Knowledge Mapping and Research Progress of Wind Energy Application Based on CiteSpace

Chengwei Ni, Minxiang Ma, Lin Ye, Jiayunrui Li and Zhe Tan

1Yunnan Academy of Scientific and Technical Information, Kunming, Yunnan Province, 650051, China

*a Email: ncw2609@dingtalk.com

Corresponding author’s e-mail: Minxiang518@163.com

Abstract. The global demand for new energy has entered an unprecedented era, and the application of wind energy is one of the key contents in the development of new energy. Taking the "wind energy + application" in WOS (Web of Science) and CNKI database as the retrieval target, and the relevant papers retrieved as the research data, this paper uses the scientific knowledge mapping software (CiteSpace5) to carry out the keyword commonality analysis, cluster analysis and time mapping analysis on wind energy application scenarios. Finally, summarized research hotspots and forecasted its research trends in wind energy application scenarios in global and China. The results show that the international wind energy application research hotspots and trends are wind energy storage and wind power project site selection; In China there are offshore wind power and wind energy evaluation.

1. Introduction

On September 22, 2020, Chinese president Xi Jinping announced China’s "3060" "dual carbon" targets to the world. During the "14th Five-Year Plan" period, China’s ecological civilization construction strategy will focus on reducing carbon and promoting greener economic and social development in all respects. Energy is not only related to the country’s economic development, but also the top priority of the country’s energy security strategy. It is foreseeable that in the coming decades, the development of new energy will be the general trend and a clean energy system supported by clean energy will be established. At the same time, China's energy industrial structure will be rearranged [1].

Wind power is one of the power generation modes with the most mature technology, the most large-scale development and the prospect of commercial development in the field of new energy [2]. The Global Wind Energy Council (GWEC) released the 2021 Global Wind Energy Report recently. The report shows that 2020 was the best year in history for the global wind industry with 93 GW of new capacity installed - a 53% year-on-year increase. With technology innovations and economies of scale, the global wind power market has nearly quadrupled in size over the past decade and established itself as one of the most cost-competitive and resilient power sources across the world. In 2020, record growth was driven by a surge of installations in China and the US. The two largest wind power markets in the world who together installed nearly 75% of the new installations in 2020 and account for over half of the world’s total wind power capacity.

While wind power has seen unprecedented growth, but this growth is not sufficient to ensure the world achieves net zero by 2050. The world needs to be installing wind power three times faster over
the next decade in order to stay on a net zero pathways and avoid the worst impacts of climate change. The development of wind power not only focuses on power generation costs and technology, but also designs a more suitable market for wind power development [3]. Understanding the application scenario of wind energy is an important prerequisite for the marketization of wind energy. This paper attempts to use bibliometric and CiteSpace knowledge graph to grasp the global and Chinese research hotspots and trends on "wind energy application", in order to provide a reference for the healthy development of China’s wind energy market.

2. Materials and methods

2.1. Materials
Foreign literature materials are Science Citation Index Expanded (SCI-Expanded) and Social Sciences Citation Index (SSCI), which are the core collections of WOS (Web of Science). During the global wind energy application field, by using "title= (wind energy AND application) OR (wind energy AND water extraction) OR (wind energy AND power generation) OR (wind energy AND energy storage)" as the search condition, and the search time is ten years (by the end of April 28, 2021). A total of 1001 valid sample documents were obtained. Literature materials in China are CNKI general database (in Chinese). During China, by using "SU= ((wind energy AND application) OR (wind energy AND water extraction) OR (wind energy AND power generation) OR (wind energy AND energy storage)) " as the search condition, and the retrieval time is from April 9, 2011 to April 9, 2021, a total of 1960 valid sample documents were obtained.

2.2 Methods

This paper uses co-word analysis and cluster analysis etc. of CiteSpace5.6R3 software, to analyze the basic situation, research hotspots and research trends of related articles. CiteSpace series software is visualization software for scientific literature analysis and knowledge graph analysis developed based on Java programming language. It can effectively avoid the problems such as unreasonable ranking, inability to reflect the word frequency of literature and unbalanced research time sequence in traditional literature retrieval. The development and evolution process of each discipline and the hotspots and trends of scientific development can be intuitively obtained through the graph of scientific knowledge [4-5]. The knowledge graph generated in the software can intuitively reflect the connection relationship between hot words, in which the thickness of the connecting line is positively correlated with the correlation degree between two hot words, and the dot area of hot words is positively correlated with the frequency of hot words. The time zone diagram can express the hot issues studied in different periods through the time areas where the keywords appear [6].

