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Combining QuickSCAT wind data and Landsat ETM+ images to evaluate the offshore wind power resource of East Vietnam Sea

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Abstract
Since the East Vietnam Sea has an advantageous geographical location and rich natural resources, we can develop and manage islands and reefs in this region reasonably to declare national sovereignty. Based on 1096 scenes of QuikSCAT wind data of 2006–2009, wind power density at 10 m hight is calculated to evaluate wind energy resources of the East Vietnam Sea. With a combination of wind power density at 70 m hight calculated according to the power law of wind energy profile and reef flats extracted from 35 scenes of Landsat ETM+ images, installed wind power capacity of every island or reef is estimated to evaluate wind power generation of the East Vietnam Sea. We found that the wind power density ranges from levels 4–7, so that the wind energy can be well applied to wind power generation. The wind power density takes on a gradually increasing trend in seasons. Specifically, the wind power density is lower in spring and summer, whereas it is higher in autumn and winter. Among islands and reefs in the East Vietnam Sea, the installed wind power capacity of Hoang Sa archipelago is highest in general, the installed wind power capacity of Truong Sa archipelago is at the third level. The installed wind power capacity of Discovery Reef, Bombay Reef, Tree island, Lincoln island, Woody Island of Hoang Sa archipelago and Mariveles Reef, Ladd Reef, Petley Reef, Cornwallis South Reef of Truong Sa archipelago is relatively high, and wind power generation should be developed on these islands first.

Keywords: QuikSCAT wind data, East Vietnam Sea, wind energy resource evaluation, wind power generation evaluation, Truong Sa, Hoang Sa.

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INTRODUCTION

Recent studies have reported the risk of anthropogenic greenhouse gases to earth's climate, oceans and ecosystems and in response to this concern government have been stimulating energy alternatives to fossil fuels [1]. Among renewable sources, wind power is a very large resource, with proven commercial technology and very low CO_2 emissions [2]. It is the fastest growing energy source in the world with more than 74,000 MW installed capacity; led by Germany (20,622 MW), Spain (11,615 MW), US (11,603 MW), India (6270 MW), and Denmark (3136 MW) [3]. Latin America has the modest wind energy development, with less than 300 MW of installed capacity. Even in Brazil, the largest Latin American wind developer with 237 MW, wind only accounts for 0.24% of national electrical generation [4]. The Brazilian national program PROINFRA seeks to increase the share of new renewable resources to 10% of annual electricity consumption, now predominantly from hydro- (77%) and fossil-fueled thermal electricity (21%).

Offshore wind exploration is becoming more feasible and different initiatives have succeeded in Europe [5, 6]. In comparison to a land site offshore winds are attractive because they have greater speeds and fluctuate less due to the absence of physical barriers such as mountains, buildings, and vegetation [7, 8]. Resources are also presumably very large and near populated coastal centers. (These advantages must be weighed against the generally higher cost of installation in water.) In the US, it is estimated that offshore wind resources in the shallow Middle-Atlantic Bight (330 GW average output) surpass the average electrical demand of the corresponding coastal states (73 GW) by several times [9, 10]. Two initiatives for offshore wind development are currently in the permitting phase in the US East Coast. In Europe, a ‘‘Super-Grid’’ has been recently proposed to connect the many anticipated offshore wind farms from the Baltic and North Seas to the Atlantic and Mediterranean [11, 12]. While the methods for evaluating wind resources over land are reasonably well established [13, 14], there is presently a need for tools to assess offshore wind over large extensional areas. Direct measurements at sea are rare and most countries lack sustained oceanic meteorological towers or buoy observations. But even for well-established programs such as the US National Data Buoy Center (NDBC/NOAA), measurements are usually too separated to provide a proper description of wind fields.

Coastal areas of Vietnam, especially in the South, consist of an area of about 112,000 km^2, areas with a depth of 30 m to 60 m, and an area of about 142,000 km^2 with great potential for developing good wind power. Especially the sea area of about 44,000 km^2 wide has a depth of 0–30 m from Binh Thuan to Ca Mau. According to wind data of Phu Quy and Con Dao, wind speed in this region reaches an average of more than 5–8 m/s at an altitude of 100 m. Currently, the first marine wind farm with a capacity of nearly 100 MW has been operating and is deploying the stages to 2025, up to 1,000 MW, which is 10 times higher.

