Wind energy potential assessment to estimate performance of selected wind turbine in northern coastal region of Semarang-Indonesia

Cite as: AIP Conference Proceedings **1788**, 030026 (2017); https://doi.org/10.1063/1.4968279
Published Online: 03 January 2017

B. S. Premono, D. D. D. P. Tjahjana and S. Hadi

Wind Energy Potential Assessment to Estimate Performance of Selected Wind Turbine in Northern Coastal Region of Semarang-Indonesia

B.S. Premono[1,b)], D.D.D.P. Tjahjana[1,a)] and S. Hadi[1,c)]

[1]*Mechanical Engineering Department, University of Sebelas Maret, Surakarta 57126, Indonesia*

[a)]Corresponding author: ddanardono@staff.uns.ac.id
[b)]bagussuryap2@gmail.com
[c)]syamsulhadi@ft.uns.ac.id

Abstract. The aims of this paper are to investigate the characteristic of the wind speed and wind energy potential in the northern coastal region of Semarang, Central Java, Indonesia. The wind data was gained from Meteorological Station of Semarang, with ten-min average time series wind data for one year period, at the height of 10 m. Weibull distribution has been used to determine the wind power density and wind energy density of the site. It was shown that the value of the two parameters, shape parameter k, and scale parameter c, were 3.37 and 5.61 m/s, respectively. The annual mean wind speed and wind speed carrying the maximum energy were 5.32 m/s and 6.45 m/s, respectively. Further, the annual energy density at the site was found at a value of 103.87 W/m^2, and based on Pacific North-west Laboratory (PNL) wind power classification, at the height of 10 m, the value of annual energy density is classified into class 2. The commercial wind turbine is chosen to simulate the wind energy potential of the site. The POLARIS P25-100 is most suitable to the site. It has the capacity factor 29.79% and can produce energy 261 MWh/year.

INTRODUCTION

The energy needs are very important, especially for socio-economic of human life. It has been increased as the growth of population. In 2020, the world population is estimated to reach 8 billion people [1]. Therefore, the increasing in energy supply becomes the important thing which must be done. Up until now, the fulfilling of energy needs is still dominated by using fossil fuel. However, the use of fossil fuel is not wise to meet the energy demand. Fossil fuel is non-renewable resources because it will be depleted. In addition, fossil fuel gives some disruption for the environmental, such as green house effect [2,3].

Indonesia is one of the countries that still use fossil fuel as the dominant energy resources. In 2010, approximately 96% of national energy mix was dominated by fossil fuel and only 4% from renewable energy resources [4]. As the fossil fuel is limited and can be depleted, Indonesia should be moved from using fossil fuel to other resources. The use of renewable energy resources is the best way to meet the energy demand and reduce the environmental effect of using fossil fuel. Renewable energy has zero emission, thus it is called clean energy. As it is known, Indonesia has abundant of renewable energy resources. This is caused by the geographical condition of Indonesia that is placed on equator line, having long coast line and having some volcanoes [4,5].

Among renewable energy resources, wind power is an important source of environmental-friendly energy and has become more important in the recent years [6]. North coastal region of Java, located at north part of Semarang, Central Java, is a viable site that is naturally windy and having a constant all year round mean wind speed between 4-6 m/s [7]. Based on this, utilization for generating electricity from this site is very attractive in order to meet the energy shortage in this remote area.

International Conference on Engineering, Science and Nanotechnology 2016 (ICESNANO 2016)
AIP Conf. Proc. 1788, 030026-1–030026-10; doi: 10.1063/1.4968279
Published by AIP Publishing. 978-0-7354-1452-5/$30.00

METHOD

Wind speed data

The location of the wind energy potential assessment is in the northern coastal region of Semarang, Central Java, Indonesia. The wind speed data of the location was gained from Meteorological Station of Semarang that is located in the same region, as depicted in the Fig. 1. The daily wind speed data was collected using cup anemometer at the height of 10 m, with ten-minute interval over a period of 1 year, from January 2014 to December 2014.

