

# ASSESSING THE WIND ENERGY POTENTIAL IN PROVINCES OF WEST JAVA, PAPUA, AND EAST BORNEO IN INDONESIA

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Due to technological advancements and environmental concerns, wind power generation using wind turbines has increased significantly in recent years. In the current study, meteorological data over five years (2015 – 2019) have been used in order to estimate the Weibull distribution function, wind power, and energy density for ten meteorological stations in three provinces. Monthly and yearly wind speed variations are analyzed. The results demonstrated that the values of the shape and scale parameters are varied over a wide range for each site. Moreover, the results illustrated that the highest wind power potential occurs at Jayawijaya city with a potential of 36.23 w/m<sup>2</sup>. On the other hand, results showed that the monthly wind speed varies in a large range in each site. In the Jayawijaya city, for example, it ranged between 2.27 and 2.9 m/s, whereas in the Bogor Regency it ranged between 0.58 and 0.25 m/s. According to the predicted yearly power and energy densities, the evaluated sites are appropriate for small-scale power generation.

**Keywords:** Weibull distribution, power density, wind turbine, wind energy potential, Indonesia

## 1 INTRODUCTION

Energy is considered as the most crucial requirements for the development of the countries. The utilization of clean energy has now become a necessity of life. This is due to the extensive utilization of fossil fuels, which increases the harmful gas emissions such as Carbon Dioxide (CO<sub>2</sub>) and Carbon monoxide (CO), causing a climate crisis [1,2]. These fossil fuels are causing serious economic issues besides the issues related to air pollution. Consequently, by utilization clean and sustainable sources of energy such as renewable energy, the effect of these fossil fuels will decrease. Wind energy has been gaining popularity as a form of renewable energy, and academics have been working to develop the wind energy sector in order to attain high reliability in renewable energy systems [3, 4]. Wind energy provides a promising source of renewable energy that can cover the energy demand in the on-grid modes and off-grid remote applications; this is due to the falling cost of raw materials and technology advancement [5-9].

Since the use of wind turbines for energy generation, the wind power sector has seen significant growth in recent years. For the years 2009 to 2019, Fig. 1 depicts global annual installed wind capacity. As shown in the figure, the installed capacity was raised continuously year by year. In 2019, the installed capacity was 60 Gigawatts. This was the second-largest yearly growth in capacity ever, and it came after three years of decrease following the 2015. (63.8 GW) [10].

Indonesia still depends on fossil fuels for electricity generation, including 59.9% coal, 22.3% gas, and 6% crude oils [11]. However, by 2025, Indonesia's new energy plan requires that at least 23% of the country's energy be generated from renewable energy sources [12]. This target will be accomplished by replacing the old power plants with new plants that adopt renewable energy, with an overall capacity of 11 Gigawatt [13]. At the beginning of 2018, a commercial wind power plant with an overall capacity of 75 Megawatt has been accomplished in Sidrap district, Indonesia. The power plant consisted of 30 wind turbines with 2.5 Megawatt capacity for each [14]. This wind power station marked a watershed moment in Indonesia's renewable energy development and marked the country's first usage of wind energy. Over the past years, very few studies estimated the potential of wind energy in Indonesia; these studies showed that Indonesia has an effective wind power potential in different locations [15,16]. Global warming has an effect on the climate by raising the temperature; this rising has an impact on wind speeds in several regions in the world [17] [18]. In order to analyze the potential of wind energy in the last 5 years, this study will use the most recent available wind speed and direction data. Wind Energy potential in a specific site can be determined by conducting an investigation on the wind characteristics, i.e. wind speed, wind direction, and the availability [19]. Wind speeds vary in a similar geographic terrain; this difference is due to the characteristics of the wind system that may result in uneven power output. Consequently, wind distribution at different timescale and wind speeds modeling is essential to evaluate the wind potential of a specific site. Additionally, wind speed increases as altitude increases, particularly in coastal areas. Based on that, the current study aims to assess the potential of wind energy at three different provinces i.e. West Java, Papua, and East Borneo.