Therefore, Vietnam Sea Wind Power Development Policy Strategy needs to be developed soon. With the wind energy works on the sea, the solution options simultaneously combined with other sources such as the sun, waves, OTEC, biomass energy, aquaculture, aquatic conservation will bring more economic effects, help prevent coastal erosion. On the other hand, there will be attractions, tourism and “god eyes” that help strengthen the protection of the sovereignty and security at sea of the fatherland.

Satellite technologies have revolutionized several areas of earth sciences and the advent of scatterometers has given researchers the capability to explore ocean winds. From scatterometer data, winds are estimated by indirect techniques that relate the ocean roughness to speed and direction through a geophysical model function [15, 16]. Presently, two satellite technologies are being used, the Synthetic Aperture Radar (SAR) and QuikSCAT.

However, for evaluation of the large-scale distribution of resources, QuikSCAT may be a better alternative. Launched in late August 1999, the mission has presently 7.8 years of near global (90% of ice-free ocean) coverage and its spatial resolution (12.5–50 km) is reasonable for mapping of continental shelf wind resources, if small-scale details are not needed. Additionally, its products are continuously collected, with readings approximately daily, and are freely available to the public [17]. QuikSCAT information has been of critical importance for practical applications, such as weather prediction and wave forecasting [18].

Since the East Vietnam Sea has an advantageous geographical location and rich natural resources, we can develop and manage islands and reefs in this region reasonably to declare national sovereignty. Based on 1096 scenes of QuikSCAT wind data of 2006–2009, wind power density at 10 m is calculated to evaluate wind energy resources of the East Vietnam Sea. With a combination of wind power density at 70 m calculated according to the power law of wind energy profile and reef flats extracted from 35 scenes of Landsat ETM+ images, installed wind power capacity of every island or reef is estimated to evaluate wind power generation of the East Vietnam Sea.