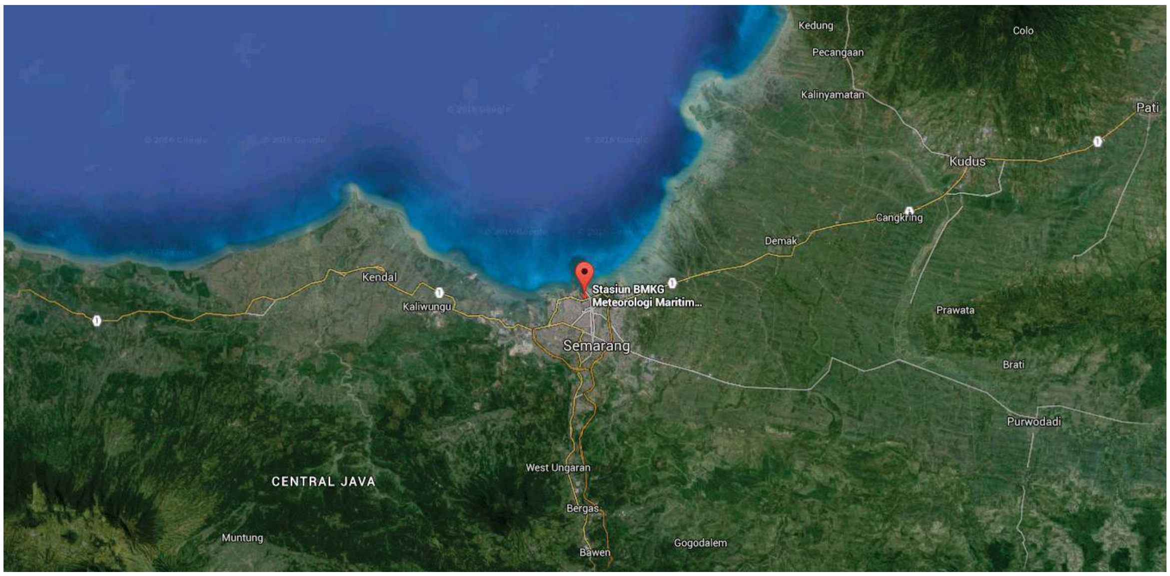


FIGURE 1. Location of Meteorological Station-Semarang

The wind speed data must be extrapolated into hub height with the consideration of surface roughness. As the effect of the boundary layer, wind speed increases with height in the logarithmic pattern [8]. The wind speed at a certain height is given by [9,10],

$$V(Z_R) = V(Z)\frac{\ln(Z_R/Z_0)}{\ln(Z/Z_0)} \quad (1)$$

where Z is the height of wind data, Z_0 is the height of surface roughness, Z_R is the hub height, V(Z) is the wind speed at the height of Z and $V(Z_R)$ is the wind speed at the height of Z_R.

The roughness height of a surface has the value of zero (surface of the sea) or even as high as 2 (town centers). The roughness height has a value of 0,005 for smooth and flat terrains; 0,025-0,1 for open grass lands; 0,2-0,3 for row crops; 0,5-1 for orchard and shrubs; and 1 to 2 for forests and town centers [8].

Weibull Distribution

In this paper, Weibull distribution is used because it gives the good measurement of probability density distribution than other statistic function [11,12]. Moreover, once the parameters of Weibull distribution at a certain height is known, then the same parameters at different height can be determined [13]. The two parameters of Weibull distribution that used in this paper are probability density function *f(V)* and cumulative distribution function *F(V)*. Probability density function shows the probability of the wind at a speed *V*, it can be used to illustrate the time fraction of wind speed that occurs at a certain place. While, the cumulative distribution function of a speed *V* shows the probability of wind speed same or less than *V*. It also can be used to estimate the time of wind speed at a certain wind speed range [8,14].

