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Comparative Analysis of Wind Energy Potential with Nakagami and Weibull Distribution Methods for Wind Turbine Planning

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Abstract – Wind energy is renewable energy used as an energy source for wind power plants (PLTB). The most common distribution method used to model wind speed distribution data is the Weibull distribution. The Nakagami distribution has begun to be widely used in several studies to model wind speed distribution data. The Nakagami distribution is considered an alternative to the Weibull distribution in modeling wind speed distribution data. This study aims to compare the distribution of Nakagami and Weibull in analyzing wind power potential and calculating the resulting Wind Energy Production (WEP), using wind speed distribution data from both distributions in Kuta Raja, Banda Aceh and Lhoknga, Aceh Besar. The wind speed data used is satellite data (secondary data) downloaded via windguru.cz, with the most stable wind speed being a wind speed of 3-5 m/s. The value of wind power potential at the Kuta Raja location, Banda Aceh was obtained at 64.16% with the Nakagami distribution and 62.73% with the Weibull distribution, and 73.60% with the Nakagami distribution and 73.28% at the Lhoknga location, Aceh Besar. The comparison of these two distributions produces a Weibull distribution that is superior to the Nakagami distribution for both locations, where the Weibull distribution has a smaller error value and produces a WEP value that is in accordance with the actual/observable data compared to the Nakagami distribution. In this study, the Nakagami distribution has results that make this distribution an alternative or comparison to the Weibull distribution in distributing wind speed data with further research.

Keywords: Wind power potential, wind speed, Nakagami distribution, Weibull distribution, Goodness of Fit Test, Wind Energy Production (WEP).

Introduction

One of the renewable energy is wind energy. The utilization of wind power plants or wind power plants (PLTB) in Indonesia is still relatively low. In 2020, PLTB only contributed 0.21%, or 154.31 MW, of the total 72,750.72 MW installed national power generation capacity (Herdian *et al*., 2023; Kementerian Energi dan Sumber Daya Mineral Direktorat Jenderal Keteragalistrikan, 2021). The potential for wind power for PLTB is highly dependent on wind speed distribution throughout the year (Amano, 2017; Burke *et al*., 2019). The average wind speed that can be utilized starts from 3 m/s which is sufficient for small propeller wind turbines, above 5 m/s for medium-type wind turbines, and for large wind turbines, which is 6 m/s (Yunginger and N.Sune, 2015).

The potential for wind energy for each region in Indonesia is certainly not the same from one area to another. Characterizing short-term wind speed is very important to evaluate the potential of wind energy (Feijoo, 2021; Lee *et al*., 2019; Pambudi and Nananukul, 2019). The probability Density Function (*PDF*) is generally used to characterize wind speed, which is then used for wind speed modeling in various studies in various countries (Ouarda *et al*., 2015; Sawant *et al*., 2021; Tao *et al*., 2019). The most commonly used function for wind speed probability modeling is the Weibull, which is a 2-parameter distribution consisting of the shape parameter (k) and the scale parameter (c in m/s).

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The Nakagami distribution method shows very good results in modeling wind speed distribution data and is considered an alternative to the Weibull distribution with further research (Alavi *et al.*, 2016; Dookie *et al.*, 2018; Yu *et al.*, 2019; Gugliani, 2020; Idriss *et al.*, 2020; Ounis and Aries, 2021). Comparing these two distributions from previous research uses high-speed wind speed data for their studies; therefore, this study will compare the Nakagami and Weibull distributions to model wind speed distribution data in analyzing wind power potential using low-speed wind speed data. Wind Energy Production (*WEP*) is generated based on wind speed distribution data from both distributions in Kuta Raja, Banda Aceh, and Lhoknga locations, Aceh Besar. The location of Kuta Raja, Banda Aceh, is an urban area, while the location of Lhoknga, Aceh Besar, is a coastal area. This study will focus on how these Nakagami distribution can be considered an effective alternative for Weibull distribution using low-speed wind speed data in two locations.