2.3 Trend Analysis of global "Wind Energy Application"(CiteSpace mapping)

By using CiteSpace as a document visualization analysis tool to combine metric method and visual analysis, pruning the searching literature with pathfinding algorithm and clustered, and drawing the knowledge cluster map of the research topic words and keywords. We can get 12 clusters by pruning and clustering the network with Pathfinder. Keep the top 5 clusters with better clustering effect (cluster label: # number. the smaller the cluster number is, the higher frequency of the keywords appearing in the cluster) as shown in Figure 1.
CiteSpace was used to conduct keyword co-occurrence analysis on the top 50 cited literatures, which took a year as the cut-off point. It is shown in Figure 1. It can be seen from the topic cluster graph that we can get 6 largest clusters through the cluster analysis of the subject words and keywords (cluster label: #, the smaller cluster number is, the more complete the layout of the cluster topics is). In order of size, they are: #0 learning-based energy storage system operation, #1 techno-economic assessment, #2 control system, #4 pumped-hydro storage, #5 distribution network.

After generating the co-occurrence cluster map of keywords and subject words, the cluster number is taken as Y axis and the year of citation publication is taken as X axis. The timeline map of co-occurrence word network is obtained (Figure 2).

The timeline map can show the time span and research process of the development and evolution of each cluster (i.e. sub-areas). It can be seen from Figure 2 that the related research in the six clusters continued from 2011 to 2020. Because the data in 2021 is relatively new, this cannot be fully referenced. In addition, the time span and continuity of these 5 clusters show strong crossover. It is expected that the related research on the 5 clusters will continue to be maintained and will become the hotspots and trends of future research.

Statistical analysis was conducted on the timeline nodes of each topic in Figure 2. Rank them in order of occurrence frequency from highest to lowest, and preserve hotspots associated with wind energy applications, we can get Table 1.

**Table 1. Global Topic Research Hotspots Statistics**

| Cluster Number | Clustering Topics                                    | Main Hotspots       | Frequency of Occurrence | Degree |
|----------------|------------------------------------------------------|---------------------|-------------------------|--------|
| 0              | Learning-based Energy Storage System Operation       | Uncertainty         | 54                      | 28     |
|                |                                                      | Generator           | 33                      | 23     |
|                |                                                      | Demand Response     | 29                      | 16     |
|                |                                                      | Dispatch            | 19                      | 14     |
Table 2 shows the main hotspots of the 5 clusters and their three indicators of frequency and degree. The frequency of energy storage, model and uncertainty are all higher than 50; the degree of uncertainty, battery storage, impact, operation and generator are higher.

2.4 Trend Analysis of "Wind Energy Application" in China (CiteSpace mapping)
Based on the CNKI document engine, CiteSpace was used to conduct co-occurrence analysis of technical subject words and keywords in the searched 1960 papers, which took a year as the cutoff point. We can get 13 clusters by pruning and clustering the network with Pathfinder. Keep the top 6 clusters with better clustering effect as shown in Figure 3.

**Figure3.** Topic Clustering of China Wind Energy Application Field
It can be seen from the topic clustering map that there are 6 clusters from large to small are #0 maximum wind energy tracking,#3 wind energy resource evaluation,#5 numerical simulation,#6 industrialization,#7 wind power plant, #9 wind lifting, which ranks according to the number of points (keywords).
After generating the co-occurrence cluster map of keywords and subject words, the cluster number is taken as Y axis and the year of citation publication is taken as X axis. The timeline map of co-occurrence word network is obtained (Figure 4).

![Timeline Map](image)

**Figure 4.** Topic Clustering Timeline Map in China

The time map shows the time spans and research process of the development and evolution of each cluster. It can be seen from Figure 4 that all the 6 clusters have been studied since 2011. But related researches on #0 maximum wind energy tracking, #3 wind energy resource evaluation, and #9 wind lifting began to decrease or even disappeared until 2019. There is still some research on #5 numerical simulation, #6 industrialization, and #7 wind power plant. It can be seen from the tightness and continuity of the connection that #0 maximum wind energy tracking is the hottest research point, and #5 numerical simulation will be one of the research directions in the future.

