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Assessment and Analysis of 120m Wind Energy Resources in Heilongjiang Province

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Abstract: In order to efficiently develop wind energy, multi-level mining and utilization of wind energy resources in Heilongjiang Province, and to help increase industrial value and ecological efficiency, this article evaluates and studies the 120m wind energy in Heilongjiang Province. This article uses observation data from 85 national meteorological stations in Heilongjiang Province from 1980 to 2023, and applies statistical methods to study the spatiotemporal variation characteristics, effective wind hours, and wind power density of wind speed in Heilongjiang Province. The results of this article indicate that the 120 meter low wind speed areas in Heilongjiang Province are mainly concentrated in the central part of Heilongjiang, while the high wind speed areas are concentrated in the eastern and western parts of Heilongjiang. The average annual effective wind hours over the years show a spatial distribution characteristic of high in the east, middle in the west, and low in the middle. The wind power density shows a decreasing trend, and the average wind power density in each season shows a distribution of high in the south and low in the north. The construction of wind farms is best in Jiamusi City, eastern Hegang City, and Shuangyashan City in Heilongjiang Province.

1. Introduction

With industrial development, traditional energy sources such as oil and natural gas are increasingly in short supply, and the environmental pollution caused by combustion has become more severe[1]. Renewable energy sources like wind and solar power have gained attention from countries worldwide[2]. The transformation and upgrading of the energy structure, along with the development and utilization of new energy sources, have become an inevitable trend for the sustainable development of the social economy and environment. Research indicates that Northeast China is rich in wind and solar energy resources. According to the three-tier regional classification index system for the spatial distribution of wind energy resources in China by the Chinese Academy of Meteorological Sciences[3], the near-surface (upper boundary height of approximately 50-100 meters) wind energy resources in Northeast China are relatively abundant[4], primarily consisting of wind-rich areas, moderately wind-rich areas, and wind-utilizable areas, with no wind-deficient zones. However, from 1971 to 2007, the average annual wind speed in most regions of the country showed a declining trend[5].

Wind energy resources are influenced by factors such as the broader climate background and terrain, often resulting in uneven distribution and significant volatility. To effectively avoid the impact of near-ground turbulence and obstacles, obtain more stable and efficient wind energy, better exploit and utilize Heilongjiang's wind resources, and comprehensively ensure life safety, production development, affluent living, and ecological well-being, it is crucial to implement "Meteorology+" empowerment actions around the wind power industry, mastering its higher-level spatiotemporal distribution characteristics and development potential.

2. Data and Research Methods

The research data in this study are sourced from hourly wind speed data collected by the National Ground Routine Meteorological Observation Stations in Heilongjiang Province from 1980 to 2023, with station distribution shown in Figure 1. The DEM data are obtained from the Resource and Environment Science Data Center of the Chinese Academy of Sciences, with a resolution of 1 km.

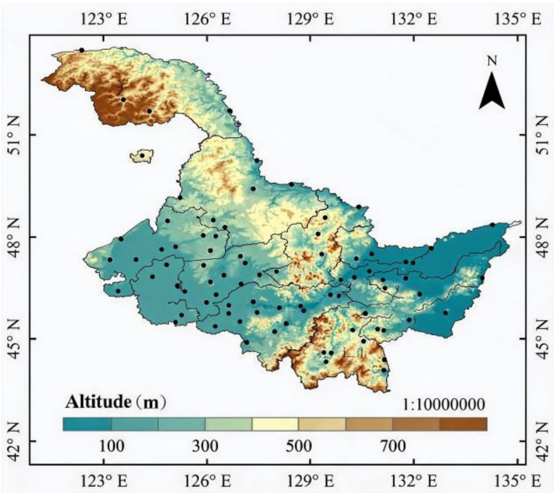


Figure 1. Distribution of Meteorological Stations in Heilongjiang

This study used station observations of 10 meter wind speed data and statistical methods to calculate 120 meter high-altitude wind speed, effective wind hours, wind power density, etc.

2.1. High altitude wind speed at 120m

In meteorological data, the wind speed data measured by the national meteorological station is obtained at a height of 10 meters above the ground, while the hub height of the wind turbine is 120 meters, and the two heights are inconsistent. Therefore, it is necessary to process the wind speed data at a height of 10 meters and extrapolate it to the hub height of the wind turbine to obtain the wind speed at the hub height. The extrapolation formula is as follows:

$$v=v_0\left(\frac{h}{h_0}\right)^m$$

Among them, v_0 is the wind speed at the original height, h_0 is the original height, m represents the wind shear index, and its value depends on the surface roughness.