Materials and Methods

The Nakagami distribution was initially used in communications as an effective model for modeling mobile radio signals and fading channels (Badrudduza *et al.*, 2020; Kristina and Ryszald, 2016; Sánchez *et al.*, 2021). Several studies have shown that the Nakagami distribution is more suitable for evaluating the ability of electrical components than the Weibull and gamma distributions (Alavi *et al.*, 2016). The Nakagami distribution has begun to be widely used in several studies to model wind speed distribution data. It is considered an alternative to the Weibull distribution in modeling wind speed distribution data. Alavi *et al.* (2016) compared eight distribution types for five different cities in Iran. The results show that the Nakagami distribution is better in modeling the probability distribution of wind speed data. Still, because the results between the Nakagami and Weibull distributions are almost balanced, the Weibull distribution gets more value because it is more flexible and widely used (Alavi *et al.*, 2016). Research by Dookie *et al.* (2018) and Yu *et al.* (2019) shows that the Nakagami distribution provides excellent results in predicting wind speed distribution data for coastal areas. Idriss *et al.* (2020) examined the accuracy of eight probability functions in wind speed data modeling. His research showed that the Nakagami distribution was superior for two stations in rural areas with large expanses. Ounis and Aries (2021) investigated the potential for wind power in Algeria; their research showed that the Nakagami and Weibull distributions showed good performance for the wind speed distribution with high average speeds.

The flow of the research can be seen in the following flow chart:

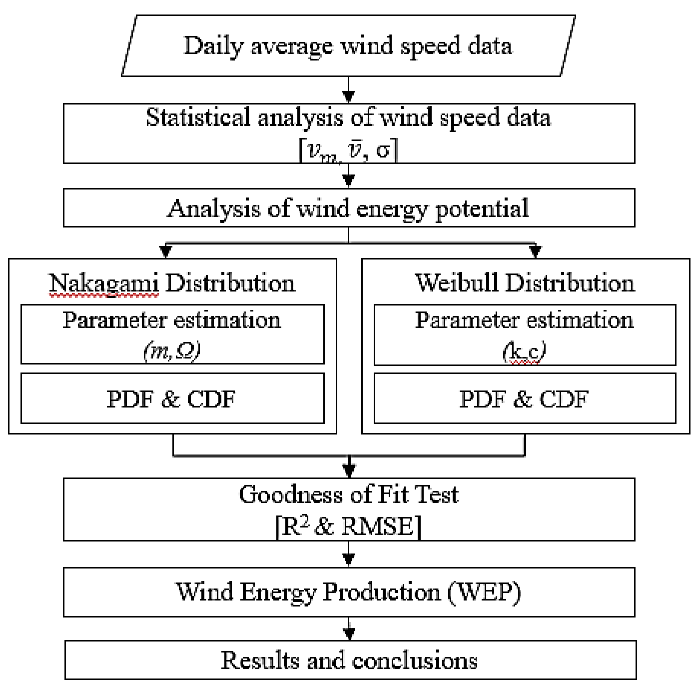

Figure 1. Research Method

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Wind Speed Data

The wind speed data used in this study is satellite data from the website www.windguru.cz for locations in Kuta Raja, Banda Aceh, and Lhoknga, Aceh Besar. The downloaded data is in the form of daily average wind speed data, from January 1, 2021, to December 31, 2021, at 10 meters above ground level. The position of the selected location on the map can be seen in Figure 2.