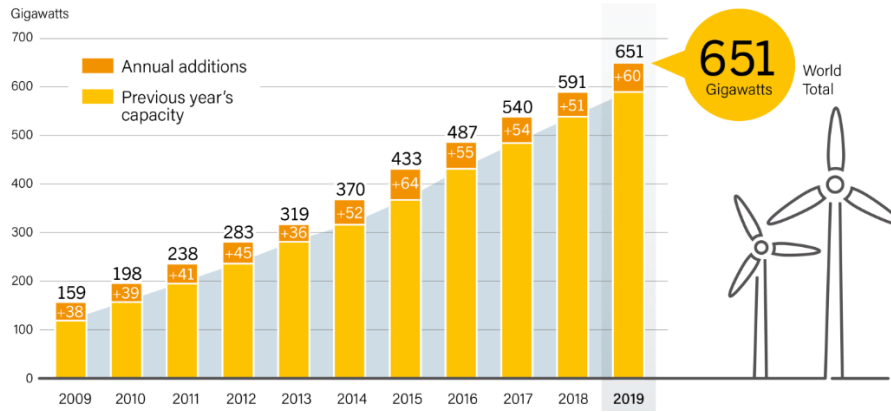


Fig. 1. Wind power global capacity and annual additions 2009-2019 [9].

## 2 SITES DESCRIPTION AND DATA COLLECTION

Indonesia is an Asian country located in South-east Asia and Oceania, strategically between the Pacific and Indian oceans, with a total area of 1,904,569 km<sup>2</sup> as the 14<sup>th</sup> largest country in terms of land area. It lies at (0.7893° S) latitude and (113.92° E) longitude. It is the world's biggest archipelagic nation, stretching 5,120 kilometers east to west and 1,760 kilometers north to south. There are two seasons in Indonesia: the rainy and the dry. November to April is the rainy season, whereas May to October is the dry season.

Indonesia has 34 provinces, however, this study will consider only 3 provinces (West Java, Papua, and East Borneo). These locations were selected for the assessment because that West Java is a monsoon region whereas Papua and East Borneo are located in the equator line. The assessment will be done for 10 cities in the selected provinces as follows: West Java: Bandung, Bogor, Regency of Bogor, and Majalengka. Papua: Biak Numfor, Jaya Wijaya, and Yapen Island. East Borneo: Balikpapan, Berau, and Samarinda.

Table 1. Physical features of the meteorological stations

No	Meteorological Station	Latitude	Longitude	Elevation (m)
1.	Biak Numfor	-1.19069	136.10361	3
2.	Jaya Wijaya	-4.07000	138.95000	1653
3.	Yapen island	-1.87540	136.23994	3
4.	Bandung	-6.88356	107.59733	791
5.	Bogor City	-6.50000	106.75000	207
6.	Bogor Regency	-6.70000	106.85000	920
7.	Majalengka	-6.73440	108.26300	85
8.	Balikpapan	-1.26000	116.90000	3
9.	Berau	2.14562	117.43375	13
10.	Samarinda	-0.48000	117.16000	10

## 3 ANALYSIS PROCEDURE

To assess the potential of the available energy in the wind for a particular site, wind speed frequency distribution is required. The frequency of the wind speed through a specific period of time can be determined using various probability density functions like Weibull, Gaussian, Exponential, and Rayleigh distribution. The Weibull distribution function is the most used method in recent researches; because this function has some features over the other functions such as simplicity and accuracy [20 - 23]. Consequently, the annual production of a given wind machine can be determined faster.

The Weibull distribution function (Eq(1)) depends mainly on two parameters; shape function (k) (Eq (2)) and scale function (c) (Eq (3)) [24].

$$f(v) = \left(\frac{v}{c}\right)^{k-1} \times \left(\frac{k}{c}\right) \times \exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{1}$$

$$k = 0.83\bar{v}^{0.5} \tag{2}$$

$$c = \frac{\bar{v}}{\Gamma(1+\frac{1}{k})} \tag{3}$$

Where  $f(v)$  is the probability of observing wind speed  $v$ ,  $\bar{v}$  is the average wind speed, and  $\Gamma$  is the gamma function. Wind power density represents the total power that can be generated from the wind using wind turbines and it can be written as follows [25]:

$$P(v) = 0.5\rho Av^3 \tag{4}$$

Where  $A$  represents the normal area to the vector of the wind speed and  $\rho$  represents the density of the air. The following equation may be used to compute wind power density using Weibull distribution analysis [26]:

$$\frac{P}{A} = 0.5 \rho \int_0^\infty v^3 f(v) dv = 0.5\rho c^3 \Gamma\left(\frac{K+3}{k}\right) \tag{5}$$