Based on the literature review, this study found that the wind shear index depends on the surface roughness, and the wind shear index is generally higher in mountainous and hilly areas than in plain areas. According to the study on the near surface wind shear index of different underlying surfaces in China, the wind shear index of flat terrain (such as Xilinhot, Inner Mongolia) under stable stratification is usually lower than 0.2, while the surface roughness in the Heilongjiang Plain is lower, so the value is more reliable, taking 0.14 [6].The study on wind shear index in wind resource evaluation points out that the vertical variation of wind speed in hilly areas is intensified due to terrain undulations, and the wind shear index calculated by speed range is generally 0.03-0.05 higher than that in plains, with a value of 0.18 [7].The frequency of stratified wind shear index $\alpha>0.4$ in Xingzi County, Jiangxi Province (with complex terrain) is 10%. Although there is no equivalent data in the mountainous areas of Heilongjiang Province, the terrain complexity is similar, and a conservative value of 0.24 is taken to cover extreme situations [8]. Comparing with the research results of other researchers [9-11], please refer to Table 1 for details.

Table 1. Wind Shear Index in Different Terrain Regions of Heilongjiang Province

Region	City	Wind shear index m
plain areas	Daqing City, Suihua City, Harbin City, Qiqihar City	0.14
hilly/transitional areas	Jiamusi City, Shuangyashan City, Qitaihe City, Jixi City, Hegang City	0.18
mountainous/high wind shear areas	Yichun City, Heihe City, Mudanjiang City, and Daxing'anling area	0.24

2.2. Differentiation of 120m wind speed range

Divide the 120m wind speed into intervals of 1 m/s, calculate the frequency of each interval, and draw a Weibull function fitting curve. The formula is as follows:

$$f(x,\lambda,k)=\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1}e^{-\left(\frac{x}{\lambda}\right)^{k}}$$

2.3. Effective wind hours

As an important indicator for wind energy resource assessment, the larger the effective wind hours, the greater the available amount of wind energy resources in the region. In general, the calculation formula for effective wind hours is:

$$T=\sum_{v_i=v_0}^{v_n}T(v_i)$$

Among them, v_i represents the wind speed at a certain moment, T denotes time, v_0 is the cut-in wind speed, and v_n is the cut-out wind speed. According to China's standard "Assessment Method for Wind Energy Resources in Wind Farms," the cut-in wind speed is 3 m/s, and the cut-out wind speed is 20 m/s.

2.4. Wind Power Density

Wind power density refers to the power contained in wind per unit area perpendicular to the wind direction. It represents the wind energy generated by air flow per unit area per unit time and serves as a crucial comprehensive indicator for wind energy resource assessment, influenced by factors such as wind speed and air density. In wind farms, wind power density can be directly measured. Due to data acquisition limitations, this project employs the following calculation method for wind power density:

$$P=\frac{1}{2n}\sum_{i=1}^{n}\rho v_i^3$$

In this context, P represents the wind power density (W/m ³), n is the number of wind records within the statistical time period, v_i is the wind speed magnitude of the i-th record, and ρ is the air density. Under standard conditions (0 ℃, 1 standard atmosphere (1 atm)), the air density is typically used for calculations, approximately 1.29 kg/m ³.

In addition, when studying the spatial distribution characteristics of various elements, Kriging interpolation was performed using ArcGIS.

3. Research Results

3.1. Spatiotemporal variation characteristics of 120m wind speed in Heilongjiang Province

According to the MK test (Figure 2), there is no intersection between the annual average wind speed UB and UF lines, indicating that there is no sudden change in the annual average wind speed of 120m in Heilongjiang from 1980 to 2023. The average wind speed in spring, summer, autumn, and winter is consistent with the annual average wind speed trend, with no sudden changes.