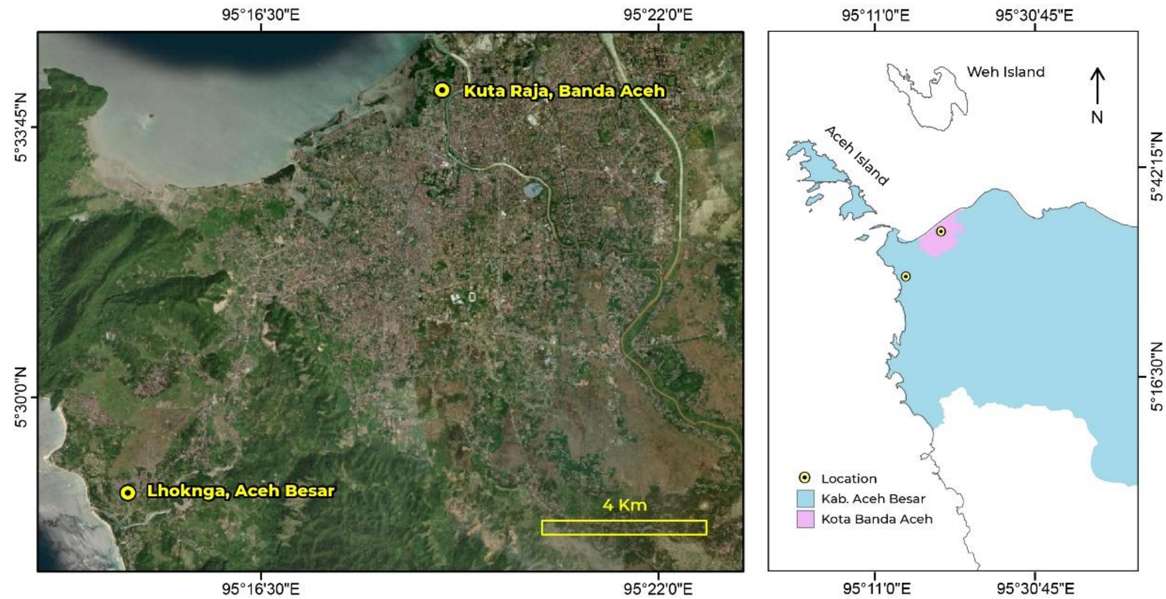

Figure 2. Wind speed data collection location.

The downloaded wind speed data is in the form of daily average wind speed data downloaded for Kuta Raja, Banda Aceh, and Lhoknga, Aceh Besar, from January 1, 2021, to December 31, 2021, at an altitude of 10 meters above ground level. The wind speed data consists of wind speed data measured every two hours each day, so the wind speed data must be averaged first for each day. The wind speed data is still in knots, so it must be converted to m/s by dividing by 1.944. After the wind speed values are averaged and converted to m/s units, the data is grouped. This data grouping is done to see the wind speed frequency in months and one year for each location.

Tabel 1. One year wind speed frequency data for Kuta Raja, Banda Aceh location

Wind Speed (m/s)	One-Year Wind Speed Frequency Data
1	9
2	31
3	61
4	85
5	86
6	47
7	35
8	9
9	1

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Tabel 2. One year wind speed frequency data for Lhoknga, Aceh Besar location

Wind Speed (m/s)	One-Year Wind Speed Frequency Data
1	12
2	48
3	100
4	106
5	64
6	30
7	3
8	1
9	0

Statistical Analysis of Wind Speed Data

Daily wind speed data analysis used statistical methods and mathematical equations to obtain the average wind speed Equation 1 and standard deviation Equation 2 from the wind speed data. This is done to describe the wind speed data to be used.

$$\bar{v} = \frac{1}{n} \sum_{i=1}^{W} m_i v_i \tag{1}$$

$$\sigma^2 = \frac{1}{n-1} \left[\sum_{i=1}^{W} m_i v_i^2 - \frac{1}{n} \left(\sum_{i=1}^{W} m_i v_i\right) \right] \tag{2}$$

Comparing Wind Potential with Nakagami and Weibull distribution distribution

The distribution method for analyzing wind power potential that will be compared in this study is the Nakagami and Weibull distribution, which have 2 types of parameters (shape and scale parameters).