As a result, the density of wind energy over time  $T$  may be calculated as follows: [27]:

$$\frac{E}{A} = \frac{P}{A} T = 0.5 \rho c^3 \Gamma\left(1 + \frac{3}{k}\right) T \tag{6}$$

The most probable wind speed  $V_{mp}$ , on the other hand, is a crucial quantity that must be evaluated during the evaluation of wind energy. This wind speed is significant in calculating the most common wind speed for a particular wind probability distribution, and it may be determined using the equation below. [28]:

$$V_{mp} = c \times \left(\frac{k-1}{k}\right)^{\frac{1}{k}} \text{ (m/s)} \tag{7}$$

In addition, the wind speed that carries the peak energy,  $V_{(max,E)}$ , is a significant speed that must be estimated. It represents the greatest amount of energy that can be stored in a given area and may be calculated as follows: [29]:

$$V_{max,E} = c \times \left(\frac{K+2}{k}\right)^{\frac{1}{k}} \text{ (m/s)} \tag{8}$$

## 4 RESULTS AND DISCUSSION

### 4.1 Wind speed characteristics

Wind energy potential in Indonesia was investigated in 10 stations for the years between 2015 and 2019. The monthly variations of wind speed can be useful in determining the behavior of the seasonal wind in a particular site.

The monthly wind speed average is calculated and illustrated in Figure 2. The monthly average wind speed is between 0.25 m/s and 3 m/s, as seen in the graph. Furthermore, the maximum wind speed estimates for the majority of locations may be recorded around September, whereas the lowest values can be found in different months for different sites during the year. This indicates that the highest value of average wind speed occurs in the dry season for most sites and it is suitable to build the wind system in this season. Additionally, it can be seen that Bojor Regency city has the lowest average wind speed whereas Jayawijaya city has the highest wind speed during the year.

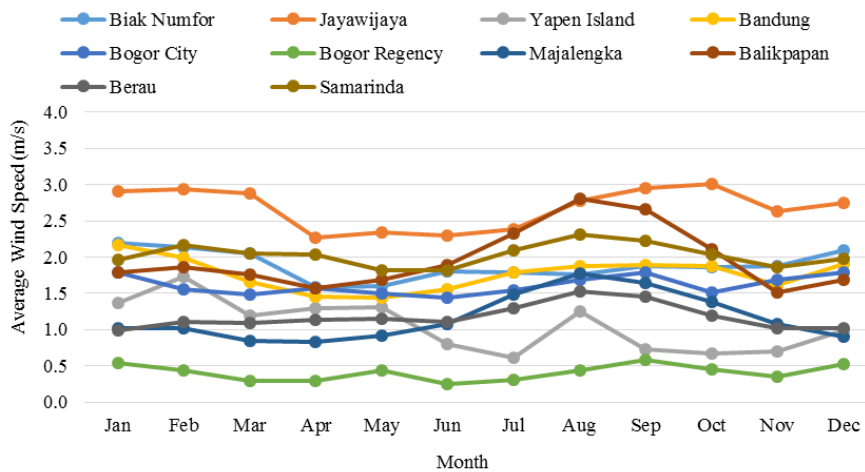


Fig. 2. Monthly variation data of average wind speed.

### 4.2 Weibull parameters

Monthly Weibull parameters  $k$  and  $c$  are calculated and illustrated for all the sites in Table 2. The shape and scale parameters of most stations are in the range of 0.5 – 1.6 and 0.13 – 3.36, respectively. The highest value of  $k$  and  $c$

can be found in Jayawijaya city with values of 1.66 and 3.36, respectively, whereas the lowest values of  $k$  and  $c$  are 0.45 and 0.13 and they can be found in Bojor Regency city. This shows that Jayawijaya has a great stable wind with high speed whereas the Bojor Regency city has the lowest wind stability with weak speed.

Fig. 3 and Fig. 4 show the cumulative distribution  $P(v)$  and frequency distribution  $f(v)$  of monthly average wind speed for all of the locations, respectively.

