Measurement and Analysis of the Development and Utilization Efficiency of Wind Energy in Jilin Province

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Abstract. On the basis of relevant literature review on energy efficiency, this paper firstly analyzed the overall situation of wind energy development and utilization in Jilin Province, then determined the input-output indicators of wind energy development and utilization according to the indicator-selection principles, and then used DEA analysis method to analyze the data of Jilin Province from 2005 to 2017. The research result shows that the scale of wind energy development in Jilin Province has been relatively appropriate since 2005, and its comprehensive efficiency value is mainly affected by pure technical efficiency. Therefore, it is necessary to strengthen the management of wind energy development in Jilin Province. But on the contrary, the comprehensive efficiency of wind energy utilization in Jilin Province is mainly affected by scale efficiency. Because the scale efficiency value has been decreasing year by year, the control of input scale of wind energy utilization should be strengthened, so as to further enhance the contribution rate of wind energy products to the national economy.

1. Introduction
Energy has played an important role in promoting social and financial development; it is the main pillar of support for the modern economy. So far, some scholars have done some research work on energy efficiency. For example, M Gao (2016) used the directional distance function to measure the energy efficiency of China's provinces and cities from 2005 to 2012 under the common frontier and regional frontier, analyzed the gap ratio, and decomposed the energy inefficiency into the inefficiency of technological gap and that of management [1]. Q Y Ran and J L Shen (2013) analyzed the characteristics of energy efficiency in Xinjiang Province of China, revealed the causes of low energy efficiency in Xinjiang Province, and finally put forward some corresponding countermeasures and suggestions [2]. X Wang and X E Qu (2010) used Manquist index method of non-parametric data envelopment analysis to analyze the data of 28 industries in China's manufacturing industry from 2001 to 2007. The results showed that the total factor energy efficiency of manufacturing industry was on the rise as a whole, but significant differences existed among different industries [3]. Q Y Ran (2010) used co-integration theory and error correction model to analyze the relationship between the industry structure and energy efficiency of Xinjiang Province from 1978 to 2007. The results showed that there was a long-term co-integration relationship between the second and third industry structure and energy efficiency in Xinjiang Province [4]. Z F Tan and J L Zhang (2010) used impulse response function and
variance decomposition model to further analyze the dynamic relationship between energy efficiency and its influencing factors in China [5].

In summary, in recent years, the research on energy efficiency mainly focuses on the overall energy efficiency of China and Xinjiang Province, as well as the energy efficiency of manufacturing industry. However, the research on wind energy development and utilization conducted from the perspective of efficiency is relatively few. Therefore, this paper took this as a breakthrough, and carried out an empirical study on the evaluation of the efficiency of the development and utilization of wind energy in Jilin province of China.

2. Overall situation of wind energy development and utilization in Jilin Province
Jilin Province, one of China’s important historical industrial bases, has been rapidly expanding amidst increasing industrialization and urbanization since the Chinese government’s Northeast Revitalization Strategy was implemented in 2003, and the demand for energy has risen. However, fossil fuels are relatively scarce in Jilin, and the self-sufficiency rate for this type of energy is less than 50%. Jilin has abundant secondary energy sources such as wind, biomass, solar energy, and other new and renewable sources that have great potential for growth.

Jilin Province has relatively strong wind resources and obvious regional advantages. The plains account for about 35% of all land. The western region belongs to one of the three most intensive areas of wind resources in the country. Wind resources are mainly concentrated in the western region, including Baicheng, Tongyu, Taonan, Songyuan and Qian’an areas. Under the guidance of China’s policy to develop clean energy, Jilin’s wind power sector has grown rapidly and is now the second largest power supplier for Jilin’s power grid. From Figure 1, we can see that the wind power generation of Jilin Province has increased by year since 2005, reaching 8.23 billion kilowatt-hours in 2017, and its proportion in the total power generation of Jilin Province has also increased year by year since 2005, reaching over 11% by 2017.

![Figure 1. Wind power generation and its proportion to the total power generation in Jilin province.](image)

From the perspective of the total installed capacity of wind power, the overall scale of wind power construction in Jilin has increased significantly. From Figure 2, we can see that, by 2017, it reached 5,480 MW, ranking the twelfth among all of China’s provinces and cities. However, the average number of usage hours for wind power equipment in Jilin was only 1,721 in 2017, the amount of abandoned wind power was 2.3 billion kWh, and the rate of abandoned wind reached 21%. Among Chinese provinces, Jilin has one of the highest rates of abandoned wind power, ranking only after Gansu Province and Xinjiang Province.
3. Selection of input-output indexes for wind energy development and utilization efficiency

3.1. Principle of Index selection
Index selection should first consider what the purpose of the evaluation is, so as to reasonably determine the input and output indicators; secondly, excessive input and output indicators will lead to an increase in the number of effective DMU, leading to a decline in DEA effectiveness, so the index selection should be streamlined; thirdly, the selected indicators should be logically correlated, but not numerically correlative; fourthly, diversity should also be considered while selecting the indexes. Based on the above principles, the results of wind energy development and utilization index selection are as follows.