Probability density function can be illustrated by the equation [8],

$$f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} e^{-\left(\frac{V}{c}\right)^k} \tag{2}$$

The cumulative distribution function is the integral of probability density function and can be expressed by equation [8],

$$F(V) = \int_0^a f(V)\, dV = 1 - e^{-\left(\frac{V}{c}\right)^k} \tag{3}$$

Where *V* is the wind speed, *k* is shaped parameter (dimensionless) and *c* is scale parameter (m/s). The shape parameter, *k*, resemble the wind potential of the location and indicates how peaked the wind distribution is and the scale parameter, *c*, indicates how 'windy' a wind location under consideration is [15]. There are several methods for determining the *k* and *c*, some of these are [8]:

(1) Graphical method
(2) Standard deviation method
(3) Moment method
(4) Maximum likelihood method
(5) Energy pattern factor method

In this study, the standard deviation method is used to determine Weibull parameters. The two values, *k* and *c* respectively, can be obtained by equation

$$k = \left(\frac{\sigma_V}{V_m}\right)^{-1{,}090} \tag{4}$$

$$c = \frac{Vm\ k^{2{,}6674}}{0{,}184 + 0{,}816 k^{2{,}73855}} \tag{5}$$

In order to determine the mean wind speed V_m and standard deviation σ_V, it can be used the expression as,

$$V_m = \left(\frac{\sum_{i=1}^{n} fiVi^3}{\sum_{i=1}^{n} fi}\right)^{1/3} \tag{6}$$

$$\sigma_V = \sqrt{\frac{\sum_{i=1}^{n} fi(Vi - Vm)^2}{\sum_{i=1}^{n} fi}} \tag{7}$$

As the wind speed measured at the height of 10 m, the wind blows slowly at low altitude and then increase at higher altitude. Consequently, since the height of the wind turbine is higher than the height of wind speed data, the wind speed data should be extrapolated to hub height of the turbine. Since *k* and *c* are the parameters that used in wind turbine performance calculation, respectively, it also should be extrapolated at the desired height or the hub height. The value of *k* and *c*, respectively, can be expressed as follows [13, 15],

$$c\ (h) = c_0 \left(\frac{h}{h_0}\right)^n \tag{8}$$

$$k(h) = k_0 \left[1 - 0.088\ ln\left(\frac{h_0}{10}\right)\right] / \left[1 - 0.088\ ln\left(\frac{h}{10}\right)\right] \tag{9}$$

Where c_o and k_o are scale parameter and shape parameter at a reference height h_o, respectively. The exponent, n, can be calculated by equation,

$$n = [0.37 - 0.088\ ln(c_o)] / \left[1 - 0.088\ ln\left(\frac{h}{10}\right)\right] \tag{10}$$

Wind Power Density and Wind Energy Density

To analyze the wind energy potential in a region at a period, there are two parameters that should be known; there are power density and energy density, respectively. Power density indicates the capacity of wind resources in a region [16]. Power density can be calculated as follows [8],

$$P_D = \frac{\rho_a c^3}{2}\frac{3}{k}\Gamma\left(\frac{3}{k}\right) \tag{11}$$

While energy density is defined as the power density over a period, energy density can be determined by the following expression,

$$E_D = \frac{\rho_a c^3}{2}\frac{3}{k}\Gamma\left(\frac{3}{k}\right)T \tag{12}$$

where T is a period of time (hour).

To estimate the wind energy potential, the two meaningful wind speeds, the most probable wind speed and wind speed carrying maximum energy, respectively, should be determined. The most probable wind speed, V_F, denotes the most frequent wind speed for a given wind probability distribution. This value can be determined by using the following expression [12],

$$V_F = c\left(\frac{k-1}{k}\right)^{\frac{1}{k}} \tag{13}$$

The other meaningful wind speed is wind speed that carrying maximum energy, V_E. This value also called with rated wind speed and it is included in wind turbine design calculation [17]. This parameter is expressed by,

$$V_E = \frac{c\,(k+2)^{\frac{1}{k}}}{k^{\frac{1}{k}}} \tag{14}$$

Wind Turbine Capacity Factor, Power and Energy Output

There are several parameters that must be included in consideration of wind turbine selection. The following parameters are the average power output, capacity factor, and energy output. Capacity factor (*Cf*) represents the fraction of the average power output over a period, to the rated electrical power (*PeR*) [12,18]. The average power output $P_{e,ave}$, and capacity factor of a wind turbine can be expressed as [17],