Table 2. Monthly variation data of  $k$  and  $c$

Meteorological Station	Parameter	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Biak Numfor	k	1.39	1.37	1.34	1.18	1.18	1.26	1.25	1.24	1.28	1.28	1.28	1.36
	c	2.41	2.33	2.23	1.68	1.70	1.95	1.92	1.89	1.03	1.01	2.02	2.28
Jaya Wijaya	k	1.58	1.60	1.58	1.40	1.43	1.42	1.44	1.54	1.58	1.61	1.50	1.55
	c	3.24	3.27	3.21	2.49	2.57	2.53	2.62	3.09	3.29	3.36	2.90	3.05
Yapen island	k	0.98	1.10	0.79	0.95	1.06	0.73	0.47	0.88	0.62	0.59	0.60	0.72
	c	1.47	1.89	1.30	1.37	1.34	0.77	0.65	132	0.74	0.67	0.71	1.05
Bandung	k	1.37	1.32	1.21	1.13	1.12	1.17	1.25	1.29	1.29	1.28	1.19	1.29
	c	2.36	2.17	1.77	1.53	1.50	1.65	1.92	2.04	2.04	2.03	1.71	2.06
Bogor City	k	1.25	1.16	1.14	1.17	1.15	1.12	1.16	1.21	1.25	1.15	1.22	1.24
	c	1.92	1.64	1.56	1.66	1.57	1.51	1.63	1.80	1.92	1.59	1.81	1.92
Bogor Regency	k	0.67	0.61	0.50	0.51	0.60	0.45	0.45	0.55	0.69	0.60	0.52	0.65
	c	0.43	0.32	0.15	0.16	0.33	0.13	0.21	0.35	0.49	0.34	0.23	0.41
Majalengka	k	0.95	0.95	0.86	0.85	0.89	0.97	1.14	1.24	1.18	1.09	0.96	0.89
	c	0.99	0.99	0.79	0.76	0.87	1.07	1.56	1.91	1.74	1.43	1.06	0.86
Balikpapan	k	1.25	1.28	1.24	1.17	1.22	1.29	1.43	1.57	1.52	1.35	1.15	1.22
	c	1.93	2.01	1.89	1.66	1.80	2.05	2.55	3.12	2.95	2.29	1.59	1.80
Berau	k	0.93	0.99	0.98	1.00	1.00	0.99	1.07	1.16	1.13	1.03	0.94	0.95
	c	0.96	1.11	1.08	1.13	1.15	1.10	1.32	1.60	1.52	1.20	1.00	1.00
Samarinda	k	1.3	1.37	1.34	1.34	1.27	1.27	1.36	1.43	1.40	1.34	1.28	13.2
	c	2.13	2.37	2.24	2.22	1.96	1.97	2.29	2.54	2.44	2.22	2.02	2.14

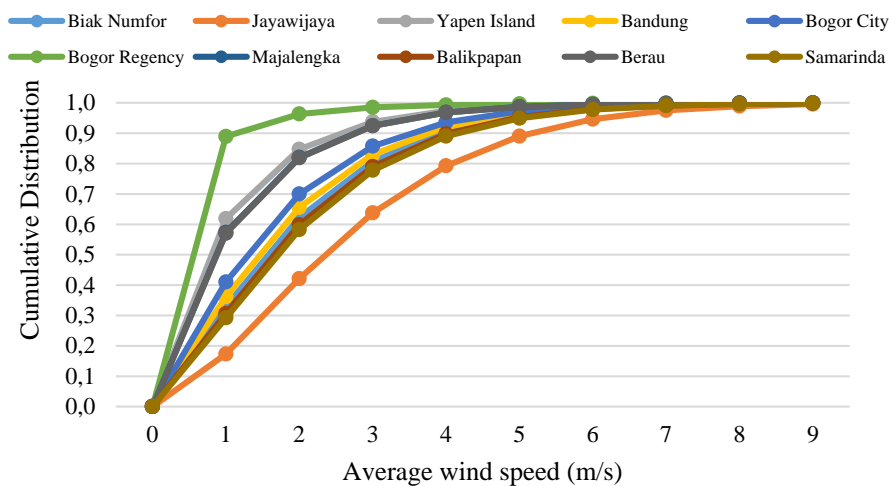


Fig. 3. Cumulative distribution vs. average wind speed.

