ASSESSMENT OF WIND ENERGY POTENTIAL IN THE BIEN DONG SEA USING CCMP SATELLITE DATA

Nguyen Van Thang, Pham Thi Thanh Nga, Vu Van Thang, Truong Thi Thanh Thuy, Tran Duy Thuc

Viet Nam Institute of Meteorology, Hydrology, and Climate Change

Received: 21 July 2022; Accepted: 30 August 2022

Abstract: *This study assessesed the wind energy potential in the Bien Dong Sea by using the Cross-Calibrated Multi-Platform (CCMP) satellite wind data from 1991 to 2020. The results showed that the wind energy potential at 10 m height above ground is not high in the offshore areas with annual mean wind speeds ranging from 5 to 8 m/s. At heights of 100 m, 150 m, and 200 m, the greatest wind energy potential is found in the offshore areas of the North Bien Dong Sea Region, Binh Dinh - Ninh Thuan, Binh Thuan - Ca Mau, and the central part of the Gulf of Tonkin. Especially, the wind energy is quite high in the Sea of Ninh Thuan to Ba Ria - Vung Tau with annual mean wind speeds of 8 to 10 m/s, and the annual mean wind power density of 500 to 700 W/m² at a height of 100 m. On the seasonal scale, the wind energy potential of January and October is greater than that of April and July for the Northern offshore areas while the wind energy potential of January is the greatest, followed by July and transition months for the southern offshore areas.*

Keywords: *Wind energy, potential, high distributions, wind potential, Bien Dong Sea.*

1. Introduction

In recent years, traditional energy resources have become increasingly scarce due to economic development and the increasing population. Therefore, to develop renewable energy sources in general and wind energy in particular for any country, it is necessary to study and evaluate the theoretical wind energy potential as well as its characteristics and evolution pattern. Besides, compared to wind energy on land, offshore wind energy is a renewable energy source with outstanding advantages as it is possible to install offshore wind farms over a large area of the sea.

The term "wind energy" describes the process of using wind to produce mechanical energy, and it is the kinetic energy of air moving through the Earth's atmosphere [10, 11, 12, 13]. Wind energy is widely used, sustainable and little impact on the environment, and the development of wind energy is considered one of the most important solutions to mitigate global climate change [1, 16, 20, 24].

Up to now, the Atlas of wind energy for the region as well as for countries around the world [18, 19, 22, 23, 28] has been built to serve the growing needs of development and energy consumption. Notably, in the wind energy resource assessment project funded by the World Bank (WB), the US TrueWind company (2001) built a wind energy atlas for Southeast Asia, including Viet Nam [28] and in 2018 the Danish University of Technology collaborated with other organizations to build a global wind Atlas (maps of wind speed and wind energy density at the heights of 50 m, 100 m and 200 m) [23]. The atlas was generated using the WRF model at 3 km resolution and then scaled down to 250 m resolution using the Wind Map Analysis and Application Program (WAsP). The maps have provided a panoramic view of wind energy resources for Viet Nam both on land and offshore. However, to exploit wind energy or assess wind energy potential for Viet Nam, a

Corresponding author: Vu Van Thang
E-mail: vvthang26@gmail.com

more detailed analysis from different types of data such as satellite images, modelling data and for additional height levels is required.

Viet Nam is located in the Asian monsoon with a wide sea and coastal area, so the potential for wind energy is abundant. According to the survey results of the Energy Assessment Program for Asia of the World Bank (WB) [29, 30], Viet Nam has the largest wind potential in Southeast Asia with a total wind power potential estimated at 513,360 MW, 200 times more than the capacity of Son La hydropower and more than 10 times the total forecasted capacity of Viet Nam's power industry in 2020.

Studies on the assessment of wind energy potential has been carried out since several decades in Viet Nam [2, 3, 7, 8, 10, 13, 14], typically as a state-level study in the period 1996 - 2000: “Strategies and policies for sustainable energy development”. This study gave the general assessment that wind energy in Viet Nam is low but better in islands, coastal areas, and some places with topographic wind [13]. Ta Van Da (2006) used the Weilbull distribution function to calculate wind energy density and the logarithmic function to interpolate altitude levels. The results produced a set of atlas of wind energy for the typical months of the year at different altitudes in the territory of Viet Nam including the coastal zone [10] Bui Van Dao (2008) used wind data at an altitude of 10 m, which is measured from Nasa's QuickBird satellite in the period 2000 - 2007 to assess wind potential in the Bien Dong Sea. The results showed the greatest wind potential in the North Bien Dong Sea and coastal zone from Ninh Thuan province to Ca Mau province. Nguyen Manh Hung et al. (2010) made a relatively complete assessment of Viet Nam's marine energy resources “Research and evaluate the potential of marine energy sources and propose solutions for exploitation” [7]. In which, the sea areas assessed of having a remarkable density of wind energy resources are the Gulf of Tonkin, and the middle and southern areas of the Bien Dong Sea. From an altitude of 80 m, the area extending along the Northeast - Southwest from the Taiwan Strait to the south Bien Dong Sea has high wind power potential, reaching 300 - 600 W/m², especially the South - Central Coast region has a center with the power density of 400 - 600 W/m². In addition, in the Gulf of Tonkin, there is also a center with a power density of 300 - 400 W/m².

Recently, a remarkable study has applied a WRF model to simulate wind energy resources at a resolution of 10 x 10 km in the period 2006 - 2010 in the Bien Dong Sea. The results showed that the wind energy potential was significantly higher than that in previous studies, with the wind power density distribution of 500 - 1400 W/m². Many sea areas have a high density of wind energy, notably the Gulf of Tonkin, the Hoang Sa and Truong Sa archipelagoes of Viet Nam, the middle of Bien Dong Sea and the South - Central Coast [17].

Thus, the research results are consistent with the potential areas of wind energy in the sea region of Viet Nam. However, there is difference in values between recent studies compared to those before 2010, even the wind energy potential of later studies is higher, even 2 times higher in some places than before. The reason may be due to the following: (1) The data used is re-analyzed data with raw resolution or the wind monitoring data series is not long enough and not detailed; (2) Not yet applied high-resolution numerical model and new generation satellite and radar data; (3) Not using many estimation algorithms for evaluation and comparison. Therefore, it is necessary to study using new data sources such as satellites and radars in combination with high-resolution computational models.

This study presents the results of research on assessing wind energy potential in the Bien Dong Sea based on re-analyzed data sources corrected from CCMP satellite data. Research results for renewable energy development towards Viet Nam's net zero commitment at COP 21.

2. Data and Methodology

2.1. Data

CCMP satellite data for the period 1991 - 2020 was used to calculate wind energy potential in the Bien Dong Sea. The 0.25° high-resolution CCMP dataset was built based on the surface wind field of ERA-Interim data (European Center for Medium-Term Forecasting) combined and corrected from satellite winds such as SSM/I, SSMIS, AMSR, TMI, WindSat, and GMI and other observations through the use of variance analysis methods (VAM). All wind observation and model analysis are referenced to a height of 10 meters. The CCMP data is available from 1987.

2.2. Methodology

a. Calculation of wind distribution

In this study, the theoretical wind potential at the altitudes of 10 m, 50 m, 100 m, and 200 m over the Bien Dong Sea is analyzed and assessed by regions as shown in Figure 1.

Currently, due to the limitation of Aero meteorological stations, the high wind speed is indirectly determined by the distribution function of altitude based on ground wind monitoring. The distribution of wind by altitude in each area, or at each specific time depends not only on the roughness of the terrain but also on the stratosphere of the atmosphere and other factors. Many studies in the world as well as in Viet Nam have used the logarithmic rule to estimate indirectly wind distribution according to altitude [6, 9, 10, 12, 25, 27]. Studies show that using a logarithmic distribution function suitable for atmospheric wind speeds from the ground to an altitude of about 100 m [9, 10, 12]. Therefore, the logarithmic function is chosen as the method to calculate wind distribution.