$$Pe,ave = PeR\left\{\frac{e^{-\left(\frac{Vc}{c}\right)^k} - e^{-\left(\frac{Vr}{c}\right)^k}}{\left(\frac{Vr}{c}\right)^k - \left(\frac{Vc}{c}\right)^k} - e^{-\left(\frac{VF}{c}\right)^k}\right\} \tag{15}$$

$$Cf = \frac{Pe,ave}{PeR} \tag{16}$$

Where *Vc*, *Vr* and *Vf* are the cut-in wind speed, rated wind speed and cut-off wind speed, respectively. The capacity factor and average power output are important performance parameters of wind energy conversion system [19]. The accumulated annual energy output (AEP) which represents the fraction of the total energy delivered over a year period can be calculated by [18],

$$AEP = Cf \times PeR \times t \tag{17}$$

where *t* is time and for one year period it has a value of 8760 in hours.

RESULTS AND DISCUSSION

The Wind Speed Distribution

Figure 2(a) depicts the probability density function curve. From the figure, it can be seen that the most probable wind speed occurs at a speed of 5.5 m/s with the probability of 22.5%. This means that on the site, the wind speed that often arises is at 5.5 m/s. Figure 2(b) depicts the cumulative distribution function, from the figure, it can be known that the cut-in wind speed 2.7; 3; 3.5 having the probability of 91.28%; 87.66%; 81.63%.

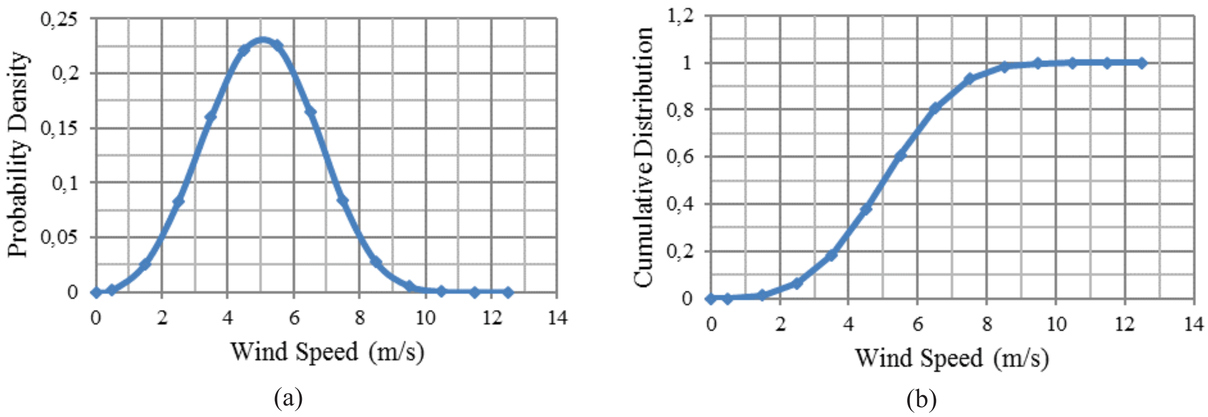


FIGURE 2. probability density function (a) and cumulative distribution function (b)

Analysis of Weibull Parameters, Power and Energy Densities

Table 1 illustrates the monthly mean shape parameter, scale parameter, power density and energy density. The shape and scale parameters are obtained using Eq. (4) and (5). While, to calculate the power density and energy density the eq. (11) and (12) are used, respectively. The results show that the shape and scale parameters are in the range of 2.265-7.571 and 3.458-8.430 m/s, respectively. While, the power density lies in the range of 32.859 W/m^2-397.240 W/m^2, respectively. The minimum and maximum power density occur in April and January, respectively. The energy density gives the minimum value of 23.658 kW/m^2 in April and the maximum value of 295.547 kW/m^2 in January, respectively.