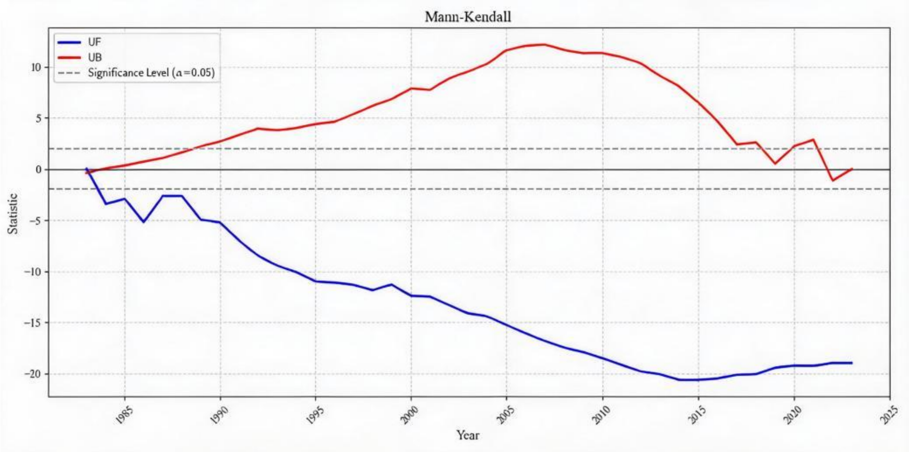


Figure 2. Annual average wind speed MK test chart

Figure 3 shows the frequency distribution in the 120m wind speed range. It can be seen that the frequency is highest in the 1-2 m/s range, at 16.4%, and the wind speed frequency is greater than 10% in the 0-5 m/s. The wind speed at 120m is mainly concentrated between 0-6 m/s, with a frequency of 70%. The fitting curve has k=1.41 and λ=4.45, and the formula for the fitting curve is as follows:

$$f(x,4.45,1.41)=0.32\left(\frac{x}{4.45}\right)^{0.41}e^{-\left(\frac{x}{4.45}\right)^{1.41}}$$

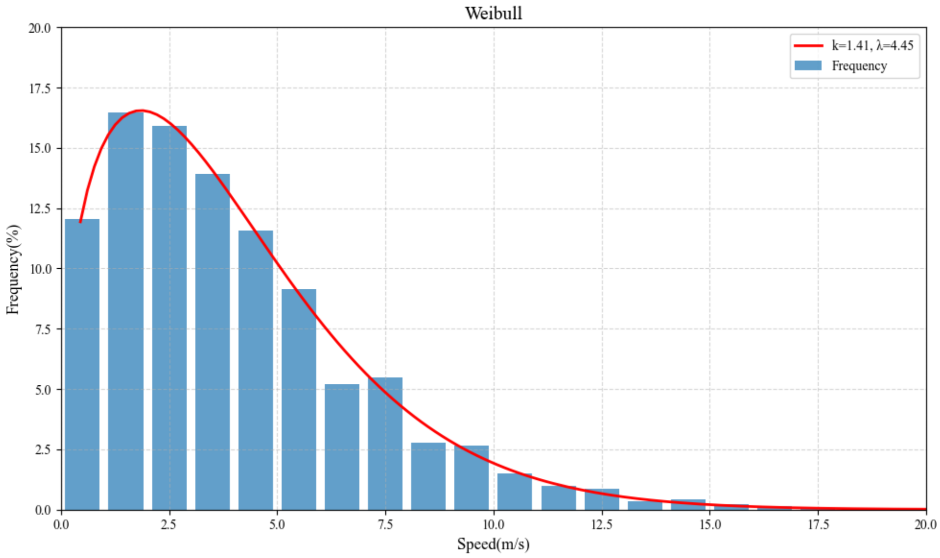


Figure 3. Frequency distribution of 120m wind speed interval

The average annual wind speed in Heilongjiang Province from 1980 to 2023 shows a trend of first decreasing and then increasing, with the lowest wind speed reaching 3.51 m/s in 2012. From 1980 to 2023, the overall wind speed at 120 m showed a decreasing trend, with a rate of -0.22 m/(s * 10a) (p>95%). From the perspective of seasonal changes, compared with other seasons, the wind speed in spring is relatively high, with wind speeds generally maintaining between 4.0 and 6.5 m/s, and decreasing at a rate of -0.26 m/(s * 10a) overall. The wind speed in summer, autumn, and winter is relatively consistent and shows a significant decreasing trend, with decreasing rates of 0.21 m/(s * 10a), 0.28 m/(s * 10a), and 0.14 m/(s * 10a), respectively. From the annual variation of wind speed, it can also be seen that the wind speed in Heilongjiang presents a bimodal characteristic, with higher wind speeds in spring and autumn, averaging around 5.0 m/s (Table 2).