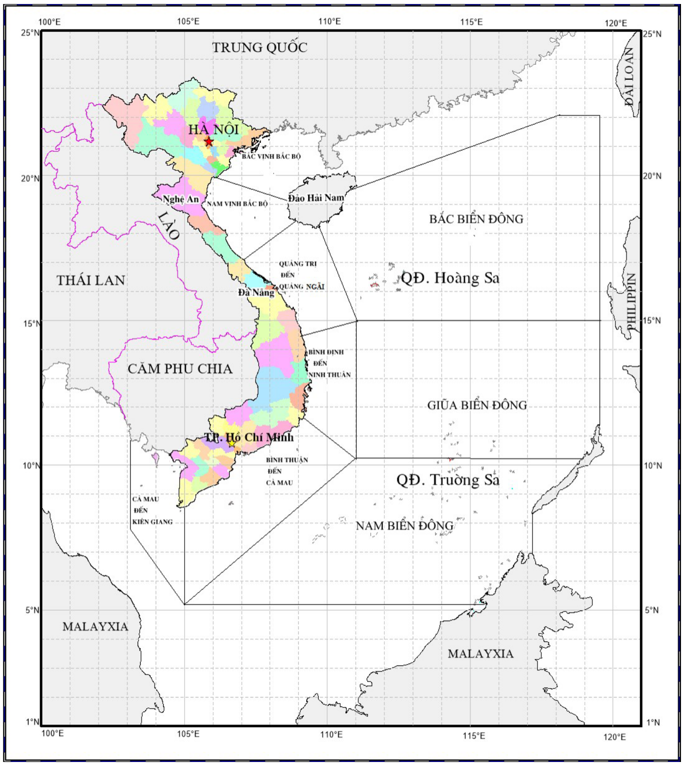


Figure 1. Bien Dong Sea zoning for wind energy potential assessment (based on the map taken from https://www.nchmf.gov.vn/kttv/)

If the wind speed V_1 at height Z_1 is known, the wind speed Vz can be calculated at height Z according to the following formula (1):

$$\frac{V_z}{V_1} = \frac{\ln(z/z_o)}{\ln(z_1/z_o)}; \qquad V_z = V_1 \frac{\ln(z/z_o)}{\ln(z_1/z_o)} \qquad (1)$$

In which, V_z is the wind speed is calculated at the height *Z*, V_1 is the ground observed wind speed, Z_1 is the altitude of the ground anemometer (Z_1 = 10 m), Z_o is the roughness of the surface (for study area, the Z_o is 0.0002).

Because $Z > Z_1$ so $V_z > V_1$ or wind speed increases with altitude. In addition, the magnitude of the increase in wind speed with altitude depends on the roughness of the surface (Z_o). When the roughness of the surface is larger, the wind speed at the height is calculated (V_z) increases faster.

b. Calculate wind energy density

Average wind energy density E (W/m^2) at a place in time (t) (year, season, month...) calculated according to the formula (2) [10, 12, 15, 17, 25, 26, 31, 32]:

$$E = \frac{1}{2}\rho\frac{1}{N}\sum_{i=1}^{N} v_i^3 \quad (2)$$

In which, ρ is the air density, assumed to be a constant 1,225 kg/m^3, v_i is the instantaneous wind speed (m/s), and N is the sample capacity.

Thus, wind energy is a quantity derived from wind speed and depends only on wind speed, so wind speed studies are the basis for assessing wind potential.

3. Evaluation of wind energy potential in the Bien Dong Sea

3.1. Wind speed distribution

At of 10 m altitude, the annual average wind speed (Figure 2a) over the Bien Dong Sea is common at 5 - 8 m/s. At offshore, the highest wind speed is in the North of Bien Dong Sea (common 6 - 8 m/s) and has a decreasing trend towards the south. In the coastal zone, the wind tends to be strongest in the sea from Binh Dinh to Ca Mau province with a common wind speed of 6 - 8 m/s.

For seasonal distribution (Figure 3), the average wind speed over the Bien Dong Sea is highest in January (6 - 11 m/s) and lowest in April (3 - 7 m/s). In the northern seas region (Northern Gulf of Tonkin, Southern Gulf of Tonkin, Quang Tri - Quang Ngai Sea, and North East Sea) the wind speed in January and October is higher than that of April and July (the average wind speed of January, April, July, and October is 6 - 11 m/s, 4 - 7 m/s, 5 - 7 m/s, 5 - 10 m/s respectively). In the southern sea region (from the coast of Binh Dinh to the south, in the middle and south of the East Sea), the highest wind speed in the main winter month (6 - 11 m/s in January), the lower in the main summer (5 - 9 m/s in July) and transition (3 - 6 m/s in April and 4 - 7 m/s in October).

The height distribution of monthly, seasonal, and yearly average wind speeds at the altitude of 100 m, 150 m, and 200 m over the sea region of Viet Nam is similar pattern at the height of 10m, but the wind speed has a larger value and a wider range.

Over the sea regions, the wind speed at 100 m altitude is about 1 - 2 m/s higher than at the 10 m altitudes. The average annual wind speed (Figure 2b) is common from 8 - 10 m/s in the North East Sea, 7 - 9 m/s on the coast of Binh Dinh to Ninh Thuan province, and from 7 - 10 m/s on the coast of Binh Thuan to Ca Mau province. In the coastal area from Ninh Thuan to Ba Ria - Vung Tau province, where the two sea regions intersect, the average annual wind speed is generally 8 - 10 m/s. In addition, a very small sea area in the center of the Gulf of Tonkin has an annual average wind speed of 8 - 9 m/s. Wind speed in January, April, July, and October is respectively 7 - 13 m/s, 5 - 8 m/s, 6 - 9 m/s, and 7 - 12 m/s in the northern sea region; and is respectively 8 - 13 m/s, 4 - 7 m/s, 6 - 11 m/s and 6 - 8 m/s in the southern sea region (Figure 4).

From 100 m altitude and above, wind speed tends to increase more slowly than at low levels. The average monthly and yearly wind speeds at 150 m are generally approximately the same as those at 100 m, but the range of high wind speeds is wider. Wind speed at 150 m altitude is about 1 m/s higher than 100 m, which occurs only in a few sea areas at certain times, such as the Gulf of Tonkin (7 - 10 m/s), Ninh Thuan to Ba Ria Vung Tau province in January (11 - 14 m/s), July (8 - 11 m/s), and Bien Dong Sea in October (8 - 13 m/s).

At 200 m altitude (Figure 2d, Figure 6), the monthly and yearly average wind speeds over the sea regions are similar to those at 150 m.