Moreover, to obtain the possibility of wind turbine utilization in a region, usually the wind classifications are used. In this study, the Battelle-Pacific North-west Laboratory (PNL) wind power classification scheme are considered as reference [20]. This classification has been developed for three heights of 10 m, 30 m and 50 m and divided into 7 different classes ranging from the lowest class 1 to the highest class 7. The PNL wind power classification is displayed in Table 2.

Based on the PNL wind power classification, the annual wind power density in the north coastal region of Semarang can be included into class 2 with a value of 103.869 W/m^2. Moreover, in January and February, wind power density is included into class 6 and 4, respectively. Class 1 and 2 are less suitable and limited for utilization of wind energy potential, respectively [20]. Nevertheless, this potential is appropriate for low capacity wind turbines in rural and small communities [15].

TABLE 1. Wind speed characteristic and wind energy potential in North Coastal region of Java at a height of 10 m

Month	Wind Characteristics						
	V_m (m/s)	k	c (m/s)	V_F (m/s)	V_E (m/s)	P_D (kW/m^2)	E_D (kWh/m^2)
Jan	7.80124	2.57060	8.43010	6.95978	10.54539	0.39724	295.54705
Feb	7.06964	2.26497	3.45800	6.74786	8.49874	0.24067	161.73036
Mar	4.45671	4.10650	4.61481	4.31161	5.08296	0.05507	40.96918
Apr	3.84193	4.81372	3.91162	3.72690	4.20441	0.03286	23.65820
May	4.34726	7.57061	4.20789	4.12988	4.34023	0.04050	30.13199
Jun	4.40958	4.67462	4.50381	4.27777	4.86037	0.05030	36.21489
Jul	4.54039	5.34978	4.56971	4.39632	4.84922	0.05200	38.68907
Aug	5.10493	5.95195	5.07739	4.92288	5.33063	0.07106	52.87040
Sep	5.08832	6.99101	4.96998	4.86144	5.15210	0.06662	47.96955
Oct	5.14810	6.23662	5.09359	4.95284	5.32590	0.07170	53.34180
Nov	4.66328	5.04764	4.72343	4.52128	5.04632	0.05763	41.49633
Dec	4.28741	4.37278	4.41034	4.15607	4.80705	0.04761	35.42065
Annual	**5.31714**	**3.37464**	**5.61477**	**5.05945**	**6.44505**	**0.10387**	**909.88905**

TABLE 2. PNL wind power classification [21]

Wind power class	10 m Wind power (W/m2)	10 m Wind speed (m/s)	30 m Wind power (W/m2)	30 m Wind speed (m/s)	50 m Wind power (W/m2)	50 m Wind speed (m/s)
1	≤ 100	≤ 4.4	≤ 160	≤ 5.1	≤ 200	≤ 5.6
2	≤ 150	≤ 5.1	≤ 240	≤ 6.0	≤ 330	≤ 6.4
3	≤ 200	≤ 5.6	≤ 320	≤ 6.5	≤ 400	≤ 7.0
4	≤ 250	≤ 6.0	≤ 400	≤ 7.0	≤ 500	≤ 7.5
5	≤ 300	≤ 6.4	≤ 480	≤ 7.5	≤ 600	≤ 8.0
6	≤ 400	≤ 7.0	≤ 640	≤ 8.2	≤ 800	≤ 8.8
7	≤ 1000	≤ 9.4	≤ 1600	≤ 11.0	≤ 2000	≤ 11.9

Performance Assessment of Wind Turbines

Some commercial wind turbines with various characteristics are introduced in this paper. Wind turbines having capacity variously from 20 kW to 900 kW are chosen from different manufacturers to simulate its performance in the north coastal region of Java. The cut-in wind speed and rated wind speed of the selected wind turbines range from 2.7 m/s - 4.5 m/s and 10 m/s - 17 m/s, respectively. Detail product specifications of the various commercial wind turbines are presented in Table 3.

The average power output $P_{e,ave}$, capacity factor C_f and annual energy production *AEP* are calculated using Eq. (15), (16) and (17), respectively. The results of the calculation are showed in Table 4. The highest annual energy production is given by ENERCON E-53 with a value of 1536.67 MWh, whereas the lowest value is given by POLARIS P10-20 with a value of 37.69 MWh. These results are affected by the wind speed criteria and capacity of each wind turbine, respectively. The lowest cut-in wind speed and the highest capacity of the wind turbine will give the highest value of annual wind energy production.