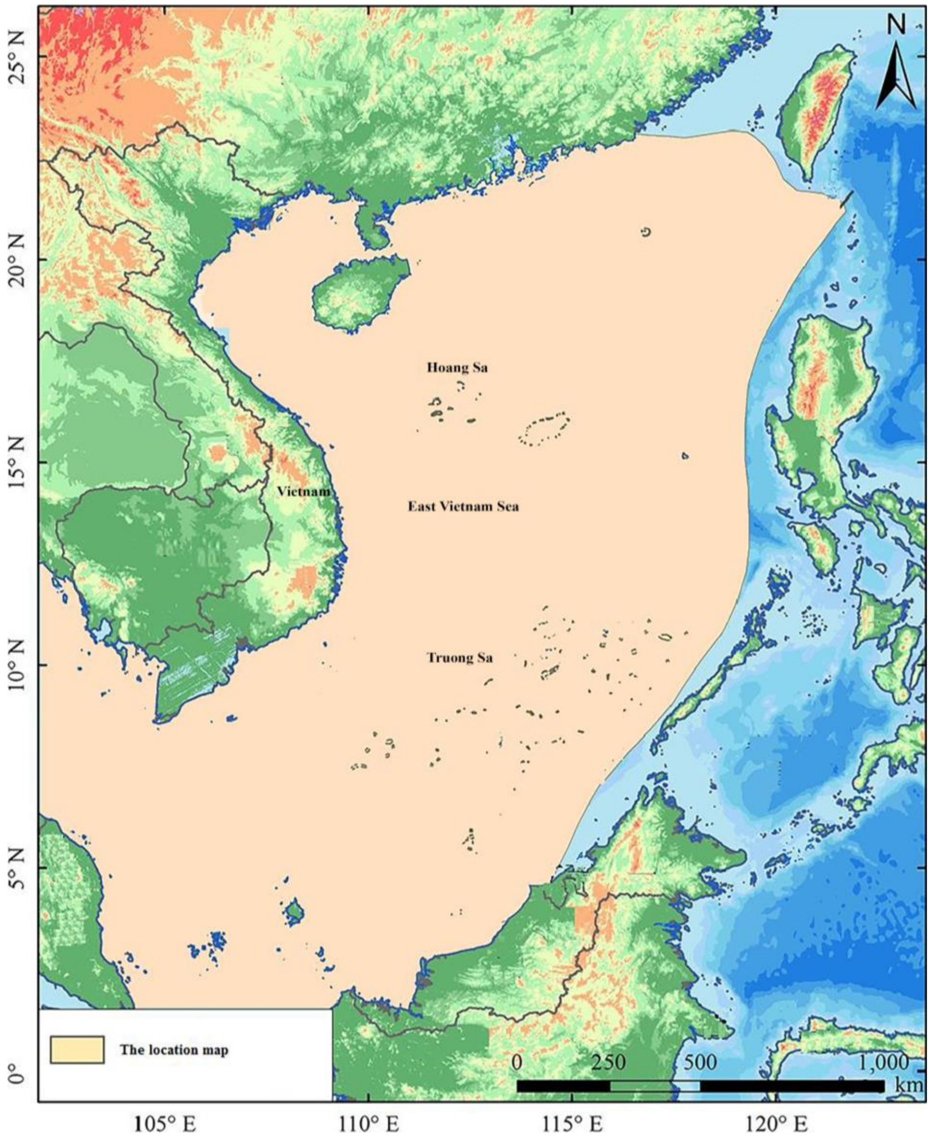

Figure 1. The location map

DATA AND PROCESSES

AWIPS Scatterometer Winds product description

Table 1. AWIPS BUFR descriptors

BUFR descriptor	Field ID
1007	Satellite ID
5040	Orbit number
4001	Year of observation
4002	Month of observation
4003	Day of observation
4004	Hour of observation
4005	Minute of observation
4006	Second of observation
5002	Latitude of observation
6002	Longitude of observation
21109	Quality flag
21120	SeaWinds Prob. of Rain
11012	Wind speed
11011	Wind direction

The QuikSCAT NRT processing system has been recently modified to include a new Marine Scatterometer Wind product for AWIPS. This product consists of a reduced set of field variables derived from the full MGDR BUFR product. Unlike the full MGDR BUFR product which encodes all points, whether or not a valid retrieval was calculated, the AWIPS product only encodes those points where a valid wind retrieval is produced [19]. A complete list of field variables and the corresponding BUFR descriptors for the AWIPS product is given in table 1.

The boundaries for the nine AWIPS regions are defined in table 2. An additional area 10, including everything outside the other nine regions is not currently implemented.

In this study, the 3-year wind data (August 2006 to June 2009) are provided from National Center for Hydrometeorological Forecasting. The data collection and processing system of National Center for Hydrometeorological Forecasting include the following modules: data transmission from JPL, data separation and storage for Southeast Asia, appropriate conversion of HDF format to BUFR format to display on AWIPS system.

We checked the dataset by comparing it with Truong Sa island weather station data: We collocate the QSCAT winds and weather station winds by extracting the wind cells from each satellite swath pass that fell in an area of the weather station for comparison.

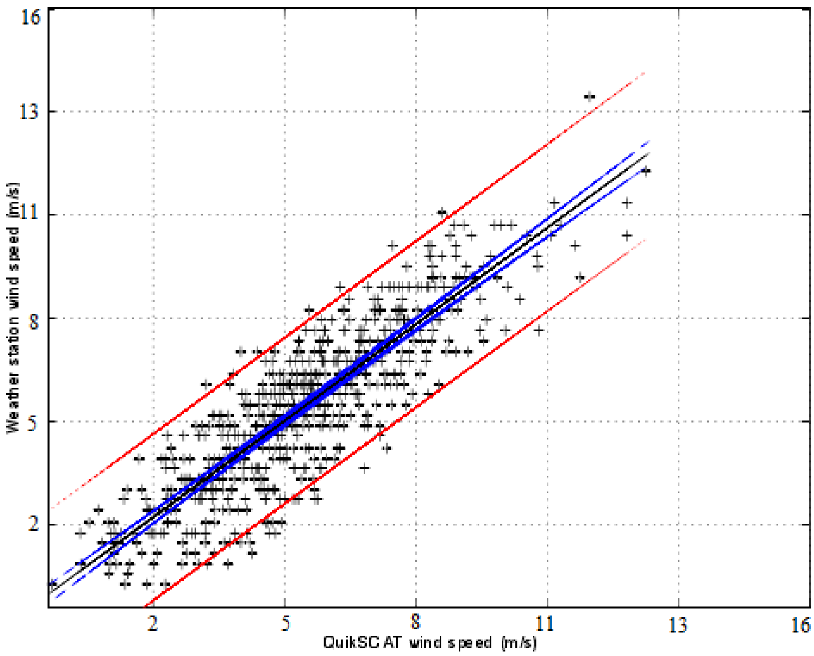

Figure 2. Scatter plot of observed wind speeds of QSCAT and Truong Sa island weather station after erroneous data pairs were removed. Black line is the linear regression. The blue and red lines are the 95% confidence level for the regression line and regression points, respectively