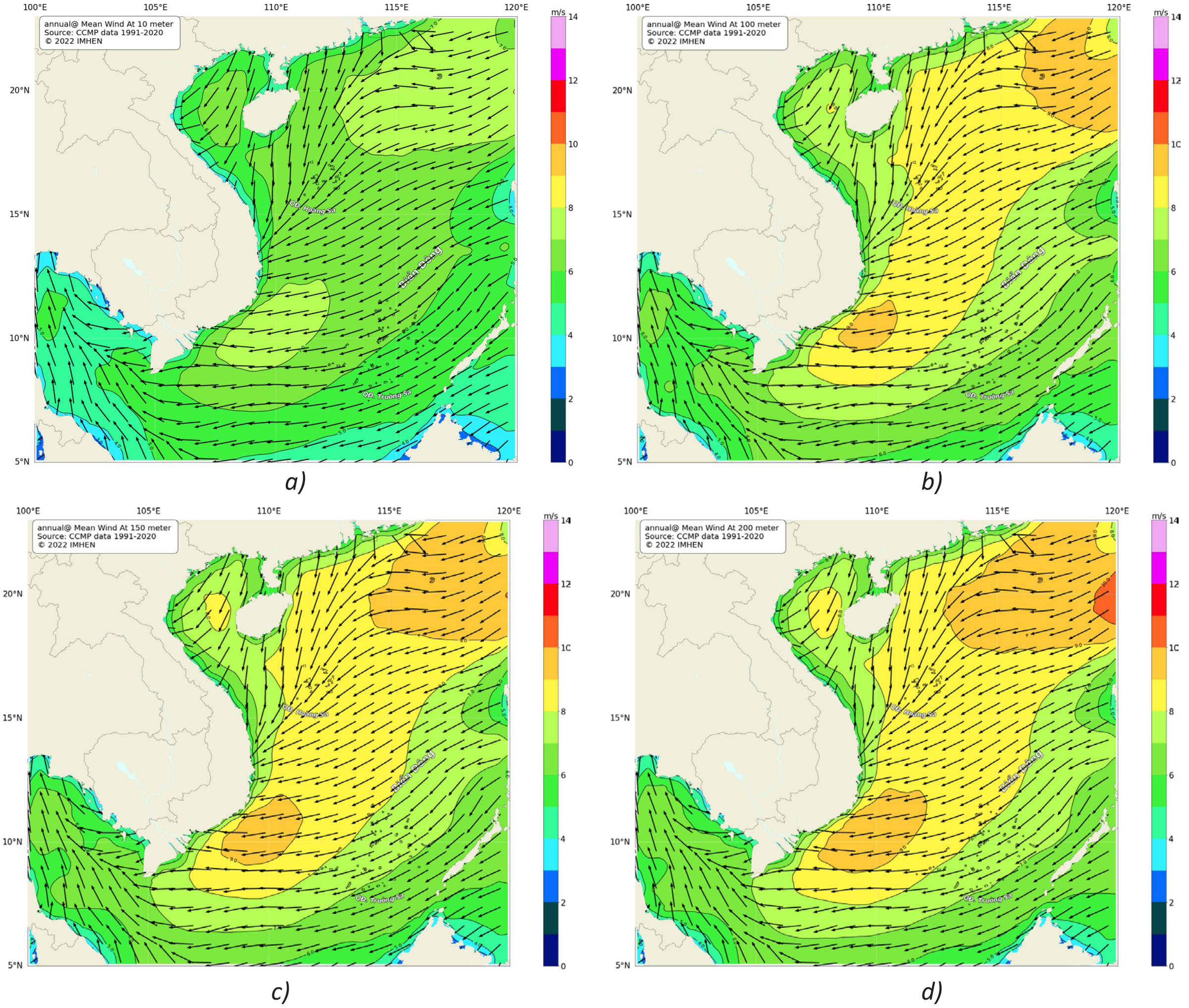


Figure 2. Maps of the distribution of annual average wind speed (m/s) over the Bien Dong Sea at elevations of 10 m (a), 100 m (b), 150 m (c), and 200 m (d), period 1991 - 2020

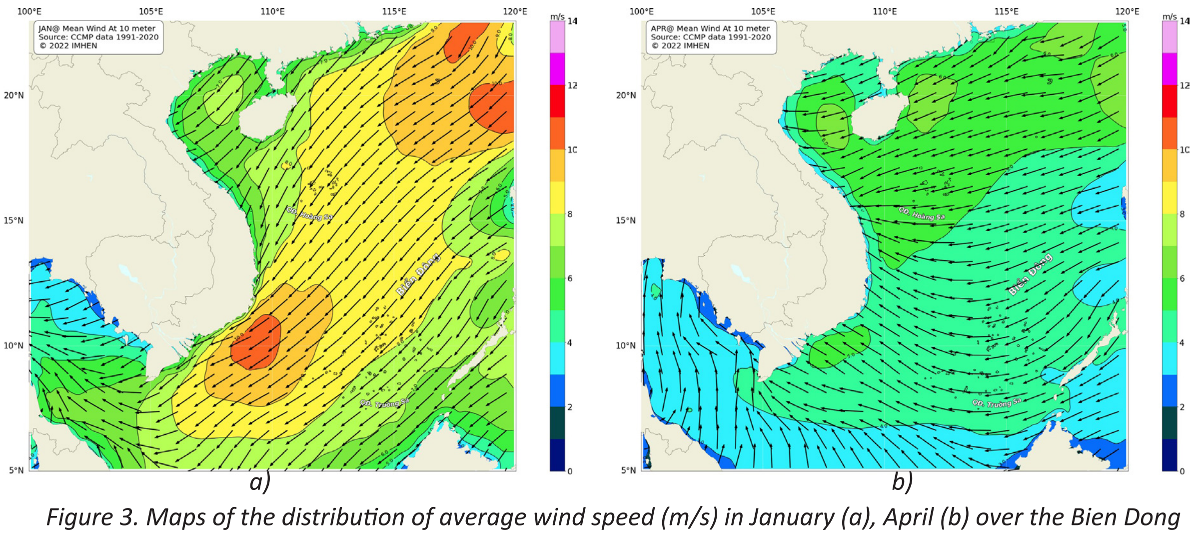


Figure 3. Maps of the distribution of average wind speed (m/s) in January (a), April (b) over the Bien Dong Sea at the altitude of 10 m, period 1991 - 2020

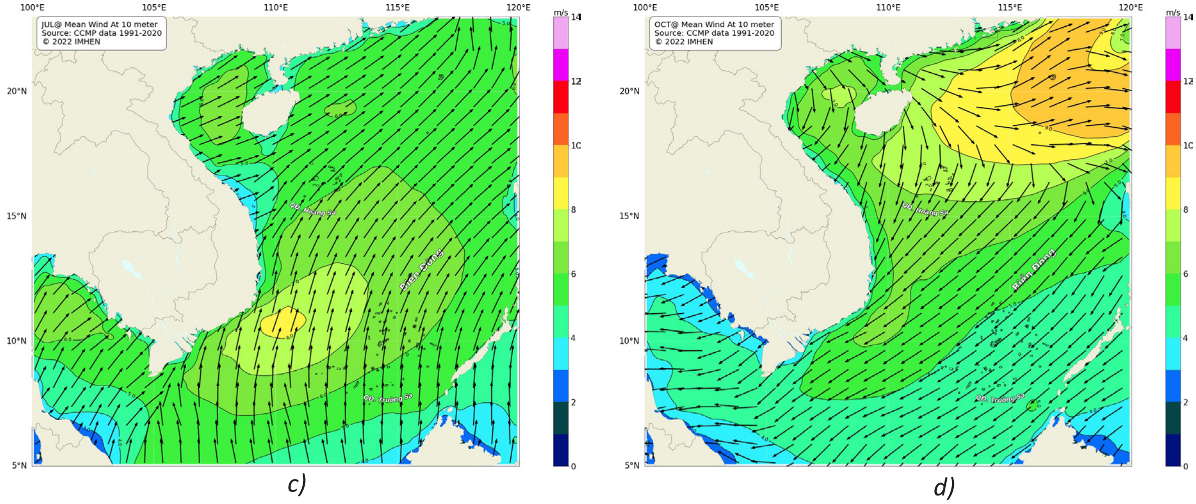


Figure 3. Maps of the distribution of average wind speed (m/s) in October (d) over the Bien Dong Sea at the altitude of 10 m, period 1991 - 2020