TABLE 3. Wind turbine specifications from different manufacturers

Turbine index	Wind Turbine Model	Turbine operating speed range (m/s)			Rotor diameter (m)	Hub height (m)	Rated power (kW)
		Vc	*Vr*	*Vf*			
A	ENERCON E-44	3	17	28	44	45	900
B	ENERCON E-48	3	14	28	48	50	800
C	ENERCON E-53	2	13	28	52.9	60	800
D	VESTAS V20	4.5	13	25	20	24	120
E	VESTAS V27	3.5	14	25	27	30	225
F	VESTAS V29	3.5	14	25	29	31	225
G	VESTAS V47	4	15	25	47	50	660
H	VESTAS V52	4	16	25	52	55	850
I	SUZLON S52	4	13	25	52	75	600
J	POLARIS P10-20	2.7	11	25	10	30.5	20
K	POLARIS P12-25	2.7	10	25	12	30.5	25
L	POLARIS P15-50	2.7	12	25	15	30.5	50
M	POLARIS P21-60	2.7	10	25	21	30.5	60
N	POLARIS P21-100	2.7	12	25	21	30.5	100
O	POLARIS P25-100	2.7	10	25	25	30.5	100

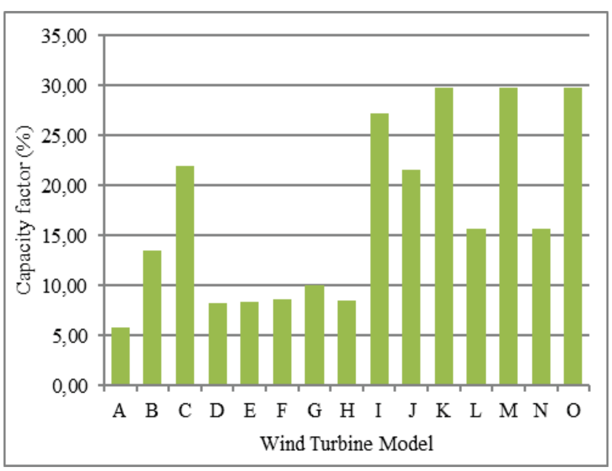
TABLE 4. Wind turbine performance from different manufacturers

Turbine index	*Vc* (m/s)	*Vr* (m/s)	*Vf* (m/s)	*k*	*c* (m/s)	*PeR* (kW)	*Pe,ave* (kW)	*Cf* (%)	*AEP* (MWh)
A	3	17	28	3.89	8.20	900	51.71	5.75	452.99
B	3	14	28	3.93	8.45	800	108.35	13.54	949.16
C	2	13	28	4.01	8.93	800	175.42	21.93	1536.67
D	4.5	13	25	3.66	6.91	120	9.84	8.20	86.19
E	3.5	14	25	3.74	7.32	225	18.84	8.38	165.07
F	3.5	14	25	3.75	7.39	225	19.37	8.61	169.71
G	4	15	25	3.93	8.45	660	66.01	10.00	578.23
H	4	16	25	3.97	8.70	850	72.46	8.52	634.72
I	4	13	25	4.10	9.58	600	162.94	27.16	1427.34
J	2.7	11	25	3.74	7.35	20	4.30	21.51	37.69
K	2.7	10	25	3.74	7.35	25	7.45	29.79	65.25
L	2.7	12	25	3.74	7.35	50	7.83	15.66	68.57
M	2.7	10	25	3.74	7.35	60	17.88	29.79	156.60
N	2.7	12	25	3.74	7.35	100	15.66	15.66	137.14
O	2.7	10	25	3.74	7.35	100	29.79	29.79	261.00

