart grid, and other aspects. Promoting technology research and development and tackling key problems will also promote the coordinated development of relevant manufacturing and service sectors and expand the whole energy industry chain, which is very important for the numerous resource-based cities in the Yellow River Basin to get rid of resource dependence and cultivate continuous alternative industries. Herein, solar power is taken as an example. There are many coal mining subsidence areas in the Yellow River Basin, and the construction of photovoltaic power generation bases in the subsidence areas has become one of the important means of comprehensive governance of coal mining subsidence areas [20]. The Yellow River Basin has established the leading photovoltaic power generation application bases in Datong and Yangquan of Shanxi, Baotou and Wuhai of Inner Mongolia, Xintai of Shandong, and other coal mining subsidence areas. While promoting the environmentally-friendly development of power structure, it also drives the comprehensive governance of subsidence areas, which has produced good social and economic benefits. Meanwhile, the development of the electricity industry also needs to strengthen the mechanism innovation and further promote the power reform dominated by the reform of power transmission and distribution price, incremental distribution, and electricity sales business, so as to give full play to the energy advantages of the region, reduce the energy cost of enterprises, and promote the overall development of regional economy.

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

5 Conclusions

Through the statistical analysis of the micro data of power enterprises in the Yellow River Basin and the sorting of relevant policies, this paper mainly draws the following four conclusions.

(1) On the whole, the total installed capacity and power generation of thermal power are absolutely dominant in the power structure of the Yellow River Basin. The hydropower is generally stable, and the solar power and wind power take the lead in the whole country. In terms of regions, Shanxi, Inner Mongolia, and Shaanxi are the main areas of thermal power development. The wind power is developing rapidly in Inner Mongolia, Ningxia, and Gansu. Inner Mongolia, Ningxia, and Qinghai are the main growth areas of solar power. The spatial pattern of power production gradually evolves from single center to dual center and even to multiple centers.

(2) The existing problems of the electricity industry in the Yellow River Basin are mainly manifested in the serious surplus of installed capacity of thermal power, low power generation efficiency, and low technical level. The development of thermal power does not match the rich coal resource reserves in the basin and strategic positioning of coal power base. At the same time, great ecological environment pressure is caused. The hydropower development has been sluggish for a long time. The increment space is extremely limited. The wind power and solar power are insufficient in local consumption and transmission capacity. The problem of wind power and light power curtailment is frequent. The renewable energy power generation has limited effect on the improvement of the current power structure. Meanwhile, there is a certain contradiction between the development of renewable energy and the development of thermal power.

(3) The formation of spatial and temporal development pattern of electricity industry in the Yellow River Basin is mainly affected by resource endowment and electricity demand. The renewable energy power generation is more sensitive to these two factors. There is a contradiction between resource endowment and electricity demand in the upper reaches of the Yellow River.

(4) The main paths of environmentally-friendly development of electricity industry in the Yellow River Basin include the followings: (1) promoting the overcapacity cutting of thermal power, and improving the clean and efficient utilization of thermal power; (2) promoting the reform of power transmission and distribution, and exploring the integrated development path of resource-based industries such as “joint operation of coal and power”; (3) solving the problem of wind power and solar power consumption by means of the “transformation of coal-fired plants’ flexibility” and “complementary production of hydro and solar electricity”; (4) focusing on rational planning and investment construction, and coordinating the resource endowment and local consumption in the main areas of wind power and solar power, as well as the development contradiction between wind power, solar power, and thermal power; (5) driving the regional development by promoting power technology progress and mechanism innovation.