Nakagami Distribution

In the Nakagami distribution, the shape and scale parameters are written as m and Ω (m/s). Estimation of m and parameters on the Nakagami distribution was carried out through the RStudio program using the Maximum Likelihood Estimation (MLE) method based on Equation 3 and Equation 4.

$$m = \frac{E[v^2]}{Var[v^2]} \tag{3}$$

$$\Omega = E[v^2] \tag{4}$$

The Nakagami distribution functions (PDF and CDF) and their average wind speed values can be calculated using Equation 4, Equation 5, and Equation 6 below.

$$f(v,m,\Omega)=\frac{2m^m}{\Gamma(m)\Omega^m} v^{2m-1} e^{-\left(\frac{m}{\Omega} v^2\right)} \tag{4}$$

$$F(v,m,\Omega)=1-\frac{P\left(m,\frac{m}{\Omega} v^2\right)}{\Gamma(m)} \tag{5}$$

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$$v_{rata-nak} = \frac{\Gamma(m+\frac{1}{2})}{\Gamma(m)}\left(\frac{\Omega}{2m}\right)^{1/2} \quad (6)$$

Weibull Distribution

In the Weibull distribution, the shape and scale parameters are written as *k* and *c* (m/s). Estimation of parameters *k* and *c* for the Weibull distribution can be done using Equation 7 and Equation 8 if the wind speed and standard deviation values have been obtained.

$$k = \left(\frac{\sigma}{\bar{v}}\right)^{-1.086} \quad . (7)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (8)$$

Weibull distribution functions (PDF and CDF) and their average wind speed values can be calculated using Equation 9, Equation 10, and Equation 11 below.

$$f(v,k,c) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-(\frac{v}{c})^k} \quad (9)$$

$$F(v,k,c) = 1 - e^{-(\frac{v}{c})^k} \quad (10)$$

$$v_{rata-wei} = c\Gamma(1+\frac{1}{k}) \quad (11)$$

Calculating Wind Energy Production (WEP)

After statistical and probability analysis of wind speed data has been carried out, the Wind Energy Production (WEP) calculation is then carried out. *WEP* calculation uses wind speed data on a certain date randomly selected within a certain range (wind speed with the highest frequency for each location). The wind speed v value used in the *WEP* calculation uses the average wind speed value. The average wind speed ($\bar{v}$) for observation/actual data is calculated using Eq. 1, the average wind speed ($\bar{v}$) is calculated using the Nakagami distribution, and the average wind speed ($\bar{v}$) is the Weibull distribution. It is calculated using Eq. 11.

The calculation of the *WEP* value with this random date aims to see the energy produced in one day using the average wind speed value ($\bar{v}$) on that date. The *WEP* values obtained for each distribution and location will then be compared.

Results

Calculation Results of Average Wind Speed ($\bar{v}$) and Standard Deviation (σ)

Calculations of the average wind speed ($\bar{v}$), maximum wind speed (v_m), and standard deviation of the wind speed data (σ) are needed to provide a statistical description of the wind speed data. The value of the mean wind speed ($\bar{v}$) and standard deviation (σ) is also significant in determining the shape parameter (k) of the Weibull distribution (Eq. 7). The results of the calculation of the average wind speed ($\bar{v}$), maximum wind speed (v_m), and standard (σ) for each location in one year can be seen in Table 5.

Table 3. The statistical description of wind speed data in one year

Height (m)	Location	Vm (m/s)	$\overline{V}$ (m/s)	σ (m/s)
10 m	Kuta Raja, Banda Aceh	9	4.47	1.61
	Lhoknga, Aceh Besar	8	3.68	1.30

Based on Table 3, it can be seen that the maximum wind speed (v_m), average wind speed ($\bar{v}$), and the highest standard deviation (σ) for a height of 10 m is located at the Kuta Raja location, Banda Aceh, with a value of 9 m/s. , 4.47 m/s, and 1.61 m/s. A low standard deviation (σ) indicates a more stable distribution of wind speed data because the lower the standard deviation, the less variable the wind speed data obtained, where wind speeds that do not have much variation are much better for wind turbines.