Table 2. AWIPS nine geographical areas for winds (and other BUFR products)

AREA #	Area boundary (Lat., Long.)	
Area 1	35W ≤ Long. ≤ 90W, 35S ≤ Lat. ≤ 37N	
Area 2	35W ≤ Long. ≤ 90W, 35N ≤ Lat. ≤ 75N	
Area 3	90W ≤ Long. ≤ 109W, 35S ≤ Lat. ≤ 37N	
Area 4	35W ≤ Long. ≤ 90W, 35N ≤ Lat. ≤ 75N	
Area 5	109W ≤ Long. ≤140W, 35S ≤ Lat. ≤ 45N	
Area 6	109W ≤ Long. ≤ 128W, 42N ≤ Lat. ≤ 75N	128W ≤ Long. ≤ 140W, 42N ≤ Lat. ≤ 75N
Area 7	140W ≤ Long. ≤ 180W, 35S ≤Lat. ≤ 50N	
Area 8	180W ≤ Long. ≤ 130E, 35S ≤ Lat. ≤ 50N	
Area 9	128W ≤ Long. ≤ 140W, 50N ≤ Lat. ≤ 75N	
Area 10	140W ≤ Long. ≤ 130E, 50N ≤ Lat. ≤ 75N	

Landsat ETM+ imagery of location

The study used the QuikSCAT wind field data from 2006 to 2009 to obtain the average wind power density at a height of 10 m on the sea surface to evaluate the wind energy resources of the East Island Reef. Two factors need to be considered for island reef wind power generation, namely the wind power density at the height of the fan hub (70 m above sea level) and the number of wind turbines that can be built on the island reef. As the construction cost and construction difficulty increase with increasing water depth, offshore wind turbines are generally built within a water depth of 10 m. For islands and reefs, except that the depth of the reef flat is basically within 10 m, the water depth in the atoll island and outside the island reef is generally more than 10 m. Therefore, the study used 35 Landsat ETM+ images to extract flat reefs in the East Vietnam Sea for estimating the number of wind turbines that can be built on coral reef based on their circumference.

Table 3. Landsat ETM+ imagery of location

No.	Date of taking imagery	Track number	No	Date of taking imagery	Track number
1	2006-09-16	118-54	19	2009-01-18	119-54
2	2006-09-23	119-53	20	2010-01-18	119-55
3	2006-09-30	120-52	21	2010-054-25	120-46
4	2006-09-30	120-53	22	2010-10-25	120-52
5	2006-09-30	120-54	23	2011-01-25	120-53
6	2006-09-30	120-55	24	2011-05-25	120-54
7	2006-11-26	119-54	25	2012-02-08	122-49
8	2007-03-22	122-49	26	2012-09-16	118-54
9	2007-04-16	121-54	27	2013-03-30	118-54
10	2007-04-25	120-53	28	2013-010-14	118-53
11	2007-04-27	118-53	29	2014- 01-21	119-53
12	2007-05-11	120-56	30	2014-05-21	119-54
13	2008-02-09	118-50	31	2014-11-26	122-49
14	2008-04-21	119-52	32	2015-01-28	120-53
15	2008-04-21	119-53	33	2015-07-20	121-54
16	2008-11-06	120-54	34	2015-11-01	120-52
17	2009-01-07	122-48	35	2016-04-04	118-54
18	2009-01-18	120-53			

METHODS

Meteorological wind data are obtained near the surface, or at meteorological tower height (5–20 m). In wind energy studies, we are usually interested in wind at the height of the hub of a wind turbine (70–100 m), and in this article, we calculate wind speed as well as the energy content at hub height. In order to estimate speed at the hub height over water we will make use of the so-called log-law. We assume neutral stability of the atmosphere and a surface roughness of z_o = 0.2 mm, recommended as an average value for calm and open seas [20] (Theoretical development of a time and location-specific value of z_o is underway [21]). The log-law states that a velocity V at a given height z is:

$$V = V_{ref} \frac{\ln(z/z_o)}{\ln(z_{ref}/z_o)} \quad (1)$$

Where: z_{ref} is the height of our measured wind speed (V_{ref}).

Another quantity of interest is the wind power density P, the energy content of the wind is given in unit of watts per square meter (Wm^{-2}). This quantity represents the flow of kinetic energy per unit area associated with the wind:

$$P = \frac{1}{2}\rho V^3 \quad (2)$$

For simplification, we use constant air density, ρ = 1.225 $kg.m^{-3}$

Note that the actual power production expected from a wind turbine must also take into account the mechanics of the flow passing through the blades and the efficiency of the rotor/generator. However, power density is a useful measure, because it is independent of turbine characteristics. For instance, assuming a known swept area, A, we can estimate the power production P_t by multiplying Eq. (2) by AC_p, with the given conversion efficiency C_p.