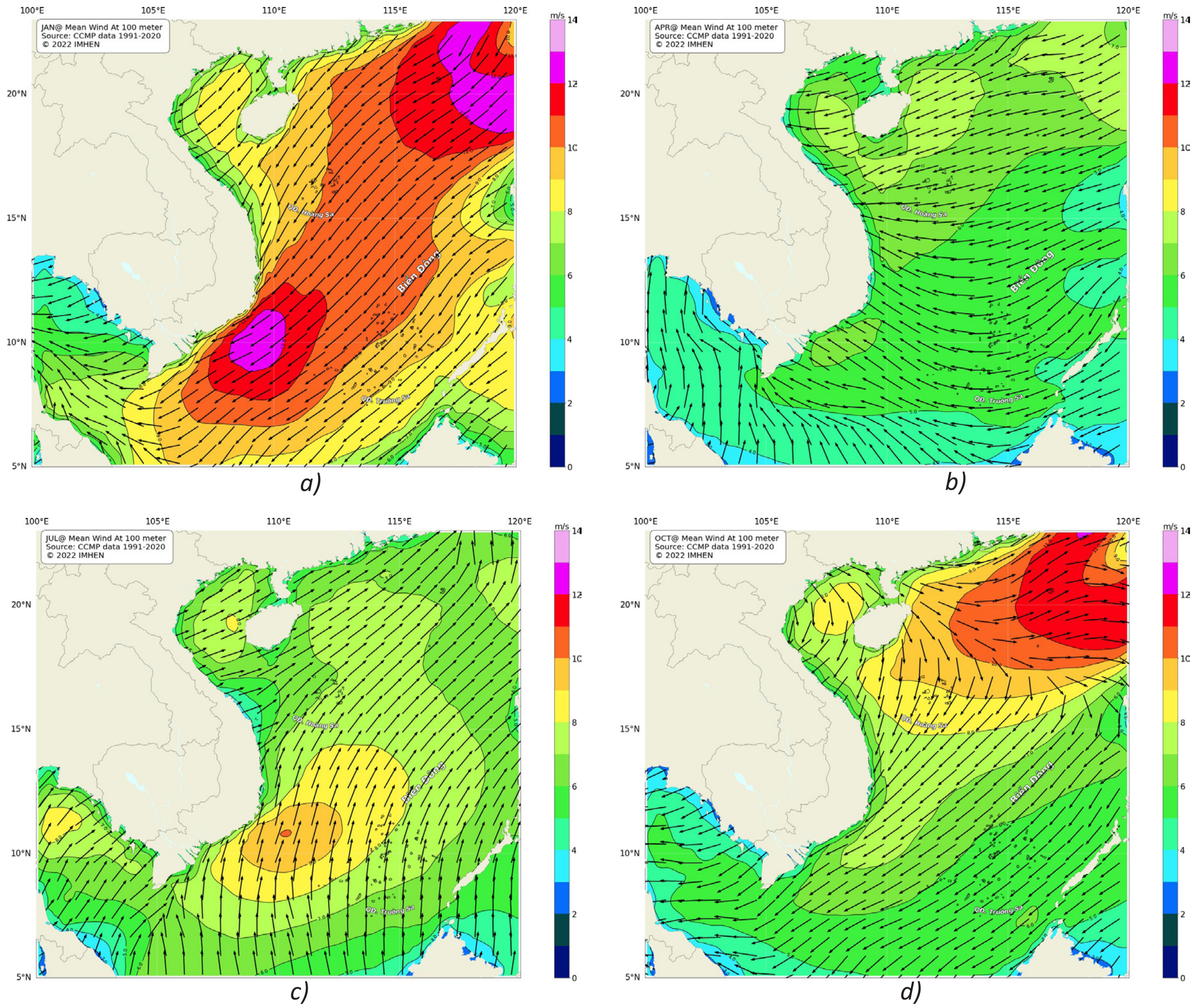


Figure 4. Maps of the distribution of average wind speed (m/s) in January (a), April (b), July (c), and October (d) over the Bien Dong Sea at the altitude of 100 m, period 1991 - 2020

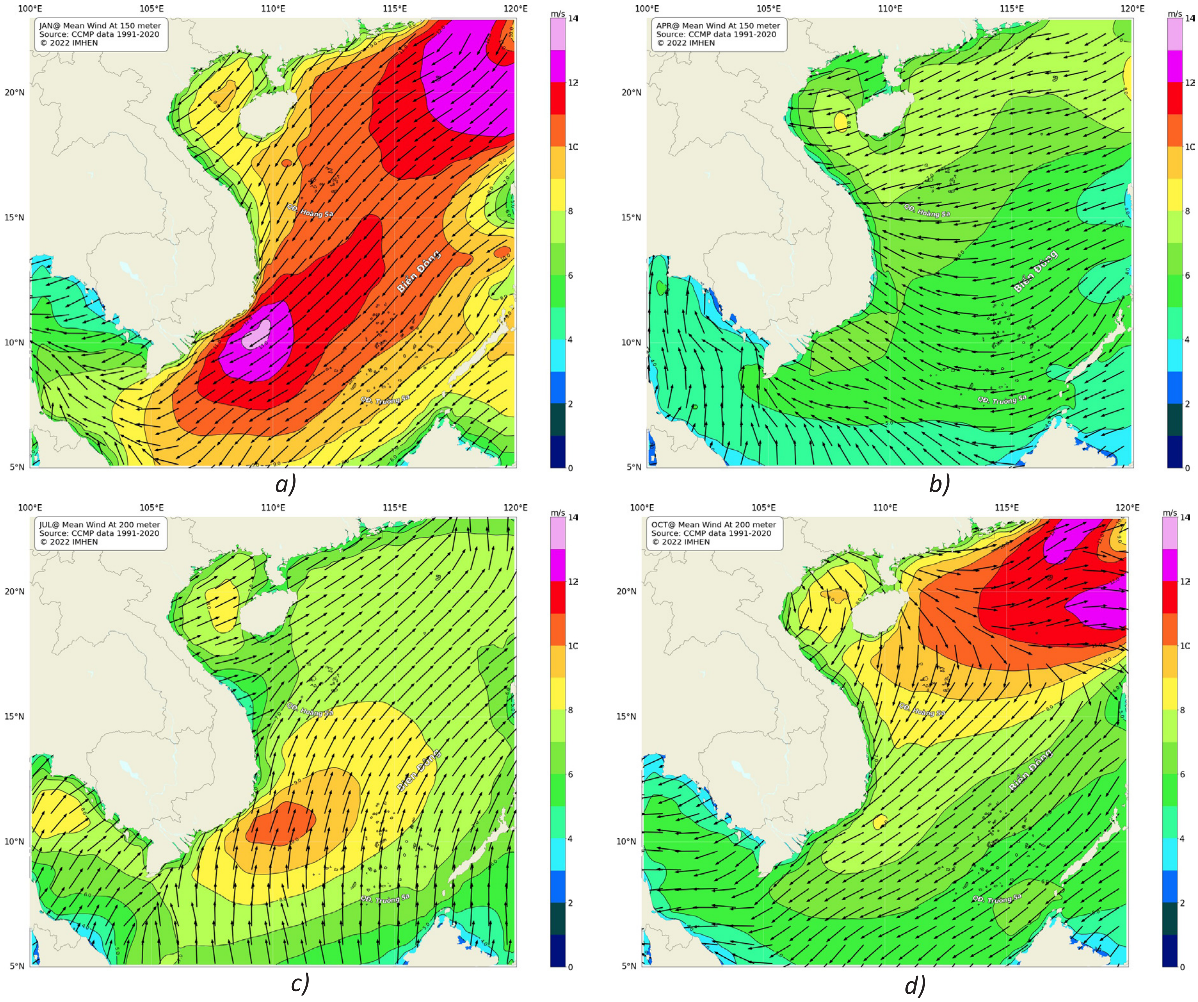


Figure 5. Maps of distribution of average wind speed (m/s) in January (a), April (b), July (c), and October (d) over the Bien Dong Sea at the altitude of 150 m, period 1991 - 2020