Parameter Estimation Result of Nakagami and Weibull Distribusi Distribution

The Nakagami and Weibull distributions are 2-parameter distributions, which have shape and scale parameters (m/s). In the Nakagami distribution, the shape and scale parameters are written as m and Ω (m/s); in the Weibull distribution, the shape and scale parameters are written as k and c (m/s).

Estimation of m and Ω parameters on the Nakagami distribution was carried out through the RStudio program using the Maximum Likelihood Estimation (MLE) method. While the estimation of parameters k and c for the Weibull distribution can be done using Eq 5 and Eq 6. The results of parameter estimation with wind speed data in one year for both distributions can be seen in Table 4.

Table 4. Nakagami and Weibull parameter estimation results for one-year wind speed data

Location	Nakagami Distribution		Weibull Distribution	
	m	Ω (m/s)	k	c (m/s)
Kuta Raja, Banda Aceh	1.928328	22.54906	3.020347	4.999401
Lhoknga, Aceh Besar	2.144840	15.63425	3.100242	4.111709

Based on Table 4 with one-year wind speed data, it can be seen that the Nakagami and Weibull parameters show alignment, where the largest and smallest parameters for both distributions are at the same location and month. High-shape parameter values (m and k) indicate a greater probability of wind speed, while high-scale parameter values (Ω and c) indicate wind speed distribution. The shape parameters (m and k) affect the distribution characteristics of the wind, where when m>1 (Nakagami distribution) and k>2 (Weibull distribution), the wind speed variation is less than the average wind speed. When the value of the shape parameters (m and k) increases, the peak of the curve will be higher, and the probability curve will be narrower, which indicates a slight variation in wind speed.

Results of Wind Speed Distribution with Methods Nakagami and Weibull Distribution

After estimating the parameters for the two distributions, the next step is to analyze the potential using the wind speed distribution function for one year, represented by the Probability Density Function (PDF) value generated by the Nakagami and Weibull distribution methods. The wind speed probability curve can be seen in Figure 3.

Figure 3 shows the Probability Density Function (PDF) value curve for one-year data at 10 m. The sharper curve is the *PDF* value curve for the Lhoknga, Aceh Besar location, and the lower curve is the *PDF* value curve for the location. Kuta Raja, Banda Aceh. Based on the picture above, it can be seen that the highest peak in each graphic is at a speed of 3-5 m/s for both locations.

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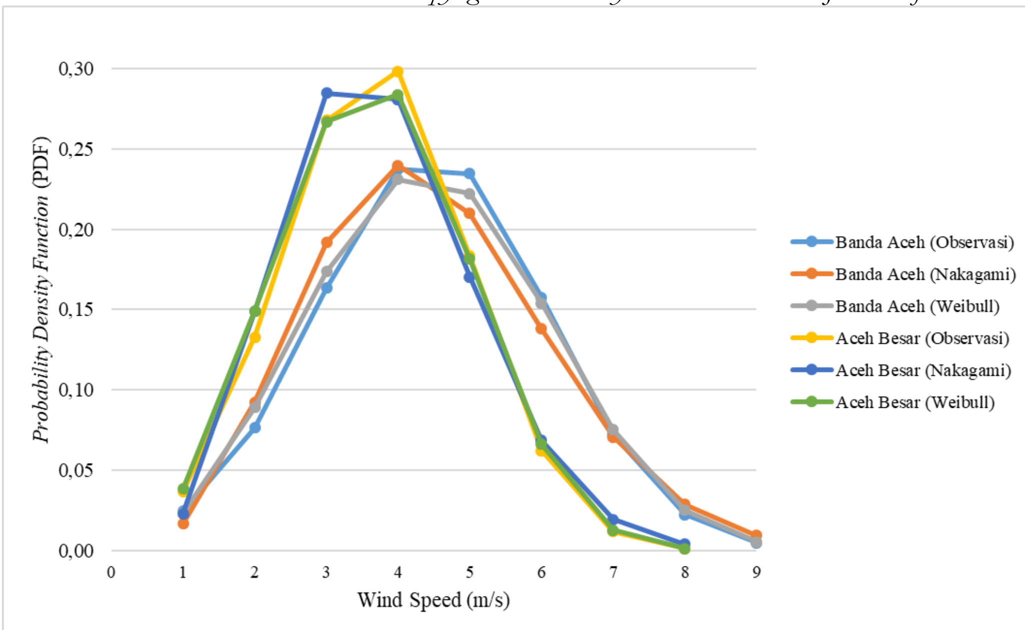