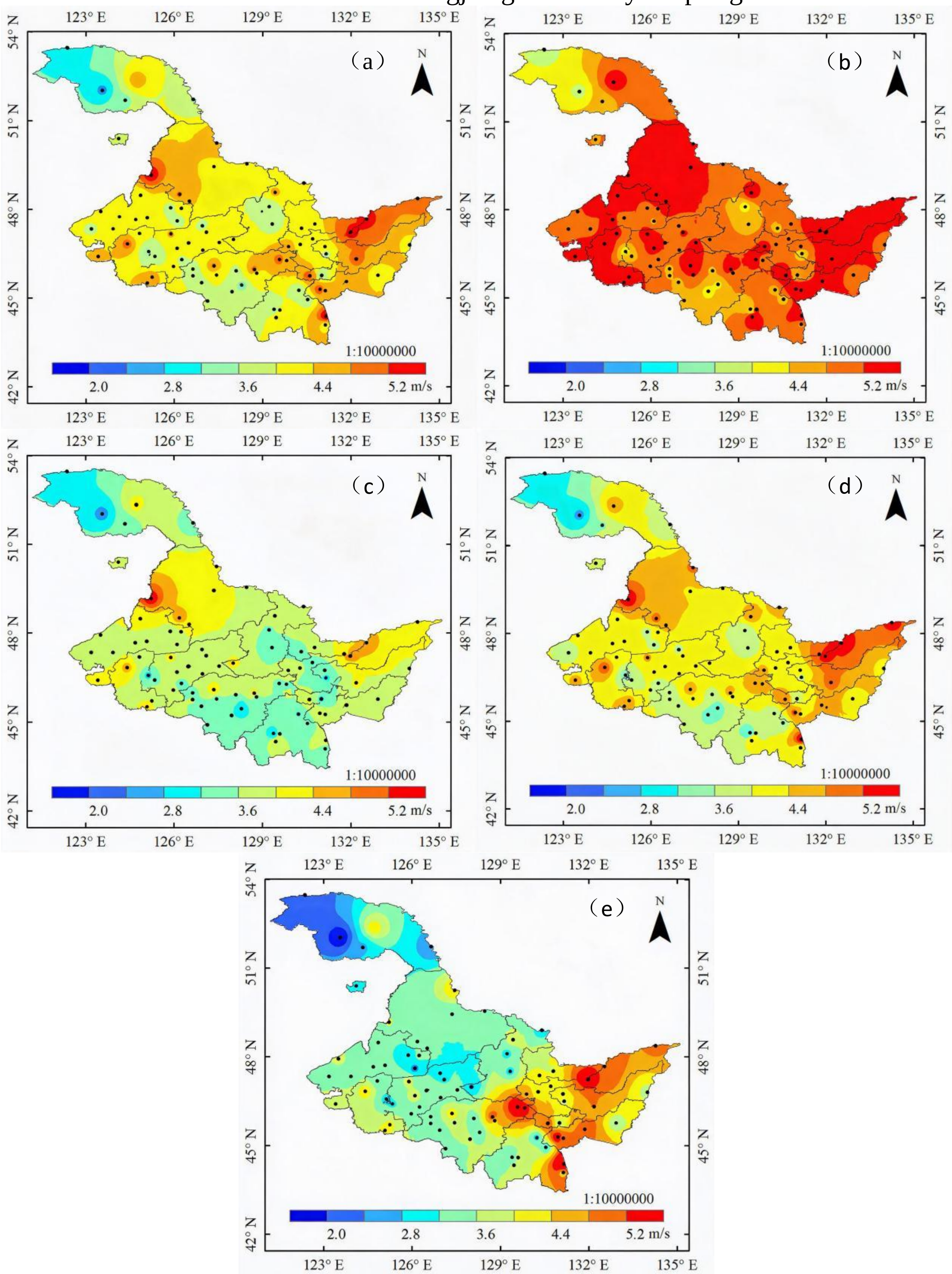
Overall, the annual and seasonal average wind speeds in Heilongjiang show a decreasing trend, with a greater decrease rate in spring and autumn. But after 2013, the wind speed showed an increasing trend, which means that the wind speed in Heilongjiang region may increase in the future.

Table 2. Climate Tendency of Wind Speed at 120m in Heilongjiang Province (Unit: m/(s * 10a))

Season	Climate inclination rate	
	Climate inclination rate	P value
spring	-0.26	0.00
summer	-0.21	0.00
autumn	-0.28	0.00
winter	-0.14	0.00
year	-0.22	0.00

Note: A P-value less than 0.05 indicates passing the significance test.