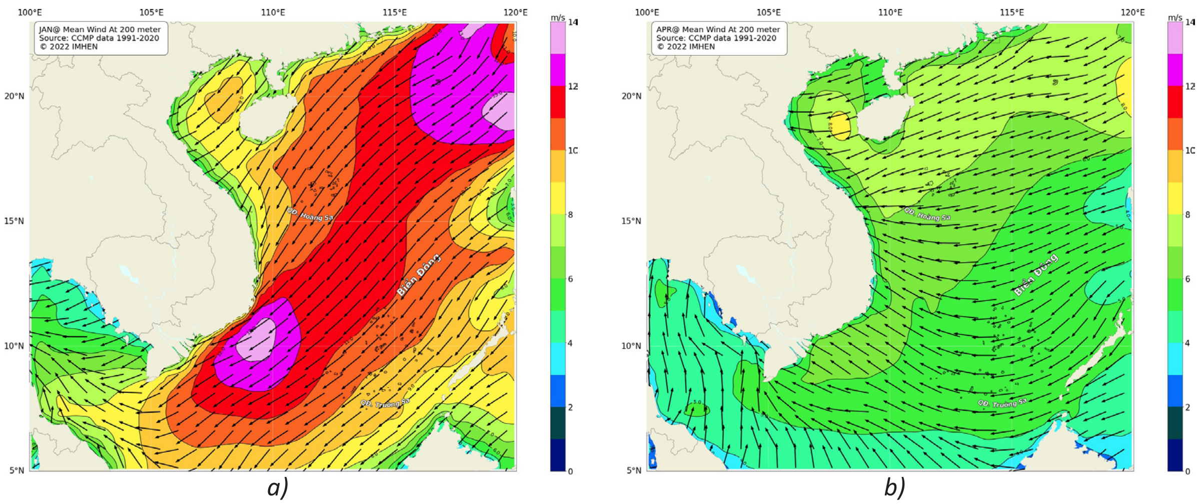
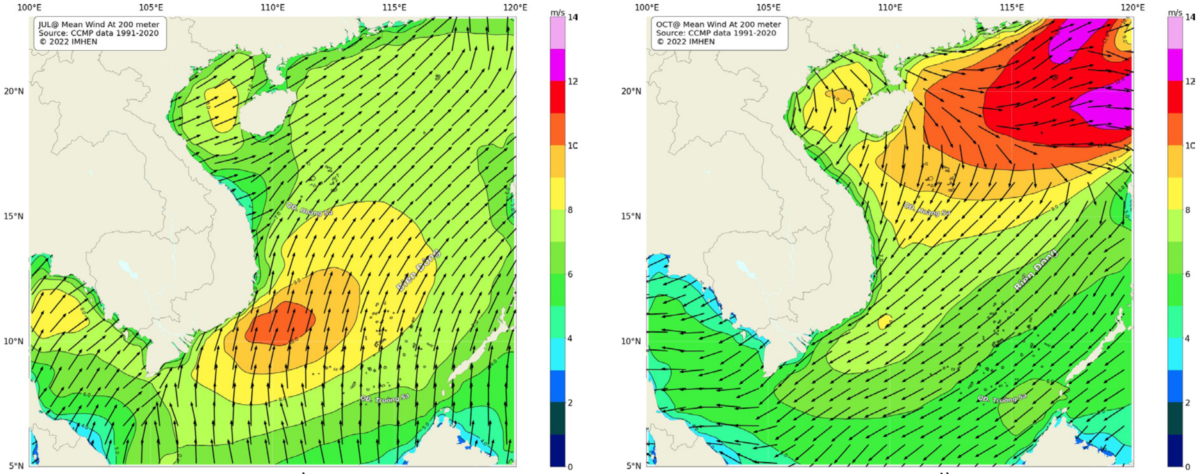


Figure 6. Maps of the distribution of average wind speed (m/s) in January (a), April (b) over the Bien Dong Sea at the altitude of 200 m, period 1991 - 2020



c) d)

Figure 6. Maps of the distribution of average wind speed (m/s) in July (c), and October (d) over the Bien Dong Sea at the altitude of 200 m, period 1991 - 2020

3.2. Evaluation of wind energy potential according to wind energy density

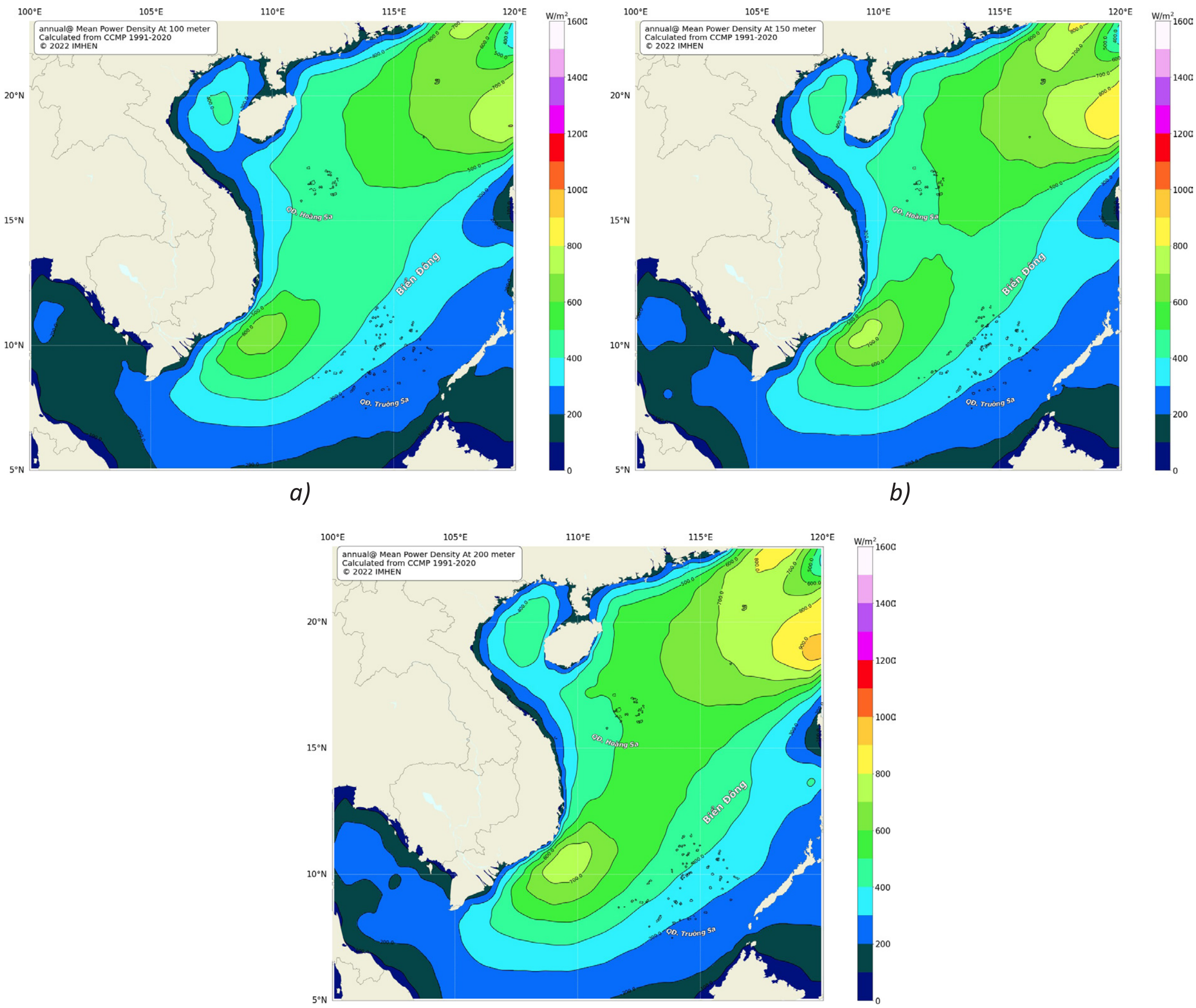
The annual mean wind energy density (E) at the altitude of 100 m (Figure 7a) is common from 200 W/m² to 800 W/m² offshore, of which the largest found in the Bien Dong Sea (300 - 800 W/m²). In the coastal areas, the highest E distribution tends to the south, belonging to the sea areas of Binh Dinh to Ninh Thuan province (common 300 W/m² to 600 W/m²) and Binh Thuan to Ca Mau province (from 300 W/m² to 700 W/m²); in which concentration is highest in coastal areas from Ninh Thuan to Ba Ria - Vung Tau province from 500 W/m² to 700 W/m².