Figure 3. Comparison of *PDF* values for one year's data at 10 m

Based on Figure 3 and Table 4, it can be seen that the higher the shape parameter value, the curve of the Probability Density Function (PDF) value will look sharper, and vice versa. The curve at the Lhoknga location, Aceh Besar has a sharper shape than the curve for the Kuta Raja location, Banda Aceh; this is because the shape parameter values (m and k) at the Lhoknga location, Aceh Besar, are more significant than those at the Kuta Raja location, Banda Aceh. (Table 4). The scale parameter also affects the *PDF* value curve; the larger the scale parameter value, the higher the wind speed value, and vice versa. Based on Figure 3, the longest curve is at a speed of 9 m/s at the Kuta Raja location, Banda Aceh, and Table 4 shows that the largest scale parameters (Ω and c) are in the same location.

Figure 3 shows that the Weibull distribution is much closer to the actual/observable data than the Nakagami distribution, where the value of the Weibull form parameter (k) produces results that can reach the actual/observable data. In contrast, the Nakagami form parameter (m) produces distribution results that are not as good as the Weibull form parameter (k). In Figure 3. it can also be seen that the Nakagami distribution cannot distribute wind speed data as well as the Weibull distribution for observation/actual data. However, this distribution can reach the three highest speed points well, such as at a speed of 7-9 m/s for the Kuta Raja location, Banda Aceh, and at a speed of 6-8 m/s for the Lhoknga location, Aceh Besar. This Nakagami distribution shows a pretty good match with the Weibull distribution for several points, such as at speeds of 2, 4, 7, and 9 m/s for the location of Kuta Raja, Banda Aceh and at speeds of 2, 4, 6, 7, and 8 m/s. s at the location of Lhoknga, Aceh Besar. The results of the wind speed distribution by the Nakagami distribution are not too bad. However, the Weibull distribution is much more flexible, and the parameters are easier to estimate than the Nakagami distribution.

Based on the *PDF* value curve (Figure 3.), the most stable wind speed is at a wind speed of 3-5 m/s; this is the wind speed with the most significant frequency for each month in each location. The wind speed of 3-5 m/s is sufficient for a small propeller wind turbine. The potential wind value for the Kuta Raja location, Banda Aceh, based on observation/actual wind speed data, is 63.55%, based on the Nakagami distribution *PDF* value of 64.16%, and based on the Weibull distribution *PDF* value of 62.73%. While the potential wind value for the Lhoknga location, Aceh Besar, based on observation/actual wind speed data, is 74.98%, based on the Nakagami distribution *PDF* value of 73.60%, and based on the Weibull distribution *PDF* value of 73.28%, the results of the Cumulative Distribution Function (CDF) calculation can be seen in Figure 4.