Statistical analysis was conducted on the timeline nodes of each topic in Figure 4. Rank them in order of occurrence frequency from highest to lowest, and preserve hotspots associated with wind energy applications, we can get Table 2.

**Table 2.** Topic Research Hotspots Statistics in China

| Cluster Number | Clustering Topics          | Main Hotspots                             | Frequency of Occurrence | Degree |
|----------------|----------------------------|--------------------------------------------|-------------------------|--------|
| 0              | Maximum Wind Energy Tracking | Wind Power                                | 104                     | 35     |
|                |                            | Maximum Wind Energy Tracking              | 36                      | 19     |
|                |                            | Maximum Wind Energy Capture               | 34                      | 15     |
|                |                            | Wind Energy Conversion System             | 30                      | 11     |
|                |                            | Wind Turbine                               | 15                      | 15     |
|                |                            | Variable Speed Constant Frequency         | 13                      | 11     |
| 3              | Wind Energy Resource Evaluation | cfd Mode                                 | 3                       | 4      |
|                |                            | Microsite Selection                       | 3                       | 3      |
|                |                            | Calmet                                     | 3                       | 3      |
|                |                            | Fluid Mechanics                            | 2                       | 2      |
| 5              | Numerical Simulation       | Numerical Simulation                       | 78                      | 23     |
|                |                            | Wind Speed                                 | 45                      | 15     |
|                |                            | Wind Power Density Evaluation              | 42                      | 15     |
|                |                            | Evaluation                                 | 31                      | 7      |
Table 2 shows the hot words of the 6 clustering topics of wind energy application in China themes from 2011 to 2021. It can be seen that the frequency of wind power generation, maximum wind energy tracking, numerical simulation, and wind speed and wind power density is relatively high; the degree of wind power, generation simulation, wind power density and maximum wind energy tracking is relatively high.

3. Conclusion

3.1. Hotspots in global wind energy applications

During the six main clusters, it can be divided into two categories: the first one is the application of wind energy in energy storage, including #0 learning-based energy storage system operation, #4 pumped-hydro storage. Another is the application of wind energy in power grid, which mainly includes #1 techno-economic assessment, #2 control system, #5 distribution network.

To sum up, not only in the past ten years, but also in the future, the research hotspots and trends in the global wind energy application field are concentrated in two major sectors on wind energy storage and combining to the grid.

3.2. Hotspots in China's wind energy application

From the perspective of the application field of wind energy, the clustering points are relatively concentrated in wind power generation, offshore wind power and wind water carrying, which are the research hotspots in recent years. From the perspective of wind energy application technology, the evaluation of maximum wind energy tracking, maximum wind energy capture, wind energy conversion system, wind speed, wind power density etc., has always been the focus of research.

To sum up, the research hotspots and trends in the field of wind energy application in China in the past decade and in the future focus on offshore wind power and wind energy evaluation.

Acknowledgments

Yunnan Science and Technology Planning Project: A Strategic Study on The Construction of Market-oriented Green Technology Innovation System in Yunnan Province, 200115
Low-carbon Development Alternative Project of Yunnan Province: China (Yunnan) and South and Southeast Asia International Cooperation Mechanism Construction and Series of Activities 200125 Young People’s Self-Selected Project of Yunnan Academy of Scientific and Technical Information

References

[1] Li Haozhang, Liu Pingyuan, Wang Jinhong, Zhang Yipeng, Chen Jianbo. Analysis on the Development Status and Future Prospects of China’s Wind Power Industry [J]. Mechanical and Electrical Information, 2020, (21): 91-94.

[2] Lu Zhengshuai, Lin Hongyang, Yi Yang. Current situation and trend of wind power development [J]. China Science and Technology Information, 2017, (02): 91-92.

[3] Global Wind Energy Council. Global Wind Report 2021[R].

[4] Shneiderman B, Bederson B B. The craft of information visualization: Readings and reflections [M]. San Francisco: Morgan Kaufmann Publishers Inc, 2003.

[5] Searns R M. The evolution of greenways as an adaptive urban landscape form [J]. Landscape & Urban Planning, 1995, 33(1-3): 65-80.

[6] Fan Rong, Xu Haowen, Zhao Kaizheng. Research progress and trend of greenway theory in recent 30 years: A research on atlas quantification based on CiteSpace [J]. Ecological Economics, 2020, 36(07): 221-229.