RESULTS AND ANALYSIS

Wind energy resource evaluation results

Based on the QuikSCAT wind speed data of Kriging interpolation, the average wind speed in the study area from 2006 to 2009 was obtained (fig. 3), which intuitively analyzed the wind speed distribution of the South island Reef and provided the basis for the evaluation of wind energy resources.

Figure 3 shows that the average wind speed in the study area is 5~8.8 m/s. According to table 4, the wind speed can be applied to wind power.

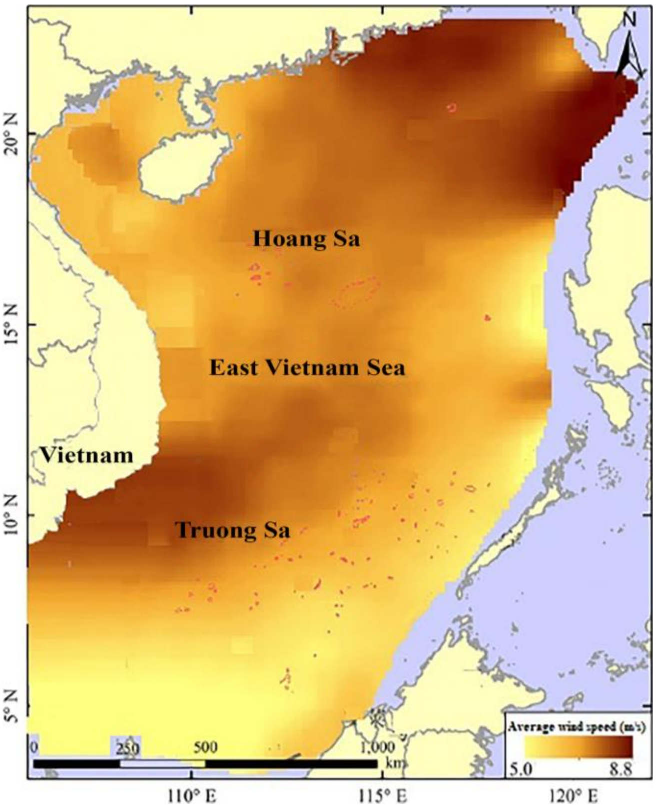

Figure 3. Average wind speed based on QuikSCAT data from 2006 to 2009 in the study area

Table 4. Wind power density level (10 m hight above the sea surface)

Level	1	2	3	4	5	6	7
Wind power density (W/m^2)	< 100	100~150	150~200	200~250	250~300	300~400	400~1,000
Annual average wind speed reference value (m/s)	4.5	5.0	5.5	6.0	6.5	7.0	9.5
Applicability to wind power generation			Better	Good	Very good	Very good	Very good

Based on the QuikSCAT wind speed data for three years, the average wind power density of the study area was calculated and classified into levels 1–7 (see table 4 for the basis of division), and the average wind of the study area for 3 years was obtained (figure 4).