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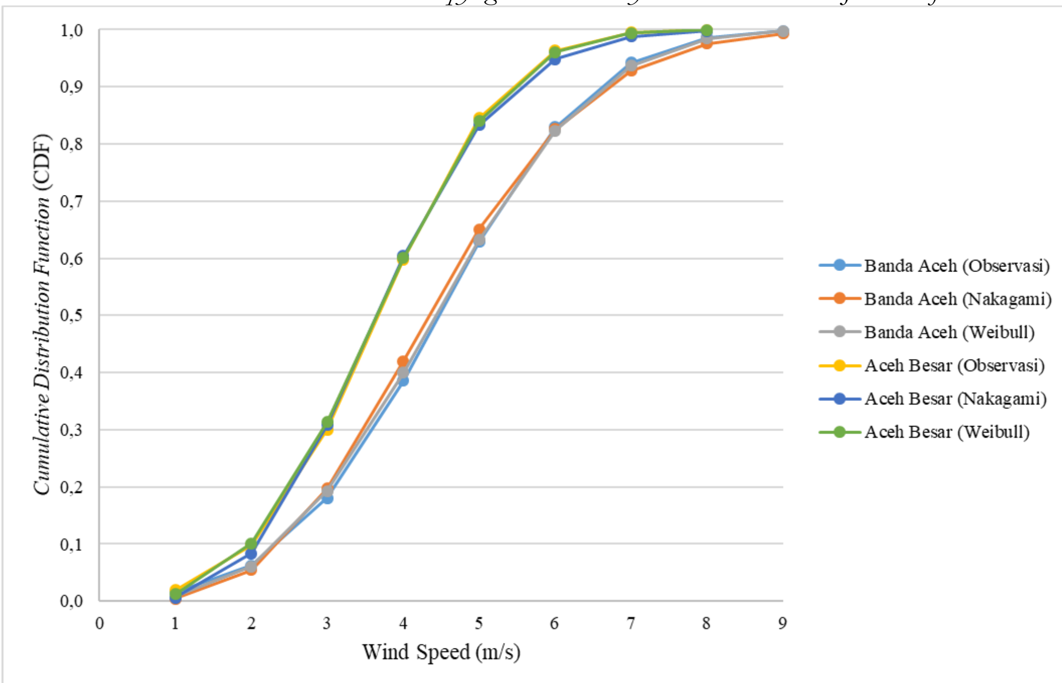

Figure 4. Comparison of *CDF* values for one year's data at 10 m.

Both locations have a potential wind speed of 3-5 m/s which is sufficient for a small propeller wind turbine, where this turbine must have a cut-in speed (v_{ci}), rated speed (v_{rs}), cut-out speed (v_{co}), and hub height corresponding to the wind speed data for these two locations. One of the turbines that meet the criteria for this location is the Aventa AV-7; this turbine has a hub height of 18 m, v_{ci} of 2 m/s, v_{rs} of 6 m/s, and v_{co} of 14 m/s. Even though the power generated when the v_{rs} speed is not high (6.2 kW), this turbine is good enough for these two locations because it matches the wind speed data for both locations. Information about the Aventa AV-7 turbine can be seen in Table 5 below.

Table 5. Aventa AV-7 Specifications

Turbine Name	P_{rs} (kW)	v_{ci} (m/s)	v_{rs} (m/s)	v_{co} (m/s)	Hub Height (m)	D (m)
Aventa AV-7	6.2	2	6	14	18	12.8

Results of Error Evaluation with Goodness of Fit Test

Evaluation of the results of calculating the *PDF* and *CDF* values can be done using the Goodness of Fit Test method, namely the coefficient of determination test (R^2) to test the suitability of the *CDF* value, and the Root Mean Square Error (RMSE) test to test the suitability of the value. *PDF*s. In the R^2 test, the closer the value is to 1, the more appropriate the distribution data is with the actual/observational data. Meanwhile, in the *RMSE* test, the closer the value is to 0, the more appropriate the predicted data will be with the actual/observational data. The results of the calculation of the goodness of fit test (R^2 and *RMSE*) for one-year wind speed data using both distributions can be seen in Table 6.