Figure 4 shows the spatial distribution of annual and seasonal average wind speeds of 120 meters in Heilongjiang. It can be seen that the average wind speed of 120 meters over the years shows significant spatial differences. The wind speed in Daxing'anling, Yichun City, Mudanjiang City, Harbin City and other areas is relatively low, with wind speeds generally maintained below 3.6 m/s, while in most other areas, wind speeds remain around 4.0 m/s. From the perspective of seasonal changes, the spatial distribution of high and low wind speeds is consistent with the annual average wind speed, but there are significant differences in the magnitude of wind speeds. Especially in spring, the wind speed in the western and eastern parts of Heilongjiang is above 5.2 m/s, while in the Greater Khingan Range, Yichun City, and Mudanjiang City, the wind speed is relatively low but still around 4.8 m/s. Secondly, in autumn, the spatial distribution is consistent with the annual average wind speed, while in summer and winter, the wind speed is lower than the annual average. It can be seen that the wind resources in Heilongjiang are mainly in spring and autumn.



(a) Year, (b) Spring, (c) Summer, (d) Autumn, (e) Winter

Figure 4. Spatial distribution characteristics of wind speed at 120m in Heilongjiang Province

There are significant spatiotemporal differences in the trend of annual average wind speed of 120m in the central and southern parts of Heilongjiang Province. In the eastern part of Daqing City and Qitaihe City, the annual average wind speed at 10m shows a significant upward trend, reaching 0.3m/s * 10a, while in areas such as Qiqihar City, Suihua City, and Shuangyashan City, the wind speed shows a significant downward trend, reaching -0.4m/s * 10a. In the Greater Khingan Range, Heihe City, and surrounding areas, the annual average wind speed of 120 meters shows a consistent decreasing trend, but the rate is generally between -0.4-0 meters per (s * 10a). From the perspective of seasonal changes, the trend of wind speed throughout the four seasons is consistent with the year.

3.2. Spatiotemporal variation characteristics of effective wind hours in Heilongjiang Province

Due to the presence of 6-hour data in the data, in order to ensure the accuracy of effective hours, this article uses data from 2005 to 2023 for statistics. The statistics show that the effective wind hours from 2005 to 2023 range from 4174-5244 hours, and overall increase at a rate of 431.3 hours per 10 years. From the perspective of seasonal changes, spring has the highest effective wind hours, ranging from 1210-1527 hours, increasing at a rate of 108.7 hours per year, followed by autumn with effective wind hours ranging from 962-1345 hours, increasing at a rate of 134.7 hours per year. The effective summer monsoon hours range from 944-1235 hours, with a growth rate of 122.3 hours per 10 years. The minimum effective wind hours in winter are between 833-1297 hours, with a growth rate of 104.2 hours per decade(Table 3). From the perspective of annual changes, the effective wind hours in Heilongjiang region reached their maximum in April, at 485 hours, and their minimum in August, at 349 hours.

Overall, among the annual effective wind hours in Heilongjiang, spring contributes the most, followed by autumn.