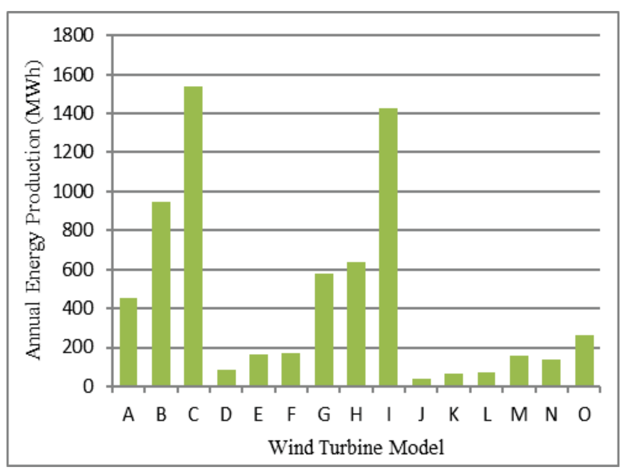
Capacity factor is important in the case of choosing the most suitable wind turbine product for a site. The capacity factor is a less intuitive indicator that measures the economic (not physical) efficiency of a technology and therefore matters for cost calculations [22]. From the Fig. 3(a), the highest capacity factor is reached by P12-25, POLARIS P21-60 and POLARIS P25-100, respectively. Those models give the same value because of the cut-in, rated and cut-off wind speed are same, respectively.

TABLE 5. The extrapolated maximum wind speed and the most probable wind speed to a different wind turbine models

Turbine index	*Vc* (m/s)	*Vr* (m/s)	*Vf* (m/s)	*k*	*C* (m/s)	V_F (m/s)	V_E (m/s)	$Vr - V_E$ (m/s)
A	3	17	28	3.89	8.20	7.59	9.12	7.88
B	3	14	28	3.93	8.45	7.84	9.38	4.62
C	2	13	28	4.01	8.93	8.31	9.88	3.12
D	4.5	13	25	3.66	6.91	6.33	7.78	5.22
E	3.5	14	25	3.74	7.32	6.74	8.21	5.79
F	3.5	14	25	3.75	7.39	6.80	8.28	5.72
G	4	15	25	3.93	8.45	7.84	9.38	5.62
H	4	16	25	3.97	8.70	8.08	9.64	6.36
I	4	13	25	4.10	9.58	8.95	10.55	2.45
J	2.7	11	25	3.74	7.35	6.77	8.24	2.76
K	2.7	10	25	3.74	7.35	6.77	8.24	1.76
L	2.7	12	25	3.74	7.35	6.77	8.24	3.76
M	2.7	10	25	3.74	7.35	6.77	8.24	1.76
N	2.7	12	25	3.74	7.35	6.77	8.24	3.76
O	2.7	10	25	3.74	7.35	6.77	8.24	1.76



(a)



(b)

FIGURE 3. The performance of the selected wind turbines. Capacity factor (a) and annual energy output (b).

Wind speed that carrying maximum energy V_E, also plays an important role in the case of determining the suitable wind turbine in a site. Rated wind speed of selected wind turbine should be as close as possible to a maximum wind speed of the site [23]. It can be seen from Table 5, three wind turbines have the rated wind speed that closes with maximum wind speed; there are POLARIS P12-25, POLARIS P21-60 and POLARIS P25-100. This can be obtained from the gap between Vr and V_E, respectively. Moreover, the easiness of maintenance and simplicity of infrastructure of the wind turbine, respectively, must be included in consideration. Based on the site that is located at north coastal region of Java, these two factors is extremely important. From Fig. 3(b), although the best annual energy output is ENERCON E-53, it has a wide diameter, a high hub and it is quite dangerous for the people around the wind turbine. The POLARIS P25-100 gives the best annual energy output with a value of 261 MWh, the highest among the other five POLARIS wind turbines and it is chosen as the most suitable wind turbine for the site.