Similar to wind speed pattern, the wind energy density in the Bien Dong Sea at the height of 100 m is the highest in January (from 300 W/m² to 1300 W/m²) and the smallest in April (from less than 100 W/m² to 500 W/m²). In the Northern Sea regions (Gulf of Tonkin, the sea region of Quang Tri to Quang Ngai province, and North of the Bien Dong regions) wind energy density is the highest in January and October with values of 300 - 1300 W/m², 300 - 1200 W/m² respectively, and the lowest in April and July with values below 100 - 500 W/m², 100 - 400 W/m² respectively. In the Southern coastal sea regions (Binh Dinh province to the South, the Middle and South East Sea regions), the wind energy density is highest in the main winter month (January) and lower in the summer months and transition months. The average wind energy in January, April, July, and October is 300 - 1300 W/m², less than 100 - 300 W/m², 200 - 700 W/m², and 100 - 400 W/m², respectively.

The altitude distribution of average annual and monthly wind energy density at 150 m, and 200 m altitude over the Bien Dong Sea is similar to its distribution pattern at 100 m altitude. The annual average wind energy density tends to increase with height, and the range of areas with high wind energy density values also tends to expand. The seasonal distribution of wind energy density at different altitudes is similar to that of 10 m.

At the 150 m height, the annual average wind energy density ranges from 200 - 900 W/m²; which is common from 300 - 900 W/m² in the Bien Dong Sea Region, from 300 - 700 W/m² in the sea region of Binh Dinh province to Ninh Thuan province, 300 - 800 W/m² in the sea region of Binh Thuan province to Ca Mau province and from 500 - 800 W/m² in the sea area between Ninh Thuan province and Ba Ria - Vung Tau province (Figure 7b). These are also sea areas that clearly show the law of wind energy density increasing with altitude. At the seasonal, wind energy density in the months at 150 m altitude is approximately 100 m over most of the Bien Dong Sea Region (Figure 9). The difference in monthly values of about 100 W/m² compared to 100 m only occurs in the sea region from Ninh Thuan province to Ba Ria - Vung Tau province in January, July, and the Bien Dong Sea Region in January and October.

At the of 200 m altitude, the annual average wind energy density is approximately 150 m in most sea areas. The most obvious difference is that the value of 900 - 1000 W/m² appeared in the Bien Dong Sea Region, but only in a very small area (Figure 7c). At the monthly scale (Figure 10), the wind energy density at an altitude of 200 m is about 100 W/m² higher than the 150 m level in the sea region of the Gulf of Tonkin in all months, the Bien Dong Sea Region in January, October; the central Bien Dong Sea Region in January; and Ninh Thuan province to Ba Ria - Vung Tau province in January and July.



a)

b)

c)

Figure 7. Maps of the annual average distribution of wind energy density (W/m²) at altitudes of 100 m (a), 150 m (b), and 200 m (c), period 1991 - 2020.

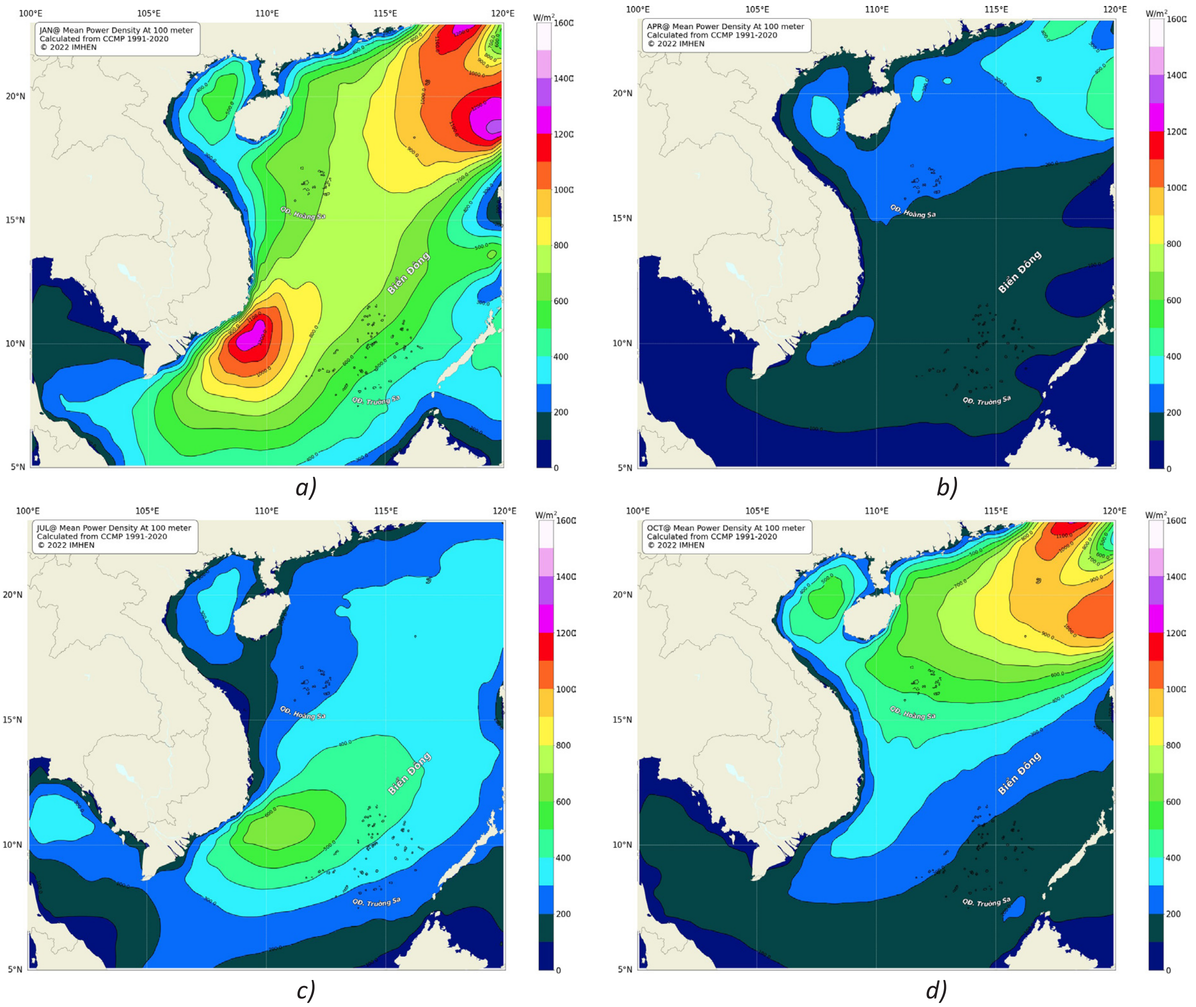


Figure 8. Maps of the average distribution of wind energy density (W/m²) in January (a), April (b), July (c), and October (d) over the Bien Dong Sea at an altitude of 100 m, period 1991 - 2020