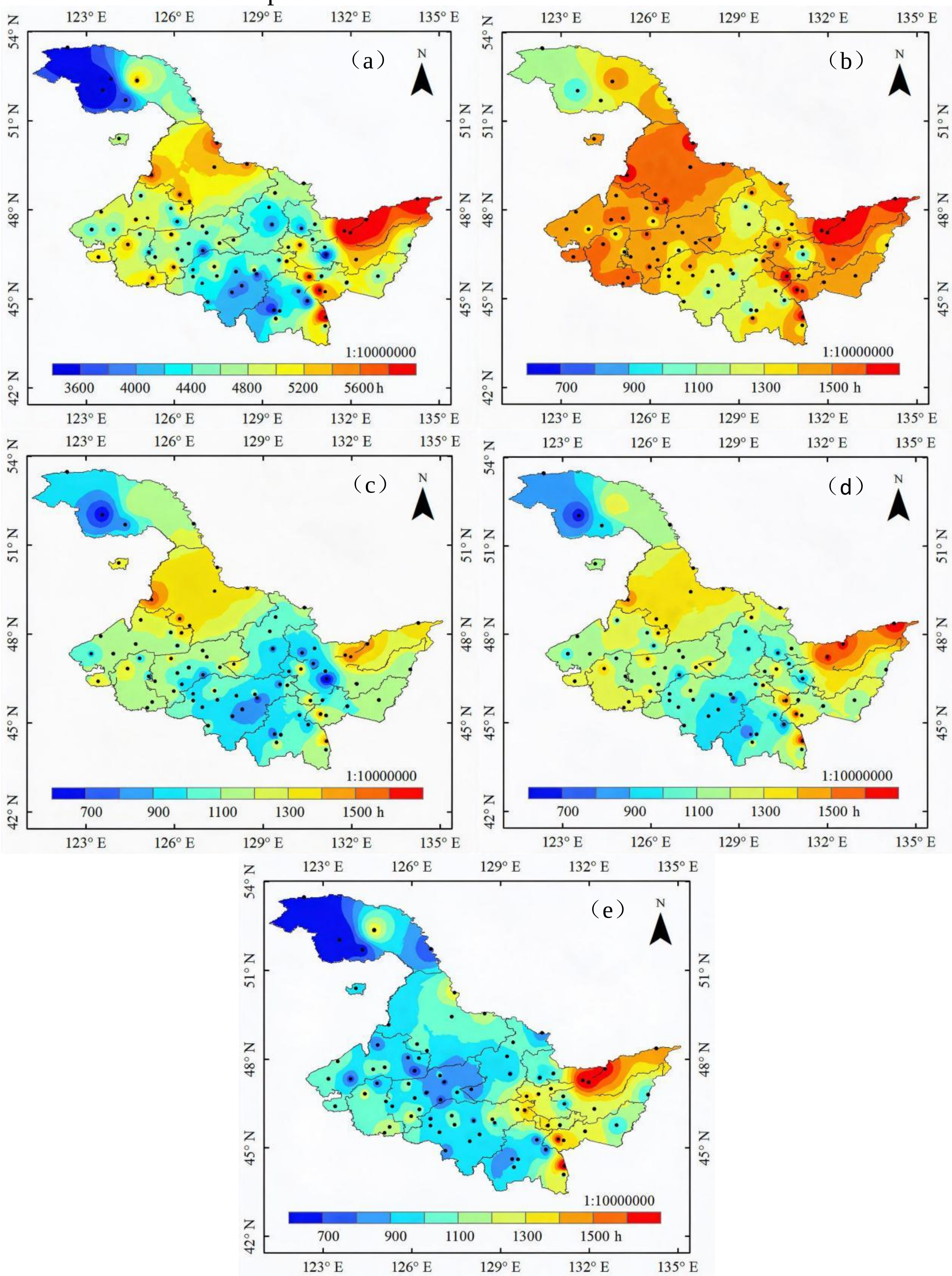
Table 3. Climate Tendency Rate of Effective Wind Hours in Heilongjiang Province (Unit: h/10a)

Season	Climate inclination rate	
	Climate inclination rate	P value
spring	108.7	0.00
summer	122.3	0.00
autumn	134.7	0.00
winter	104.2	0.03
year	431.3	0.00

Note: A P-value less than 0.05 indicates passing the significance test.

Figure 5 shows the spatial distribution of effective wind hours in Heilongjiang. It can be observed that the long-term average annual effective wind hours exhibit a spatial distribution pattern with higher values in the eastern and western regions and lower values in the central area. The Daxing'an Mountains, Yichun City, Mudanjiang City, Harbin City, and surrounding areas are low-value zones, with effective wind hours not exceeding 4,400 hours. Jiamusi City and its surrounding areas are high-value zones, reaching 5,400 hours, while effective wind hours in other regions are generally around 4,600 hours. In terms of seasonal variations, the high- and low-value zones of effective wind hours across the four seasons align with the annual distribution. However, the magnitude of effective wind hours reveals that spring has the highest values, with most regions maintaining over 1,300 hours. The maximum effective wind hours are recorded in Jiamusi, reaching 1,500 hours, while those in autumn, summer, and winter are relatively lower compared to spring.

The annual effective wind duration exhibits significant spatial variability. The most pronounced increase occurs in western Heilongjiang (Qiqihar, Suihua, Yichun, and surrounding areas), with a trend exceeding 800 hours per decade. In contrast, Shuangyashan and its surrounding regions show an increase of approximately 400 hours per decade. Meanwhile, the Greater Khingan Range, Harbin, and adjacent areas display weaker upward trends or even declining tendencies. Seasonally, the spatial distribution of effective wind duration in spring, autumn, summer, and winter aligns with the annual effective wind duration pattern.