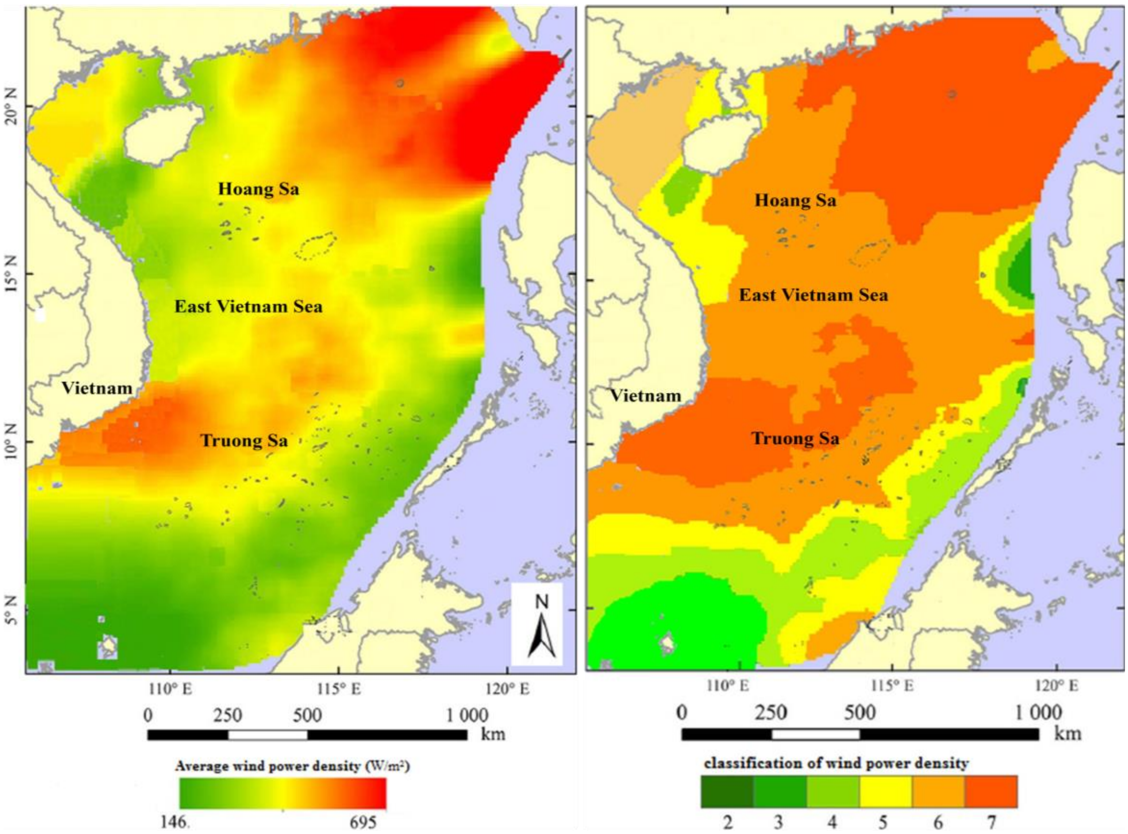

Figure 4. Average wind power density and classification of wind power density

Figure 4 shows that the average wind power density in the study area is between 146~695 W/m^2, and the wind power density level is basically 3–7, the wind power density of the Hoang Sa and Truong Sa archipelagos is 311~364 W/m^2 and 214~415 W/m^2, respectively.

The QuikSCAT wind farm data for the three years from 2006 to 2009 were classified according to the average wind power density of each season, and the wind power density was obtained (figure 5).

Figure 5 shows that the average wind power density in the study area is seasonally increasing, the average wind power density is lower in spring and summer, meanwhile it is higher in autumn and winter. In the spring, the wind power density level of the Hoang Sa archipelago is 3–4, and that of the Truong Sa archipelago is 2–5; in the summer, the wind power density level of the Hoang Sa archipelago is 5–6, and that of the Truong Sa archipelago is 3–7.

