Investigation of China's wind power based on cluster analysis and multidimensional scaling methods

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Abstract. Renewable energy today is the most dynamically developing direction of electric and heat power engineering. China is the undoubted world leader in terms of total volume and annual input of wind power capacities, and also has a developed industrial base, which allows fully meeting the needs of the industry in power equipment. The paper conducts a study of the current state and the identification of trends in the development of China’s wind power in conjunction with the problems of energy security and the potential of new and renewable energy sources as an integral part of regional (provincial) power systems. The place of China in the global use of renewable energy sources of wind has been determined. A comparative statistical analysis of the energy-bearing characteristics corresponding to the Chinese provinces was performed. The research methodology is based on the use of cluster analysis and multidimensional scaling methods. The statistical analysis of China's wind power allows us to identify and characterize the clusters of the provinces of China, within which the industry will progress further. Methods of multidimensional scaling allow us to visualize the results of the study.

1. Introduction

China's wind power is a booming industry of the People's Republic of China. As of February 2018, at the end of 2017, 188 GW of wind power stations [1] were operating in China, which is about 35% of the wind capacity of the whole world. China ranks first in the world in terms of installed wind power plants. In 2014, China’s wind power plants generated 138 TWh of electricity, or 2.6% of the total output. In 2015, 33 GW of new wind power plants were built in China, which is a world record [2]. In 2015, China’s wind power plants generated 163 TW of electricity, or 3.3% of the total output [3]. In 2016, output increased to 242 TW, which accounted for 4% of the total output and in 2017 to 305.7 TW, and 4.8% [4]. According to the plan of the 13th Five-Year Plan (2016-2020), China is going to introduce another 100 GW of wind capacity [5]. The development of wind power in China began in the 1980s and its development has lagged behind, but the starting point is relatively high. The Chinese government supports and encourages the development of wind power, so that wind power enters a stage of rapid development. At present, China has the world's largest installed capacity for wind power and cumulative installed capacity, and it has become the world's largest and fastest growing market for wind power generation. The wind energy reserves that China can develop and use are about 1 billion KW. Among them, about 253 million KW of wind energy is stored on land, and 750 million KW of wind energy is available for exploitation and utilization at sea, totaling 1 billion, and wind energy resources are abundant. China is recovering to a vast extent and has complex terrain conditions. The state and distribution of wind energy resources vary with the terrain and geographical position. The relatively
abundant areas are mainly located on the southeast coast and nearby islands as well as in the north (Northeast, North China and Northwest China). There are also individual wind energy rich spots inland. In addition, offshore wind energy resources are also very abundant [6,7]. With the rapid growth of economy development in China, the demand for power resources is increasing. According to the statistic from China Electricity Council, electricity consumption increased from 2500 TW in 2005 to 6307.7 TW in 2017, with an average annual growth of 7.9%. Due to the gradual depletion of fossil fuels and environmental issues, the proportion of traditional coal-fired power generation methods in the power production industry has gradually decreased, while renewable energies such as wind, solar and biomass energy are favored for their clean, pollution-free, and renewable characteristics, and they have occupied more and more positions in today’s power production. In 2016, coal fired power generation in China was 870 TW, while wind power contributed 130 TW with an annual growth rate of 12%. The installed capacity for wind power reached over 160GW, accounting for about 34% of global capacity worldwide, which, according to Chinese government, is expected to reach 200GW by 2020 and to increase further to contribute to the 13th five-year-plan on renewable energy [8-10]. In 2016 China supplied 30% of world's PV panels and ranks second in wind power production [11]. Chinese government has been providing the attractive policies for the local wind energy manufacturing companies with the developers. Also, from the last 2–3 years’ scenario, it has been observed that the Chinese government has also emphasised the policies especially for the outside wind energy manufacturing companies [10]. Nowadays, China is active in offshore wind, it has over 1.5 GW and plan 10 GW more by 2020.

2. Theoretical part

World Wind Energy Association (WWEA) summarized the results of 2017. Working in the world today, wind turbines produce more than 5% of world electricity. The [10] presents 16 leading countries of the world’s wind energy by installed capacity, as well as a total figure for the “Rest of the World”, that is, outside these sixteen countries [11], Fig.1,2.

![Figure 1. Dendrogram for visual presentation of the cluster analysis results economic](image-url)
According to the results of regression analysis, we can make a forecast about the total capacity in China, for example, for 2019 (240768 MW) and 2020 (265428 MW). Based on the data, we will conduct a cluster analysis. As a measure of proximity, we take the square of the Euclidean distance, as the method of organizing clusters; we choose the Ward's method, which allows us to distinguish clusters according to the criterion of minimal dispersion. To visualize the results of hierarchical clustering, we use a dendrogram, Fig. 1. The dendrogram shows the degree of closeness of individual objects and clusters, and also graphically demonstrates the sequence of their combination or separation. The dendrogram clearly shows the division of the countries in the Table I into three clusters, and China occupies a separate cluster and stands out sharply in terms of leadership. The gap in China’s wind energy indicators from other countries is impressive, even from the countries of the second cluster, which include such economically developed countries as the USA and Germany. The dendrogram, Fig. 1, also shows good positions in the use of wind energy of such countries as Spain and India, which, along with the United States and Germany, are included in the second cluster.

Now we are using a multidimensional scaling. The multidimensional scaling is a method of analyzing and visualizing data using the location of points corresponding to the objects being studied in a space of smaller dimension than the feature space of objects. The points are placed so that the pairwise distances between them in the new space differ as little as possible from the empirically measured distances in the feature space of the objects under study. The results of multidimensional scaling in our case, Fig. 2, fully confirm the results of the hierarchical cluster analysis. For example, the sharply advanced position of China is again manifested. Wind energy is used in many regions of the world. For China, this source of energy is relevant. Increased electricity generation is possible through the use of renewable energy sources. The “box-plot” diagrams for the variables given in the [4] are shown in Fig. 3 for Shandong, in Fig. 4 – for Inner Mongolia and Xinjiang. The initial data for the analysis are given in the [4]. Furthermore, “box-plot” diagrams are shown in Fig.5 for Inner Mongolia, in Fig.6 – for Fujian.
Let us consider the above diagram in Fig. 6. China's wind energy in Fujian depends on different conditions. As in the case of comparing China's wind energy with other countries, we will carry out a cluster analysis of the wind energy indicators of the provinces of China. The resulting dendrogram, Fig. 7, shows the possibility of splitting the provinces into six clusters [4]. Mean values of the source variables [4] are depicted in Fig. 8.
Figure 7. Dendrogram for provinces of China

Figure 8. Results of multidimensional scaling
3. Scientific novelty
A comparative statistical analysis of the energy-bearing characteristics corresponding to the Chinese provinces was performed. The research methodology is based on the use of cluster analysis and multidimensional scaling methods. The statistical analysis of China's wind power allows us to identify and characterize the clusters of the provinces of China, within which the industry will progress further. Methods of multidimensional scaling allow us to visualize the results of the study.

4. Practical significance
The investigation conducts a study of the current state and the identification of trends in the development of China’s wind power in conjunction with the problems of energy security and the potential of new and renewable energy sources as an integral part of regional power systems.

5. Conclusion
Thus, the models and methods developed in the study provided the following results. The results of scientific research, reflecting the use of management methods combining traditional and renewable resources according to the criteria of reducing the imbalance of the goals of efficiency and environmental-economic efficiency, are presented. This provides a focus on improving the manageability of the processes of development and implementation of projects.

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