(a) year, (b) spring, (c) summer, (d) autumn, (e) winter

Figure. 5 Spatial Distribution of Annual and Seasonal Average Effective Wind Hours in Heilongjiang

3.3. Spatial and Temporal Variation Characteristics of Wind Power Density in Heilongjiang

The annual wind power density ranges between 101.1 and 279.2 W/m^3, showing an overall decreasing trend at a rate of -33.3 W/(10a·m^3), which is statistically significant at the 95% level. After 2010, the wind power density exhibits an increasing trend, indicating a potential future rise. In spring, the wind power density ranges from 143.3 to 527.4 W/m^3, decreasing at a rate of -52.5 W/(10a·m^3). In autumn, it ranges from 77.5 to 299.5 W/(10a·m^3), decreasing at a rate of -37.8 W/(10a·m^3). During summer and winter, the wind power density is relatively close, with both showing decreasing trends at rates of -22.1 and -21.6 W/(10a·m^3) respectively (Table 4). From the monthly variation, the wind power density peaks in April at 266.7 W/m^3 and reaches its lowest point in July at 72.9 W/m^3. Overall, Heilongjiang region experiences the highest wind power density in spring, followed by autumn, with potential future increases.

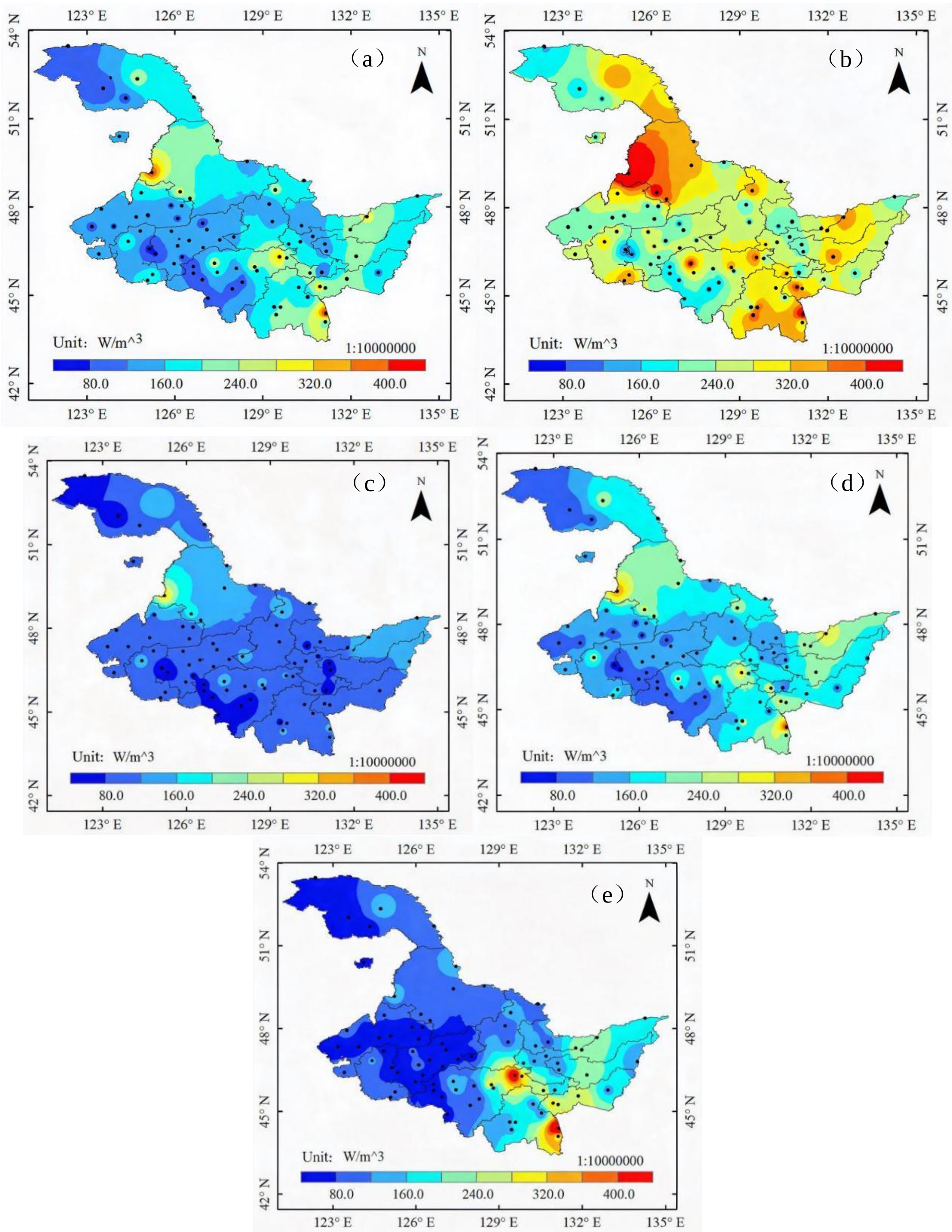
Table. 4 Linear Trend of Wind Power Density in Heilongjiang Province (Unit: W/(10a * m3))

Season	Climate inclination rate	
	Climate inclination rate	P value
spring	-52.5	0.00
summer	-22.1	0.00
autumn	-37.8	0.00
winter	-21.6	0.00
year	-33.3	0.00

Note: A P-value less than 0.05 indicates passing the significance test.