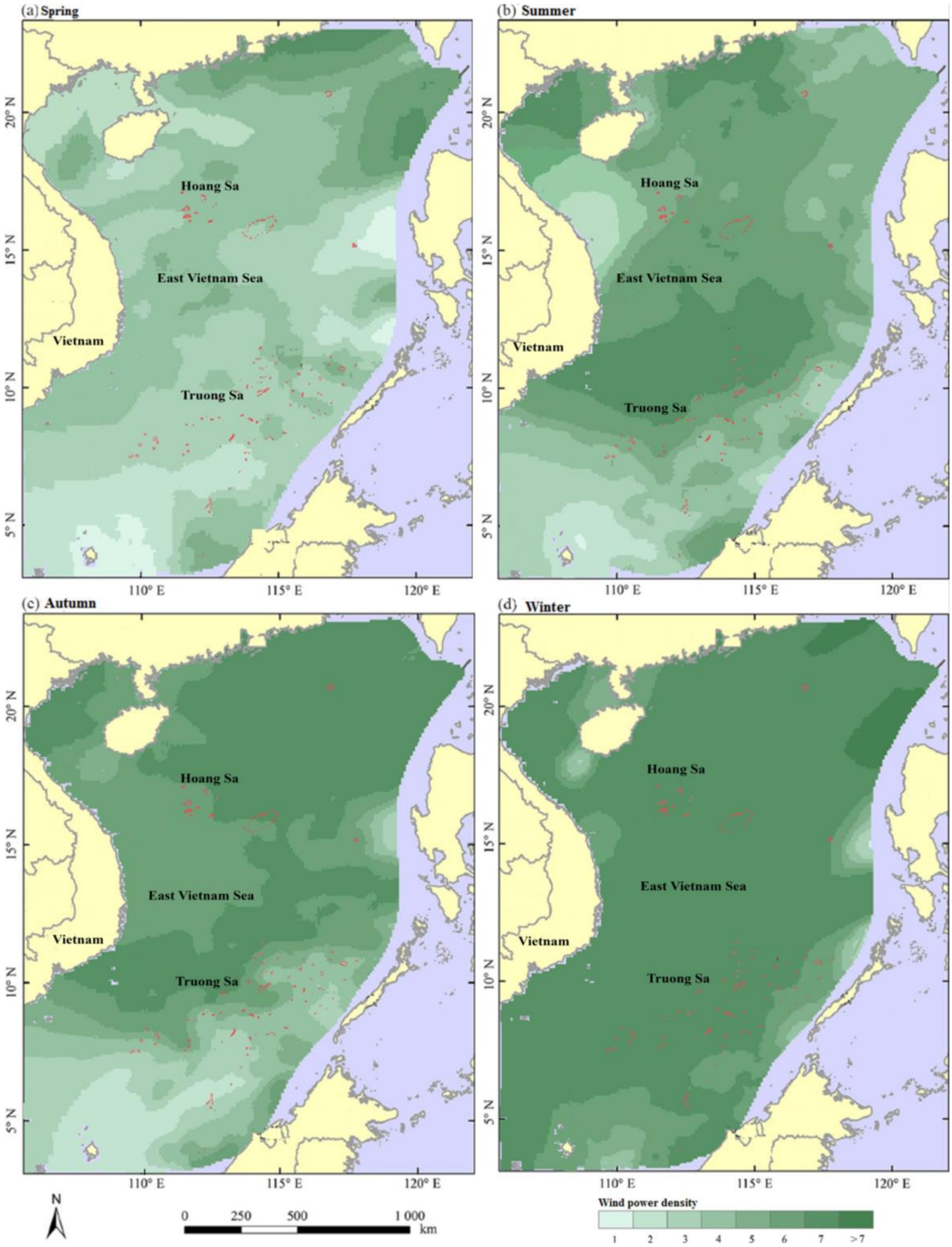

Figure 5. Seasonal variability of wind power density

Wind power evaluation results

Based on the multi-tempo QuikSCAT wind speed data, the sea surface reef flat (20 islands in the Hoang Sa archipelago, and 85 islands in the Truong Sa archipelago), the perimeter of the wind turbines that can be built on each island and reef was calculated, and estimate for the islands. The installed wind power capacity of every reefs in the East Vietnam Sea show on the figure 6.