References

1 Ma X, Zhu Y X, Li X B. 中国电力工业与国民经济增长关系的研究. Statistics & Decision, 2007, (5): 98–99 (in Chinese).
2 Liu S L, Gao Y N, Hu A G. Electricity consumption and China’s economic growth. Industrial Economics Research, 2014, (3): 71–80 (in Chinese).
3 Lin B Q. 电力消费与中国经济增长: 基于生产函数的研究. Management World, 2003, (11): 18–27 (in Chinese).
4 Jiang A Y, Liu B. Poverty Alleviation in the context of precision poverty alleviation. Journal of Agro-Forestry Economics and Management, 2017, 16 (6): 789–794 (in Chinese).
5 Lin B Q, Yang F. 电力产业对中国经济可持续发展的影响. The Journal of World Economy, 2009, (7): 3–13 (in Chinese).
6 Liu F, Zhang Q, Tong D, et al. High-resolution inventory of technologies, activities, and emissions of coal-fired power plants in China from 1990 to 2010.2015, 15 (23): 13299–13317.
7 Qin Y, Zhang Q, Li X, et al. Patterns of mortality from air pollutant emissions in China’s coal-fired power. Environmental Science, 2018, 39 (12): 5289–5295 (in Chinese).
8 Tong D, Zhang Q, Liu F, et al. Current emissions and future mitigation pathways of coal-fired power plants in China from 2010 to 2030. Environmental Science & Technology, 2018, 52 (21): 12905–12914.
9 Tong L, Qu J, Mi Z, et al. Substantial emission reductions from Chinese power plants after the introduction of ultra-low emissions standards. Nature Energy, 2019, 4 (11): 929–938.
10 Oberschelp C, Pfister S, Raptis C E, et al. Global emission hotspots of coal power generation. Nature Sustainability, 2019, 2 (2): 113–121.
11 Yuan J H, Zhang W H. 中国煤电过剩规模量化及去产能路径研究. Energy of China, 2017, 39 (8): 14–20 (in Chinese).
12 An L J. 自备电厂发展及相关问题探讨. Energy of China, 2009, 31 (2): 38–40 (in Chinese).
13 Tong D, Zhang Q, Davis S J, et al. Targeted emission reductions from global super-polluting power plant units. Nature Sustainability, 2018, 1 (1): 59–68.
14 Hou J C, Tan Z F, Wang M B. Comparison of energy efficiency indexes for power industry between China and other countries. Electric Power, 2007, (9): 6–10 (in Chinese).
15 Research Group of China Renewable Energy Development Strategy. 中国再生能源发展战略研究丛书·水能卷. Beijing: China Electric Power Press, 2008 (in Chinese).
16 Qian Y J. Study on the geographical distribution of hydropower and its development and utilization in China. Lanzhou: Lanzhou University, 2013 (in Chinese).
17 China Electric Power Planning & Engineering Institute. Report on China’s Electric Power Development 2018. Beijing: China Electric Power Press, 2019 (in Chinese).
18 Fan G F, Zhang N, Liang Z F, et al. Analysis on the “Three Norths” region wind and PV power limitation. North China Electric Power, 2016, (12): 55–59 (in Chinese).
19 Zhang P, Yang T. Research on Longyangxia hydro-photovoltaic complementary operation mechanism. Journal of North China University of Water Resources and Electric Power (Natural Science Edition), 2015, 36 (3): 76–81 (in Chinese).
20 Li J M, Yu J H, Zhang W Z. Spatial distribution and governance of coal-mine subsidence in China. Journal of Natural Resources, 2019, 34 (4): 867–880 (in Chinese).

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.

First author: MA Shiping, PhD candidate at Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (CAS), majoring in industrial location and regional development research. E-mail: masp.17b@igsnrr.ac.cn

ZHANG Wenzhong, corresponding author, Professor of Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (CAS), Vice Chairman of Chinese Association of Development Strategy Studies, Director of Resource-based City Committee from China Society of Natural Resources, majoring in economic location theory and transformation of resource-based city. He has hosted and participated in more than 50 projects sponsored by the National Natural Science Foundation of China, CAS, the National Development and Reform Commission, etc., and published more than 150 papers and more than 10 academic works. E-mail: zhangwz@igsnrr.ac.cn

CNKI

© 2020 China Academic Journals (CD Edition) Electronic Publishing House Co., Ltd.