Figure 6 shows the spatial distribution of wind power density in Heilongjiang Province. It can be seen that the annual average wind power density is mainly concentrated in Heihe City and the eastern part of Heilongjiang Province. Daxing'anling, Qiqihar, Suihua City, Daqing City, Harbin City and surrounding areas are low value areas, with an annual wind power density of no more than 200 W/m3. Jiamusi City, Shuangyashan City, Jixi City and Mudanjiang City are high-value areas, with an annual wind power density basically maintained between 200-320 W/m3. From the perspective of seasonal changes, the spatial distribution of wind power density in spring is basically consistent with the spatial distribution of annual average wind power density, but the wind power density corresponding to high and low value areas is greater than the annual average wind power density. The spatial distribution characteristics of the average wind power density in autumn, winter, and summer are consistent with the annual average, but the wind power density decreases continuously from autumn to winter to summer, especially in summer, where the wind power density in most areas does not exceed 160 W/m3.

The annual average wind power density mainly shows a decreasing trend in the Heilongjiang region, especially in the Daxing'anling area and the eastern part of Harbin city, with a reduction rate of -70.0 W/(m3 * 10a). The spring wind power density varies greatly throughout the province, showing an increasing trend in the eastern part of Daqing City, Qitaihe City, Jiamusi City, and other areas, while showing a decreasing trend in other areas, especially in Suihua City, Qiqihar and other areas where the decrease is more pronounced. Compared with summer, autumn, and winter, the absolute value of the climate tendency rate of spring wind power density is larger, indicating that the changes in spring wind power density in Heilongjiang region are more severe.



(a) Year, (b) Spring, (c) Summer, (d) Autumn, (e) Winter

Figure. 6 Spatial distribution of wind power density in Heilongjiang Province

4. Conclusion

This article uses hourly wind speed data from 1980 to 2023 and applies statistical methods to analyze the spatiotemporal characteristics of wind speed in Heilongjiang Province, and calculates the effective wind hours and wind power density throughout the province. The following main conclusions are drawn:

(1) The wind speed at 120m in spring and autumn is significantly higher than that in summer and winter. The areas with low wind speeds of 120m throughout the year and four seasons are mainly concentrated in the central part of Heilongjiang, while the areas with high wind speeds are concentrated on the east and west sides of Heilongjiang. Overall, the 120m wind speed in Heilongjiang region has shown a downward trend over the past few decades, with little difference in the trend of wind speed changes throughout the four seasons.

(2) The effective wind hours in spring are significantly higher than the other three seasons, followed by autumn. The low value areas of annual and seasonal effective wind hours are mainly concentrated in Harbin, Mudanjiang, Yichun and Daxing'anling areas, while the high value areas are concentrated on the east and west sides of Heilongjiang. There is not much difference in the climate tendency rate of effective wind hours between the year and the four seasons. The high-value areas are concentrated on the east and west sides of Heilongjiang Province, while the low value areas are mainly concentrated in the central and northern parts of Heilongjiang Province.

(3) The wind power density in spring is significantly higher than in the other three seasons. The average wind power density in different seasons shows a distribution of high in the south and low in the north, with high-value areas concentrated in Heihe City and the eastern part of Heilongjiang Province. The climate tendency rate of wind power density in Heilongjiang region for many years is generally less than 0 W/(10a * m3), so wind power density has shown a downward trend over the past few decades. The absolute values of wind power density and climate inclination rate in the four seasons are highest in spring, followed by autumn. The areas with low climate inclination rates throughout the year and four seasons are mainly concentrated in the central part of Heilongjiang, while other regions tend to be larger.

(4) As a clean energy source, the development of wind energy can help reduce greenhouse gas emissions and improve air quality. This article summarizes the spatiotemporal distribution characteristics of effective wind hours and wind power density in the Heilongjiang region, and finds that wind farm construction is best in Jiamusi City, eastern Hegang City, and Shuangyashan City, providing reference for future wind farm construction in the Heilongjiang region.

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