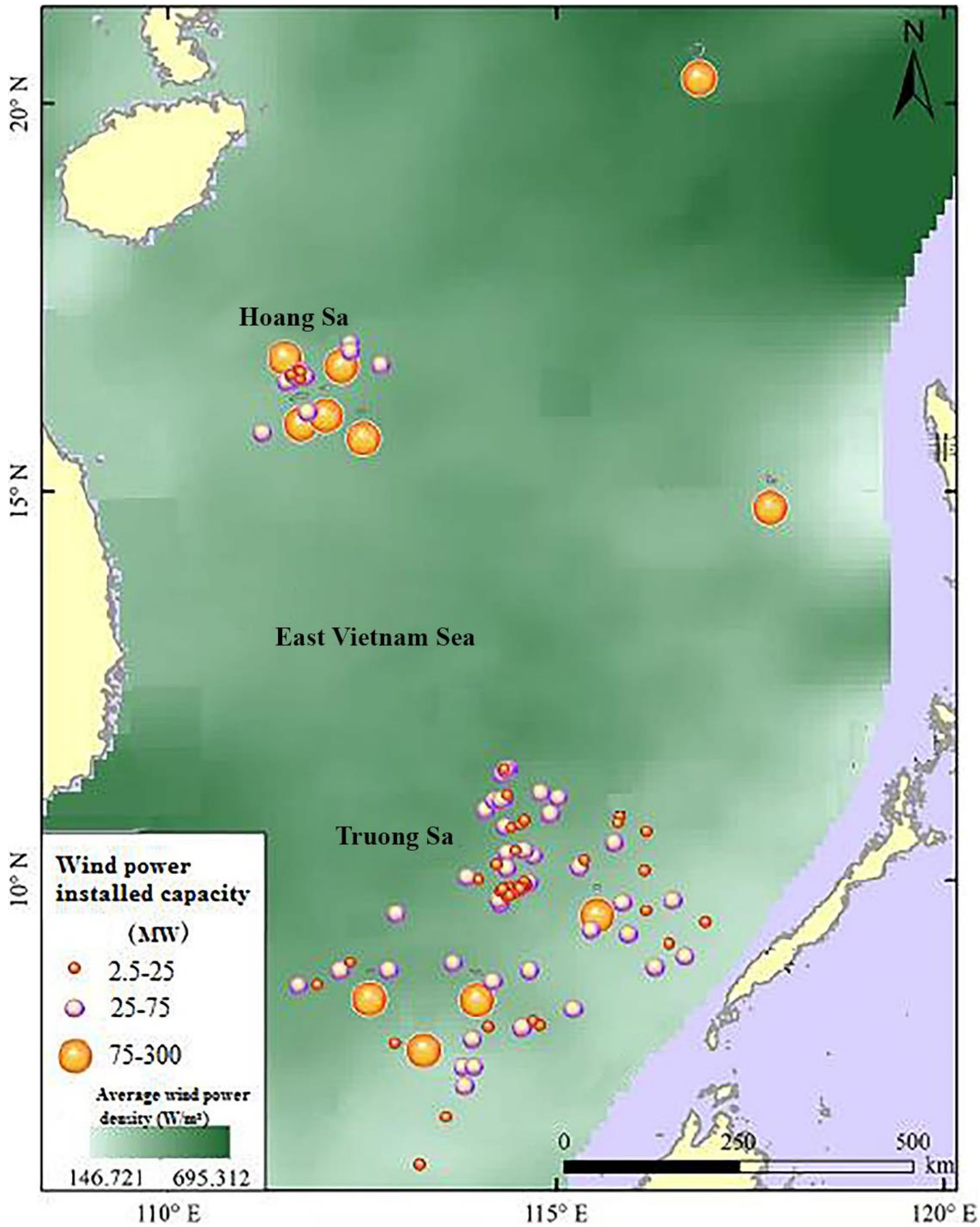

Figure 6. Installed wind power capacity of every reefs in the East Vietnam Sea

Statistics on the islands and reefs with the highest installed capacity of wind power in the archipelago are shown. The results are presented in table 5.

Table 5. Installed wind power capacity statistics of parts of reefs in the East Vietnam Sea

Island names	10 m hight wind power density (W/m^2)	70 m hight wind power density (W/m^2)	Island reef installed wind power capacity (MW）
Hoang Sa archipelago			
Discovery Reef	324	653	190
Bombay Reef	363	732	140
Tree island	353	712	110
Vuladdore Reef	333	672	100
North Reef	340	685	90
Lincoln island	353	712	60
Bach Quy Reef	325	655	60
Woody island	352	709	50
Truong Sa archipelago			
Mariveles Reef.	233	471	130
Ladd Reef	373	751	110
Cornwallis South Reef	321	647	90
Barque Canada Reef	327	659	80
Petley Reef	333	671	70
Second Thomas Shoal	274	553	70
Tennent Reef	295	594	70
Alison Reef	339	683	67
Mischief Reef	230	464	64
Johnson Reef	395	796	60

CONCLUSIONS AND DISCUSSION

Discussion

(1) Natural disasters such as winds, wind waves and storm surges usually occur in the East Vietnam Sea. These natural disasters not only have a certain impact on the operation of wind turbines, but also cause the high value in the calculation of the average wind power density in the typhoon frequent areas. When selecting a site, it is essential to avoid areas with frequent natural disasters.

(2) Although wind energy itself is a clean renewable energy source, wind power generation is not completely pollution-free. In case of wind power generation, wind turbines will generate certain noise pollution, which will have a certain impact on the living environment of the islands and reefs. Therefore, the wind noise planning of the island reef should pay attention to the fan noise problem.

Conclusion

The wind power density in the study area is between 146~695 W/m^2, and the wind power density level is basically 3–7, which can be applied to island reef wind power. Among them, the wind power density level of the Hoang Sa archipelago is 6, and that of the Truong Sa archipelago is 4–7.

The wind power density in the study area is gradually increasing. The wind power density in spring and summer is small, while that in autumn and winter is relatively large. The wind power density levels of the Hoang Sa archipelago and the Truong Sa archipelago are basically 2–5 in spring, 3–7 in summer, 5–7 in autumn, and 7 in winter. Therefore, in the case of island reef wind power generation, we should make more use of wind energy resources in winter and autumn, and simultaneously carry out energy reserve work for spring and summer.

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