3.2. Selection of input-output indexes for wind energy development efficiency

3.2.1. Input index. The input indexes are mainly considered from the input of people, money and goods. Since the equipments used for wind energy development also need to be bought using money, the financial and material input can be attributed to capital investment. The capital input may come from central finance, local finance and social capital according to its source, and the personnel input can be expressed by the number of employees at the end of the year. However, because it is impossible to collect the data of capital input and personnel input of wind power industry, and all the inputs are eventually used for the construction of wind power installed capacity, this paper regards the accumulated installed capacity of wind power as the input index.

3.2.2. Output index. Since wind power is mainly used for generating power, the output index is expressed by wind power generation capacity.

3.3. Selection of input-output indicators for wind energy utilization efficiency

3.3.1. Input index. Input index refers to the output of wind energy, that is, wind power generation capacity, which is consistent with the output index of wind energy development efficiency.

3.3.2. Output index. The output can mainly be expressed by the following two indexes: (1) the proportion of wind energy output to GDP; (2) the industrial added value of wind energy. Since the
data of these two indicators are unavailable and we mainly consider the contribution of wind energy to the economy while designing the output indicators, therefore this paper chose the percentage of wind power generation to total power generation as the output index of wind energy utilization efficiency.

4. Measurement and analysis of wind energy development and utilization efficiency in Jilin Province

4.1. Measurement and analysis of wind energy development efficiency

4.1.1. Measurement of wind energy development efficiency. Wind energy development efficiency refers to the efficiency of wind energy production process, that is, to examine the efficiency of wind energy in the production process and to measure the rationality of input scale and the utilization of various input resources from the perspective of wind energy production process. In this paper, the data of Jilin Province from 2005 to 2017 were selected to do data envelopment analysis to obtain the measurement results of wind energy development efficiency in Jilin Province. Details are shown in Table 1.

| Year | Crste | Vrste | Scale | Trend |
|------|-------|-------|-------|-------|
| 2005 | 0.609 | 1     | 0.609 | irs   |
| 2006 | 0.79  | 0.946 | 0.835 | irs   |
| 2007 | 0.653 | 0.697 | 0.937 | irs   |
| 2008 | 0.854 | 0.883 | 0.967 | irs   |
| 2009 | 0.717 | 0.726 | 0.987 | irs   |
| 2010 | 0.751 | 0.756 | 0.993 | irs   |
| 2011 | 0.745 | 0.748 | 0.996 | irs   |
| 2012 | 0.731 | 0.734 | 0.997 | irs   |
| 2013 | 0.88  | 0.882 | 0.998 | irs   |
| 2014 | 0.836 | 0.837 | 0.999 | irs   |
| 2015 | 0.89  | 0.89  | 1     | -     |
| 2016 | 0.99  | 0.991 | 1     | -     |
| 2017 | 1     | 1     | 1     | -     |
| Mean | 0.804 | 0.853 | 0.947 |

4.1.2. Result analysis. Pure technical efficiency reflects the production efficiency of the input factors of DMU at the optimal scale, and represents the production efficiency of enterprises affected by its management and technology level. Scale efficiency reflects the discrepancy between actual and optimal production scale, while comprehensive efficiency is the product of both. From the data in Table 1, we can see that the comprehensive efficiency, pure technical efficiency and scale efficiency of wind energy development in Jilin Province fluctuated from 2005 to 2017, and the three efficiency values reached 1 in 2017. In 2017, the scale efficiency was 1, showing that the scale was in the best state at that time; pure technical efficiency was 1, indicating that the resource allocation of wind energy development was optimal and the output of wind energy was the largest compared with its input. Since the comprehensive efficiency is the product of pure technical efficiency and scale efficiency, so the comprehensive efficiency was also 1 in 2017, indicating that the wind energy development in Jilin Province in 2017 was not only reasonable in scale, but also efficient in management, and the optimal allocation of resources was achieved.
The pure technical efficiency of wind energy development was close to or equal to 1 in 2005, 2006, 2016 and 2017 in Jilin Province, showing that the output of wind energy development (i.e. wind power generation capacity) basically reached the largest relative to its input (i.e. cumulative installed capacity of wind power), realizing the optimal allocation of resources. While the data of other years was basically around 0.8, showing that there were some problems in the management of wind energy development in Jilin Province, and the optimal allocation of resources was not achieved in these years, existing waste of resources.

The data of scale efficiency from 2007 to 2017 was basically close to or equal to 1, but that of 2005 and 2006 was relatively smaller, which showed that the input in wind energy development of Jilin Province had achieved scale efficiency except the initial stage of construction.