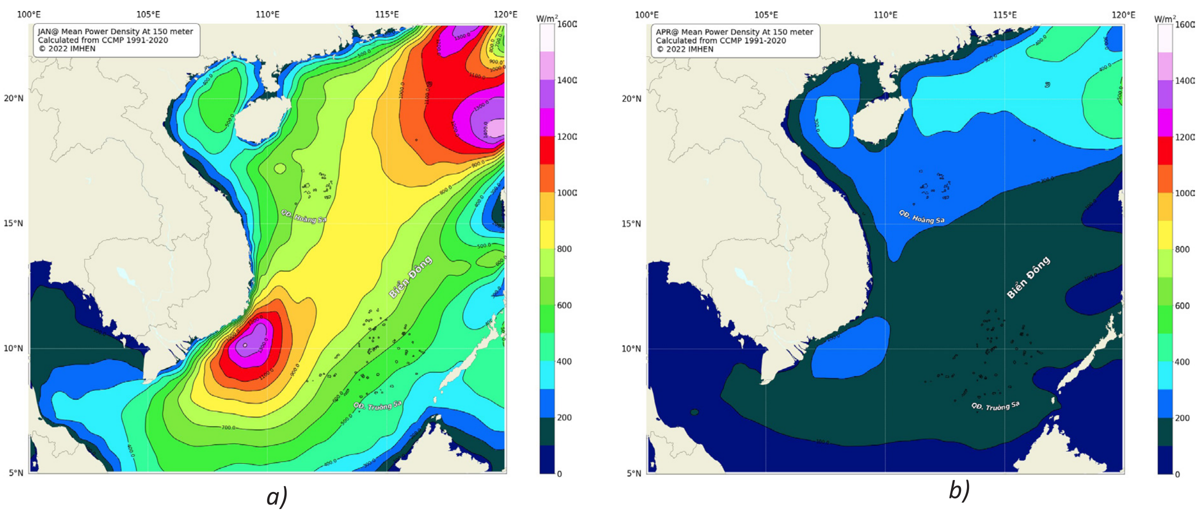
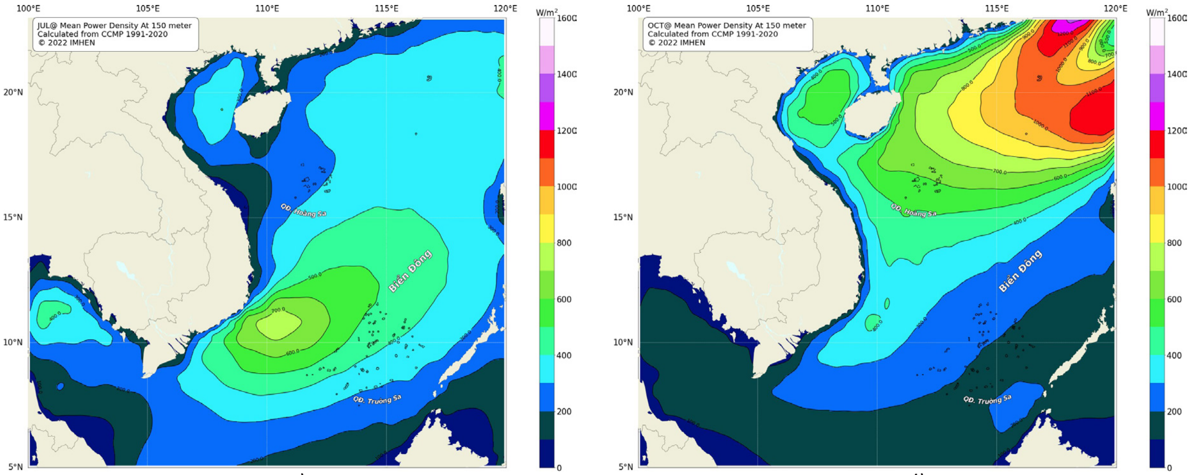
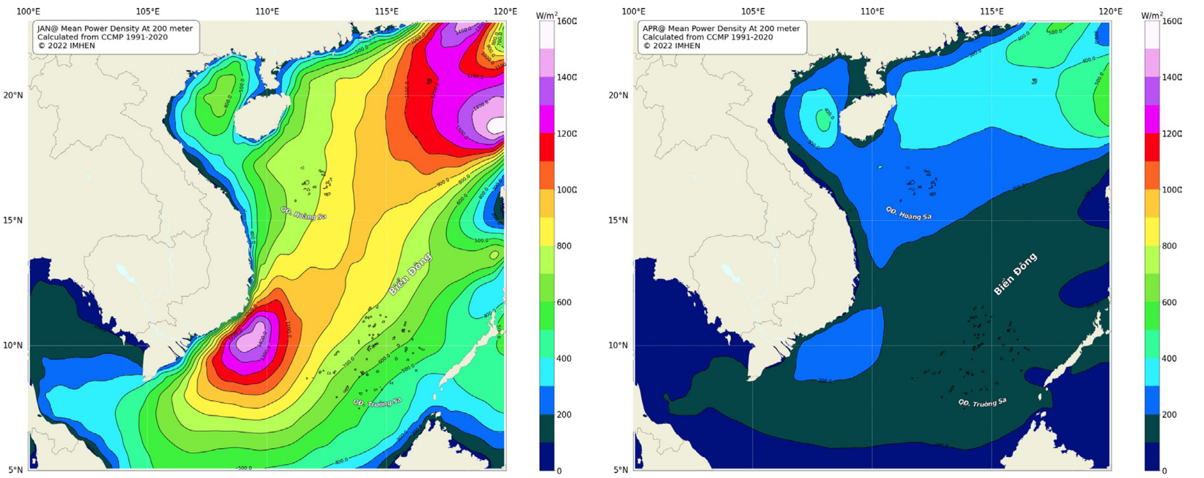


Figure 9. Maps of the average distribution of wind energy density (W/m²) in January (a), April (b) over the Bien Dong Sea at an altitude of 150 m, period 1991 - 2020

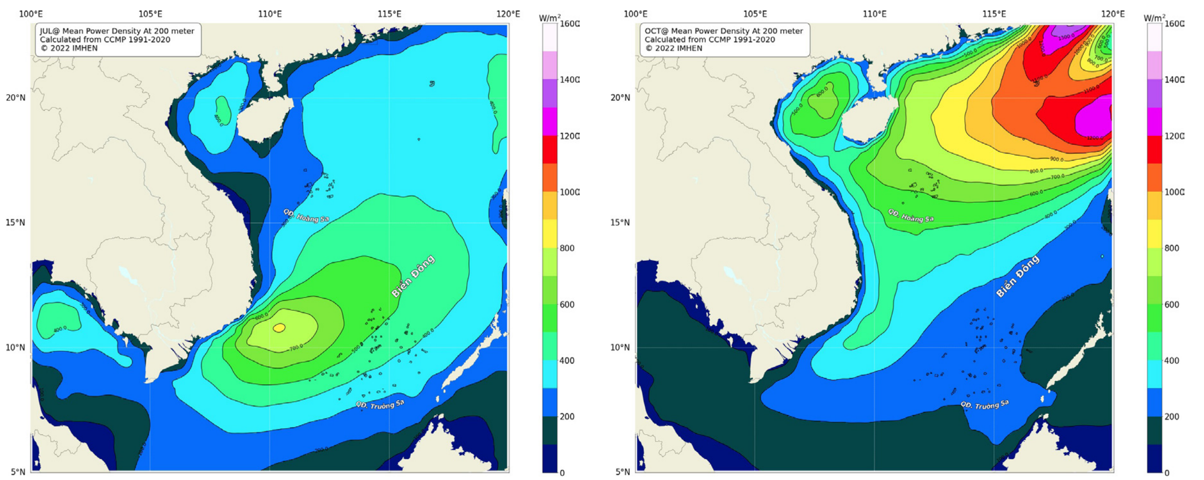


c) *d)*

Figure 9. Maps of the average distribution of wind energy density (W/m²) in July (c), and October (d) over the Bien Dong Sea at an altitude of 150 m, period 1991 - 2020



a) *b)*



c) *d)*

Figure 10. Maps of the average distribution of wind energy density (W/m²) in January (a), April (b), July (c), and October (d) over the Bien Dong Sea at an altitude of 200 m, period 1991 - 2020

5. Conclusion

The results of the assessment of wind distribution and wind energy density at altitudes from CCMP satellite data in the period 1991 - 2020 show the potential of wind energy over the Bien Dong Sea area as follows:

At the 10 m height, the wind potential is not high over the Bien Dong Sea with an annual average wind speed from 5 m/s to 8 m/s.