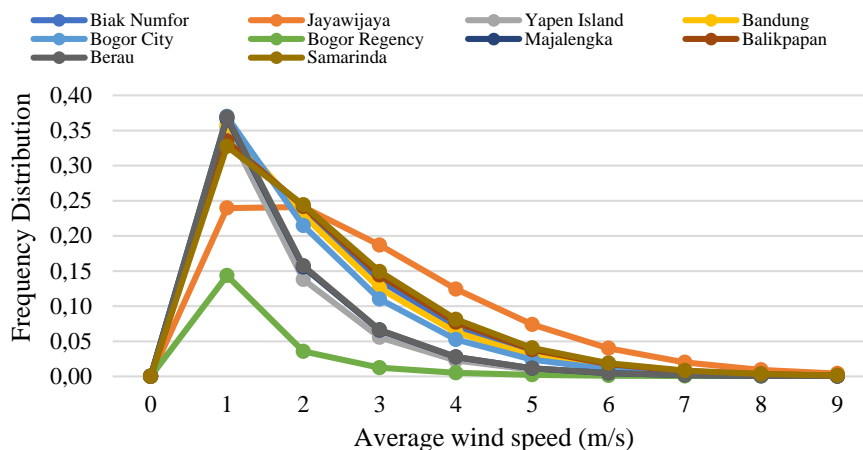


Fig. 4. Frequency distribution vs. average wind speed.

It can be observed from both figures that the curves of frequency and cumulative density are following the same trend of wind speeds. However, the peak frequency is in the range of 1 to 2 m/s for the three provinces. This reflects that most of the wind energy can be found in this range. These data can be very useful to find the amount of power that can be generated at given wind speed and so can be useful in determining the best place for installing wind turbines for each particular site.

On the other hand, the peak value of the cumulative distribution is found to be at a wind speed of 9 m/s. However, Bogor Regency city is found to be the fastest city that reaches this peak which means that the wind distribution in this city is better than the others.

#### 4.3 Most probable wind speed and wind speed carrying maximum energy

The most probable wind speed and the wind speed carrying the peak energy were calculated using Eqs (7) and (8), and the results are shown in Table 3.

It can be observed from the table that the lowest monthly most probable wind speed values were found in the months between April and July for all the sites except Samarinda, and were obtained in the range of 1.1 – 4.5 m/s. The highest monthly values for the Biak Numfor, Bandung, and Bogor City were found in January, while August for Berau, Balikpapan, and Samarinda, February for Yapen Island, October for Jaya Wijaya, June for Bogor Regency, and September for Majalengka gave the highest values.

On the other hand, wind speed carrying maximum energy values according to sites were between 3.88 and 4.57 m/s for Biak Numfor, 4.69 and 5.5 m/s for Jaya Wijaya, 2.6 and 4.07 m/s for Yapen Island, 3.72 and 4.53 m/s for Bandung, 3.73 and 4.11 m/s for Bogor City, 3.08 and 4.29 m/s for Bogor Regency, 3.13 and 4.1 m/s for Majalengka, 3.87 and 5.26 m/s for Balikpapan, 3.26 and 3.81 m/s for Berau, and 4.14 and 4.69 m/s for Samarinda. The lowest value was 2.6 m/s in Yapen Island.

Table 3. Monthly variation data of Vmp and VmaxE

Meteorological Station	Parameter	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Biak Numfor	Vmp	3.55	3.47	3.37	2.82	2.83	3.08	3.06	3.03	3.17	3.15	3.16	3.43
	VmaxE	4.57	4.49	4.40	3.88	3.89	4.13	4.11	4.08	4.21	4.19	4.20	4.44
Jaya Wijaya	Vmp	4.39	4.42	4.35	3.64	3.71	3.67	3.76	4.23	4.43	4.50	4.05	4.20
	VmaxE	5.39	5.41	5.35	4.66	4.72	4.69	4.78	5.24	5.44	5.50	5.06	5.19
Yapen island	Vmp	2.38	2.81	1.98	2.28	2.48	1.67	1.10	2.22	1.42	1.35	1.39	1.74
	VmaxE	3.22	3.62	2.60	3.13	3.59	3.35	3.83	4.07	3.49	3.39	3.54	3.96
Bandung	Vmp	3.50	3.31	2.91	2.66	2.64	2.79	3.06	3.18	3.18	3.17	2.85	3.20
	VmaxE	4.53	4.33	3.96	3.74	3.72	3.85	4.10	4.21	4.21	4.20	3.91	4.24
Bogor City	Vmp	3.06	2.78	2.70	2.80	2.71	2.64	2.77	2.93	3.06	2.73	2.95	3.06
	VmaxE	4.11	3.86	3.78	3.87	3.79	3.73	3.84	3.99	4.10	3.80	4.00	4.11
Bogor Regency	Vmp	1.56	1.45	1.30	1.30	1.45	1.65	1.13	1.24	1.65	1.52	1.56	1.55
	VmaxE	3.34	3.40	3.82	3.60	3.40	3.29	3.72	3.08	3.80	4.29	3.40	3.44