The data of comprehensive efficiency of 2016 and 2017 was close to or equal to 1, and that of the rest years showed relatively significant changes. The comprehensive efficiency of 2005 and 2006 was mainly affected by scale efficiency, indicating that the investment in Jilin Province’s wind energy development was not enough, need to be expanded, and the installed capacity of wind power also need to be increased. The comprehensive efficiency from 2007 to 2017 was mainly affected by pure technical efficiency, which was caused by management and technology factors.

The returns to scale have shown an increasing trend from 2005 to 2014, indicating that the overall scale of wind energy development in Jilin Province was relatively small, and the input in wind energy development should be increased so as to improve the input-output efficiency of wind energy development.

4.2. Measurement and analysis of wind energy utilization efficiency

4.2.1. Measurement of wind energy utilization efficiency. Wind energy utilization efficiency is to investigate the role of wind energy products in promoting regional economic growth, that is, the utilization efficiency of wind energy products. According to the input-output indexes of wind energy utilization efficiency defined above, this paper used DEAP software to do data envelopment analysis based on the data of Jilin Province from 2005 to 2017, and obtained the measurement results of wind energy utilization efficiency in Jilin Province, as shown in Table 2.

Table 2. Measurement results of wind energy development efficiency.

| Year | Crste | Vrste | Scale | Trend |
|------|-------|-------|-------|-------|
| 2005 | 0.609 | 1     | 0.609 | irs   |
| 2006 | 0.79  | 0.946 | 0.835 | irs   |
| 2007 | 0.653 | 0.697 | 0.937 | irs   |
| 2008 | 0.854 | 0.883 | 0.967 | irs   |
| 2009 | 0.717 | 0.726 | 0.987 | irs   |
| 2010 | 0.751 | 0.756 | 0.993 | irs   |
| 2011 | 0.745 | 0.748 | 0.996 | irs   |
| 2012 | 0.731 | 0.734 | 0.997 | irs   |
| 2013 | 0.88  | 0.882 | 0.998 | irs   |
| 2014 | 0.836 | 0.837 | 0.999 | irs   |
| 2015 | 0.89  | 0.89  | 1     | -     |
| 2016 | 0.99  | 0.991 | 1     | -     |
| 2017 | 1     | 1     | 1     | -     |
| Mean | 0.804 | 0.853 | 0.947 |       |
4.2.2. **Result analysis.** From the data in Table 2, we can see that the comprehensive efficiency, pure technical efficiency and scale efficiency of wind energy utilization in Jilin Province reached 1 in 2005. Scale efficiency was 1, showing that the scale was in the best state at that time; pure technical efficiency was 1, indicating that the resource allocation of wind energy utilization was optimal and the output of wind energy utilization was the largest compared with its input; comprehensive efficiency was 1, meaning that the wind energy produced that year was invested in the national economy totally, the contribution rate of wind energy to the national economy in 2005 was the highest, the energy loss was the smallest, and energy efficiency was the highest.

The pure technical efficiency of wind energy development was close to or equal to 1 from 2005 to 2017 in Jilin Province, showing that the output of wind energy utilization (i.e. the contribution of wind energy to economic growth) was basically optimal relative to its input (i.e. wind power generation), realizing the optimal allocation of resources. This also showed that the management of wind energy utilization in Jilin Province had been effective in these years.

The scale efficiency has been decreasing since 2005. In 2017, it was reduced to 0.583, indicating that the input in Jilin Province’s wind energy utilization failed to achieve effective scale.

Except for the data of 2005 to be 1, the comprehensive efficiency of the rest years was mainly affected by scale efficiency and has shown decreasing trend. The returns to scale have shown a decreasing trend from 2005 to 2017, showing that Jilin Province should reduce the input in wind energy utilization, which is good for improving the utilization efficiency of wind energy. Therefore, this requires the government to reduce the use of wind energy products in this period of time, so as to improve its contribution to economic growth.

5. **Conclusion**

In this paper, DEA data envelopment analysis was used to analyze the efficiency of wind energy development and utilization in Jilin province. According to the principle of indicator selection and the availability of data, the cumulative installed capacity of wind power and wind power generation were selected as the input and output indicators of wind energy development efficiency, and wind power generation and the proportion of wind power generation to the total generation were selected as the input and output indicators of wind energy utilization efficiency.

The research result shows that the scale of wind energy development in Jilin Province has been relatively appropriate since 2005, and its comprehensive efficiency value is mainly affected by pure technical efficiency. Therefore, it is necessary to strengthen the management of wind energy development in Jilin Province. But on the contrary, the comprehensive efficiency of wind energy utilization in Jilin Province is mainly affected by scale efficiency. Because the scale efficiency value has been decreasing year by year, the control of input scale of wind energy utilization should be strengthened, so as to further enhance the contribution rate of wind energy products to the national economy.

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