At an altitude of 100 m, 150 m, and 200 m, the sea areas with the best potential for wind energy are the Bien Dong Sea Region, the sea from Binh Dinh province to Ninh Thuan province, the seas region from Binh Thuan province to Ca Mau province, and the small area of the central seas in the Gulf of Tonkin, with wind speed and annual wind energy density respectively: 7 m/s - 10 m/s, 400 W/m² - 800 W/m²; 7 m/s - 9 m/s; 300 W/m² - 600 W/m²; 7 m/s - 10 m/s; 300 W/m² - 700 W/m². In particular, the potential for wind energy is quite good in the coastal area from Ninh Thuan to Ba Ria - Vung Tau with an annual average wind speed of 8 m/s to 10 m/s, and an average annual energy density of 500 W/m² to over 700 W/m² at an altitude of 100 m.

The annual average wind energy density at heights of 150 m, and 200 m over most sea areas is approximately the same as that of wind energy at 100 m heights, except for the Bien Dong Sea Region and the sea region from Ninh Thuan province to Ba Ria - Vung Tau province. However, the area of high value of wind energy potentials tend to expand with height.

The wind power potential in January, October is greater than that in April, July for the northern offshore areas while the wind power potential in January is the greatest, followed by July and transition months for the southern offshore areas (from 15 °N to the southern).

References

1. Ministry of Planning and Investment, Department of Science, Education, Natural Resources and Environment (2021), *Support for Environmentally Sustainable Development Program in Viet Nam, Potentials and directions to exploit different types of potentials renewables in Viet Nam*. Project BSC.
2. Bui Van Dao (2008), *Offshore wind energy*. Floating Windfarms Inc. www.tapchithoidai.org/.
3. Bui Thi Tan (1998), *Applying WASP software to calculate wind energy for complex terrain conditions in Viet Nam.* Hanoi, 1998.
4. Bui Thi Tan (2002), *Verifying the WASP model for calculating wind energy according to wind monitoring data on Lang meteorological tower*, Hanoi, 2002.
5. Do Ngoc Quynh (2003), *Assessment of marine energy potential in Viet Nam.* Final report on the topic of the Viet Nam Institute of Science and Technology.
6. Le Van Luu et al. (2002), *"Wind speed profile according to height, in the atmosphere close to the ground, Phuoc Hoa-Binh Dinh area", Journal of Earth Sciences*, 24(2), 233 -238.
7. Nguyen Manh Hung et al (2010), *Research and evaluate the potential of major marine energy sources and propose solutions for exploitation.* Topic KC.09.19/06-10. Ministry of Science and Technology.
8. Phan My Tien (1994), *Potential distribution of wind energy in the territory of Viet Nam.* Thesis PTS. Geoscience - Geology, Hanoi.
9. Phan My Tien (2001), *Some characteristics of wind regime in Viet Nam for wind energy exploitation,* Hanoi, 2001.
10. Ta Van Da et al. (2006), *Evaluation of wind energy resources and exploitation in the territory of Viet Nam*, Summary report of scientific research.
11. Ta Van Da (2007), *Evaluation of the possibility of exploiting wind energy in the territory of Viet Nam.*
12. Tran Thuc, Ta Van Da, Nguyen Van Thang (2012), *Wind energy in Viet Nam - Potential and*

exploitability, Science and Technology Publishing House.
13. Tran Viet Lien (2007), *Wind energy potential in Viet Nam*, National Conference on Hydrometeorology and Environment, 2007.
14. Tran Viet Lien, Bui Thi Tan (1998), *Wind energy potential in Ly Son island district*. Hanoi, 1998.
15. Albani, A., and Ibrahim, M. Z. (2014), *Statistical Analysis of Wind Power Density Based on the Weibull and Rayleigh Models of Selected Site in Malaysia.* doi:10.18187/PJSOR.V9I4.580.
16. Doan, V. Q., H. Kusaka, M. Matsueda, and R. Ikeda, (2019), *"Application of mesoscale ensemble forecast method for prediction of wind speed ramps". Wind Energy,* doi:10.1002/ we.2302.
17. Doan, V. Q., et al. (2019), *"Usability and Challenges of Offshore Wind Energy in Viet Nam Revealed by the Regional Climate Model Simulation". SOLA*, Vol. 15, 113-118, doi:10.2151/sola.2019-021.
18. Environment and Climate Change Canada's Wind Atlas, (2022), http://www.windatlas.dk/Home/News.html.
19. European Environment Agency, (2009), *Europe's onshore and offshore wind energy potential an assessment of environmental and economic constraints.* EEA. Technical report No 6/2009.
20. Foley, A. M., P. G. Leahy, A. Marvuglia, and E. J. McKeogh, (2012), *"Current methods and advances in forecasting of wind power generation", Renewable Energy*, 37, 1-8.
21. Hiep Van Nguyen et al. (2021), *"Observation and Simulation of Wind Speed and Wind Power Density over Bac Lieu Region", Advances in Meteorology*, vol. 2021, Article ID 8823940, 17 pages, 2021. https://doi.org/10.1155/2021/8823940.
22. International Renewable Energy Agency (IRENA), (2021), *Renewable energy statistics 2021*. https://irena.org/publications/2021/Aug/Renewable-energystatistics-2021.
23. International Renewable Energy Agency (2015), *Renewable Energy Capacity Statistics 2015*, International Renewable Energy Agency, Abu Dhabi, UAE, 2018, https://www.irena.org/publications/2015/Jun/Renewable-Energy-CapacityStatistics-2015.
24. IPCC, (2011), *Summary for Policymakers. In: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
25. Muthya, P. R. (2009), Asian and Pacific Centre for transfer of technology of the United nations-economic and social commission for Asia and the Pacific (ESCAP). *Wind Energy- Resource assessment handbook.*
26. Parajuli, A. (2016), "*A statistical analysis of wind speed and power density based on Weibull and Rayleigh models of Jumla, Nepal", Energy and Power Engineering*, Vol.8 No.7, July 2016, doi: 10.4236/epe.2016.87026.
27. Simiu, E., and Scanlan, R. H. (1978), *Wind effects on structures. An introduction to wind engineering.* A Wiley - Interscience Publication. Jhon Wiley and Sons. New York.
28. TrueWind Solutions, LLC & WB, (2001), *Wind energy resource Atlas of Southeast Asia, Prepared for The World Bank Asia Alternative Energy Program*. Albany, New York.
29. World Bank (WB), (2009), *Global Wind Atlas 3 – Validation - Viet Nam*.
30. World Bank (WB), (2021), *Offshore wind technical potential in Viet Nam.* https://esmap.org/offshore-wind.
31. Zheng CW., Li CY., Wu HL., and Wang M. (2018), *21st century maritime silk road: Constructtion of remote Islands and Reefs*. Springer.
32. Zhou, W., Hongxing, Y., and Zhaohong F. (2006), *"Wind Power Potential and Characteristic Analysis of the Pearl River Delta Region, China". Renewable Energy,* 31, 739-753.