Meteorological Station	Parameter	Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Majalengka	Vmp	2.12	2.12	1.91	1.89	2.00	2.20	2.70	3.05	2.88	2.56	2.19	1.99
	VmaxE	3.28	3.29	3.15	3.13	3.22	3.36	3.79	4.10	3.98	3.69	3.37	3.20
Balikpapan	Vmp	3.06	3.15	3.03	2.80	2.94	3.19	3.70	4.27	4.09	3.43	2.73	2.94
	VmaxE	4.11	4.19	4.07	3.87	3.99	4.22	4.71	5.26	5.09	4.46	3.80	3.99
Berau	Vmp	2.09	2.24	2.21	2.26	2.28	2.23	2.46	2.74	2.66	2.34	2.13	2.12
	VmaxE	3.26	3.38	3.36	3.40	3.41	3.37	3.56	3.81	3.74	3.46	3.31	3.29
Samarinda	Vmp	3.27	3.51	3.38	3.36	3.10	3.11	3.43	3.68	3.58	3.36	3.16	3.28
	VmaxE	4.31	4.54	4.40	4.38	4.14	4.14	4.45	4.69	4.59	4.38	4.19	4.31

#### 4.4 Wind power and energy density

Table 4 and Fig. 5 show the results of evaluating wind power and energy density. The highest value of wind power density was found at Jayawijaya with 36.23 w/m<sup>2</sup>, followed by Balikpapan and Samarinda with 17.65 w/m<sup>2</sup> and 17.49 w/m<sup>2</sup>, respectively, and the lowest value of wind power density was found at Majalengka with 6.44 w/m<sup>2</sup>, followed by Berau with 5.88 w/m<sup>2</sup> and Bogor Regency with 1.91 w/m<sup>2</sup>, respectively. Furthermore, the wind energy density was in a range between 16762 w/m<sup>2</sup>/year and 317394 w/m<sup>2</sup>/year. With a value of 317394.36 w/m<sup>2</sup>/year, Jayawijaya city had the highest energy value, while Bogor Regency had the lowest.

Table 4. Annul Weibull parameters

Meteorological Station	k	c	Vavg	Vmp	VmaxE	P(v)	E(v)
Biak Numfor	1.28	2.04	1.89	3.18	2.10	15.38	134745.70
Jaya Wijaya	1.52	2.97	2.68	4.11	2.82	36.23	317394.36
Yapen island	0.79	1.11	1.05	1.90	3.48	7.58	66381.11
Bandung	1.24	1.90	1.77	3.04	1.99	13.27	116284.08
Bogor City	1.19	1.71	1.61	2.85	1.84	11.17	97838.20
Bogor Regency	0.57	0.30	0.41	1.45	3.43	1.91	16762.72
Majalengka	1.00	1.17	1.16	2.30	1.41	6.44	56426.08
Balikpapan	1.31	2.14	1.97	3.28	2.17	17.65	154585.76
Berau	1.01	1.18	1.17	2.31	1.42	5.88	51540.05
Samarinda	1.33	2.21	2.03	3.35	2.23	17.49	153226.57

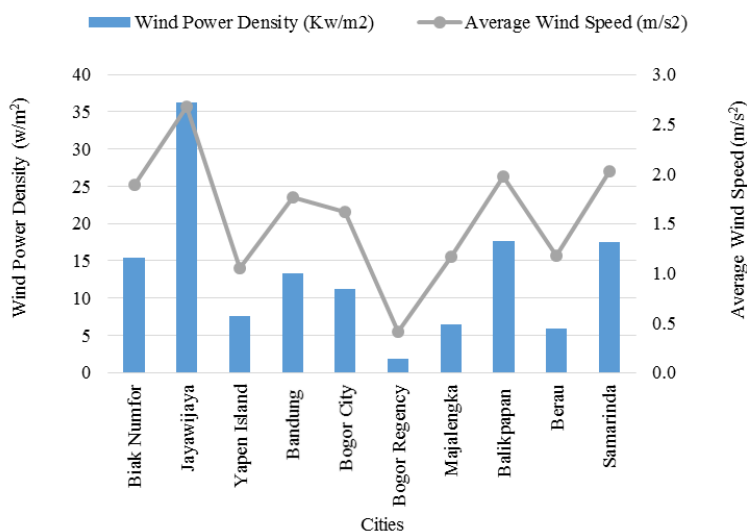


Fig. 5. Comparison of yearly wind power density and average wind speed.