CONCLUSIONS

In the present study, a year wind data was statistically analyzed. Wind speed characteristic and wind energy potential were derived using Weibull distribution function, respectively. The performance of a selected commercial wind turbine for electricity generation was also simulated. There are some important outcomes of the study and can be summarized as follows:

1. The annual mean wind speed for the north coastal region of Java, located at north part of Semarang is 5.32 m/s. The maximum annual energy is reached by wind speed of 6.45 m/s.
2. The annual value of Weibull shape parameter is 3.37, whereas the scale parameter is 5.61 m/s.
3. The annual power density is 103.869 W/m^2 and is classified into class 2.
4. The annual energy density is 909.889 kW/m^2.
5. The selected wind turbine POLARIS P25-100 showed that it could produce annual energy output about 261 MWh. It has capacity factor 29.79%.

REFERENCES

1. United Nations, Department of Economic and Social Affairs, Population Division, *World Population Prospects: The 2015 Revision, Key Findings and Advance Tables*, (United Nation: New York, 2015).
2. M.J. Shawon, L.E. Chaar and L.A. Lamont, Sustainable Energy Technologies and Assessments **2**, 1-11 (2013).
3. B. Grieser, Y. Sunak and R. Madlener, Renew. Energ. **78**, 334-350 (2015).
4. S. Mujiyanto and G. Tiess, Energ. Policy **61**, 31-41 (2013).
5. M.H. Hasan, T.M.I. Mahlia and H. Nur, Renew. Sust. Energ. Rev. **16**, 2316-2328 (2012).
6. A. Keyhani, Energy **35**, 188-201 (2010).
7. N.P. Purba, “Suitable Locations of Ocean Renewable Energy (ORE) in Indonesia Region-GIS Approached, in Conference and Exhibition Indonesia - New, Renewable Energy and Energy Conservation,” in *the 3rd Indo-EBTKE ConEx 2014* (Elsevier Ltd., 2015), pp. 230-238.
8. S. Mathew, *Wind Energy: Fundamentals, Resource Analysis and Economics* (Berlin Heidelberg: Springer-Verlag, 2006), pp. 252.
9. S. Mathew, K.P. Pandey and A. Kumar. Renew. Energ. **25**, 381–399 (2002).
10. A.V. Machias and G.D. Skikos, IEEE T. Energy Conver **7(4)**, 638-643 (1992).
11. S.A. Akdag, H.S. Bagiorgas and G. Mihalakakou, Appl. Energy **87**, 2566-2573 (2010).
12. E.K. Akpinar and S. Akpinar, Energ. Convers. Manage. **46**, 1848–1867 (2005).
13. C.G. Justus, Applied Meteorology **17**, 1977.
14. A.A. Salem, D. Danardono, D.A. Himawanto and H.M.S. Atia, International Journal of Engineering Research and Technology **3(12)**, 800-805 (2014).
15. A. Mostafaeipour, M. Jadidi, K. Mohammadi and A. Sedaghat, Renew. Sust. Energ. Rev. **30**, 641-650 (2014).
16. S.H. Pishgar-Komleh, A. Keyhani and P. Sefeedpari, Renew. Sust. Energ. Rev. **42**, 313-322 (2015).
17. S.O. Oyedepo, M.S. Adaramola and S.S. Paul, Energy and Environmental Engineering **3(7)**, 1-11 (2012).
18. A. Ucar, and F. Balo, Appl. Energy **86**, 1864-1872 (2009).
19. O.S. Ohunakin and O.O. Akinnawonu, Energy Sustain. Dev. **16**, 78-83 (2012).

20. A. Ilinca, E. McCarthy, J-L. Chaumel and J-L. Re´tiveau, Renew. Energ. **28**, 1881-1897 (2003).
21. D. Saeidi, M. Mirhosseini, A. Sedaghat and A. Mostafaeipour, Renew. Sust. Energ. Rev. **15**, 3558-3569 (2011).
22. N. Boccard, *Capacity factor of wind power realized values vs. estimates.* Energy Policy **37**, 2679-2688 (2009).
23. D.D.D.P. Tjahjana, A.A. Salem and D.A. Himawanto, "Wind energy potential analysis in Al-Fattaih- Darnah," in *4th International Conference and Exhibition on Sustainable Energy and Advanced Materials 2015 (ICE-SEAM 2015)*, AIP Conference Proceedings 1717, edited by Triyono *et al.* (American Institute of Physics, Melville, NY, 2016), pp. 030015.