Based on these data, it could be concluded that wind speeds have higher values in the dry season for most of the assessed cities. Hence, the power and energy densities are higher in the dry season and the wind system would produce more power during this period.

**4.5 Wind rose**

The evaluation of wind direction aids in exposing the influence of geographical factors on the wind in order to identify the most common wind's predominant direction and amplitude. The wind roses for all of the locations were created using the WRPLOT program. Fig. 6 to Fig. 15 shows the polar diagram of the wind direction for the recent year. It was noticed that the prevailing wind direction diverse from site to site as well as within the same site.

Based on that, the prevailing wind direction for the Papua Province was east whereas Jayawijaya was northwest. Moreover, in the West Java Province the direction provided at various directions i.e. Bandung to the East, Bogor City to the south, Bogor Regency to the southeast, and Majalengka to the west. Additionally, the wind direction in East Kalimantan was northeast except Samarinda, which has a westward wind direction.

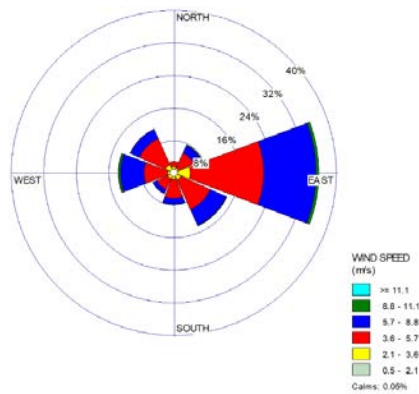


Fig. 6. Wind map in Biak Numfor.

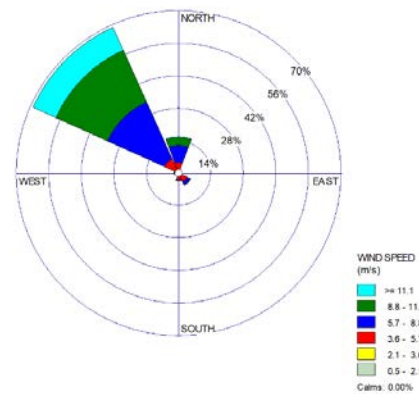


Fig. 7. Wind map in Jayawijaya.

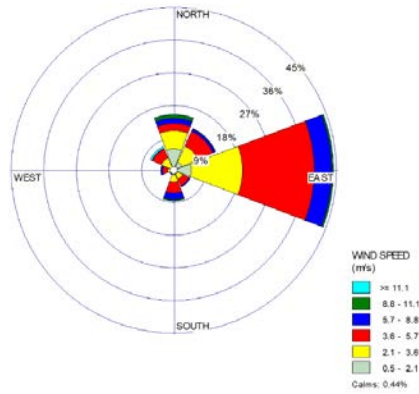


Fig. 8. Wind map in Yapen Island.

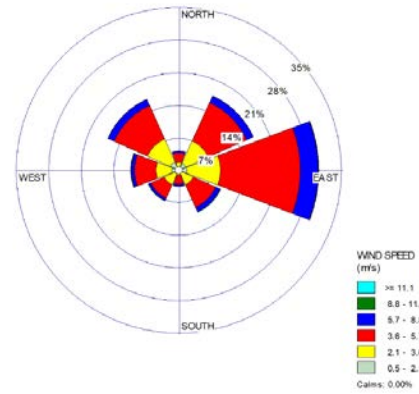


Fig. 9. Wind map in Bandung.

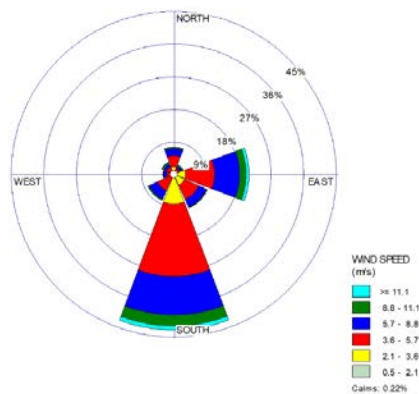


Fig. 10. Wind map in Bogor City.

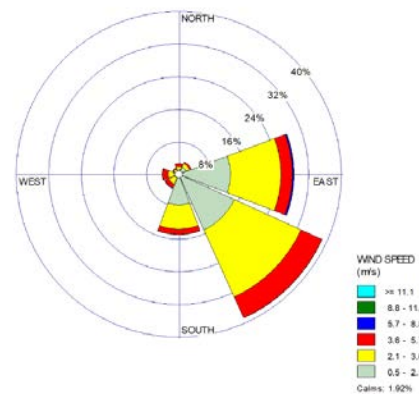


Fig. 11. Wind map in Bogor Regency.

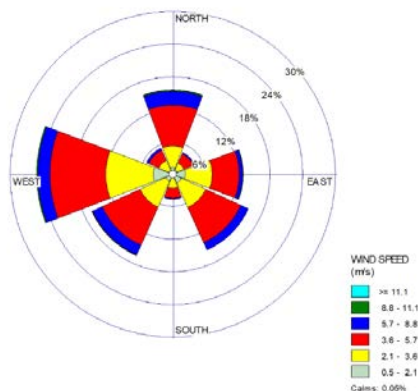


Fig. 12. Wind map in Majalengka.

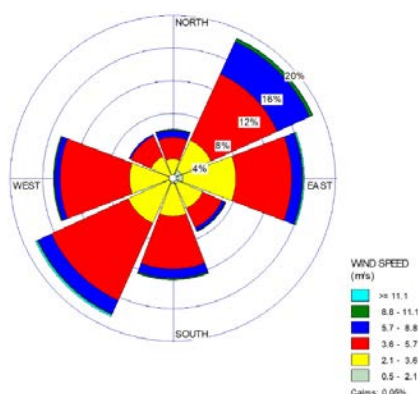


Fig. 14. Wind map in Berau.

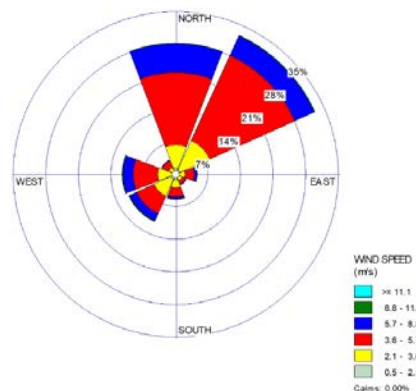


Fig. 13. Wind map in Balikpapan.

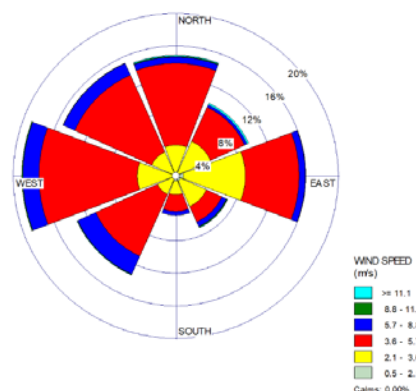


Fig. 15. Wind map in Samarinda.

## 5 CONCLUSIONS

The annual and monthly distributions of wind speed and wind power for 3 provinces including ten cities in Indonesia were estimated. The Weibull distribution function with two parameters  $c$  and  $k$  was adopted in order to analyze the data of each site during five years (2015 – 2019). The variations of the mean wind speed illustrate that the wind with high speed is available in the dry season, whereas the low wind speed is found when the season is wet. The data, on the other hand, revealed that the monthly wind speed varied greatly between sites. For example, in Jayawijaya city, it was between 2.27 and 2.9 m/s, whereas in Bogor Regency, it was between 0.58 and 0.25 m/s. Based on the average annual data, the most suitable site for wind energy would be Jayawijaya, followed by Balikpapan, Samarinda, and Biak Numfor. The wind power density at these locations ranged from 15.3 to 36.2 W/m<sup>2</sup>, with corresponding wind energy density values ranging from 134 to 317 kWh/m<sup>2</sup>/year. These findings show that these locations are appropriate for small-scale power generation and uses. Additionally, the prevailing wind direction for the best site for generating power from wind (Jayawijaya) was dominated by the northwest. For future work, it is suggested that a wind map be developed in other Indonesian provinces to support the development of wind energy industry throughout the country.

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