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Table 6. Error evaluation of *PDF* and *CDF* for both distributions with monthly wind speed data

H	Month	Kuta Raja, Banda Aceh				Lhoknga, Aceh Besar			
		Nakagami		Weibull		Nakagami		Weibull	
		R^2	*RMSE*	R^2	*RMSE*	R^2	*RMSE*	R^2	*RMSE*
10 m	Jan	0.978	0.0052	**0.998**	**0.0032**	0.974	0.0070	**0.999**	**0.0027**
	Feb	0.980	0.0049	**0.998**	**0.0036**	**0.998**	**0.0038**	0.998	0.0040
	Mar	0.997	0.0030	**0.999**	**0.0023**	0.993	0.0047	**0.998**	**0.0027**
	Apr	0.982	0.0050	**0.997**	**0.0023**	0.992	0.0046	**0.999**	**0.0021**
	May	0.981	0.0055	**0.995**	**0.0030**	0.986	0.0053	**0.994**	**0.0039**
	Jun	0.988	0.0028	**0.998**	**0.0023**	**0.980**	0.0037	0.975	**0.0029**
	Jul	0.942	0.0062	**0.998**	**0.0016**	0.993	0.0045	**0.999**	**0.0023**
	Ags	0.969	0.0050	**0.998**	**0.0017**	0.962	0.0066	**0.999**	**0.0019**
	Sep	0.960	0.0048	**0.995**	**0.0021**	0.977	0.0069	**0.984**	**0.0034**
	Oct	0.975	0.0044	**0.977**	**0.0042**	**0.991**	0.0050	0.991	**0.0036**
	Nov	0.979	0.0061	**0.994**	**0.0037**	0.987	0.0065	**0.997**	**0.0035**
	Dec	0.996	**0.0047**	**0.997**	0.0060	**0.999**	0.0512	0.993	**0.0057**
Average		0.977	0.0048	0.995	0.0030	0.986	0.0092	0.994	0.0032

Based on Table 6, it can be seen that the results of the evaluation of the average error value show the highest value for the R^2 test and the lowest value for the *RMSE* test for both locations in the Weibull distribution. The location of Kuta Raja, Banda Aceh, has the highest average R^2 value and the lowest average *RMSE* value of 0.9954 and 0.0030. During the highest R^2 and *RMSE* values in the Lhoknga location, Aceh Besar is 0.9939 and 0.0032, respectively. The results of evaluating the average error value for the Nakagami distribution are not too bad. However, the results of evaluating the Weibull distribution are slightly superior.

The results of evaluating the error value with monthly wind speed data for the Kuta Raja location, Banda Aceh, shown in Table 6, show that the Weibull distribution gets the highest value for the R^2 test every month. This distribution also gets the lowest *RMSE* value for January to November (The lowest *RMSE* value for December is in the Nakagami distribution with a value of 0.0047). This shows that the Weibull distribution best distributes wind speed data for the Kuta Raja location, Banda Aceh.

Based on the results of calculations for evaluating the error value with the Goodness of Fit Test method, it shows the results where the Weibull distribution has fewer error values for both locations and excels in this Goodness of Fit Test. The results of the evaluation of the error value of the Nakagami distribution are not harmful and only slightly different from the Weibull distribution. However, the results of evaluating the error values for the Weibull distribution are slightly superior to the Nakagami distribution.

Calculation Results of Wind Energy Production (*WEP)*

After calculating and analyzing the statistics and probability of wind speed data, the next step is to calculate Wind Energy Production (*WEP*). *WEP* calculation is carried out using wind speed data on a specific date that is randomly selected. The calculation of the *WEP* value is also carried out by ignoring the value of *A* (m2), which is the rotor's swept area so that its use can be adjusted if you want to use a certain type of turbine. The *Cp* value (Power coefficient) used in *WEP* calculations is considered to be 0.4. The average wind speed value ($\bar{v}$) for both distributions can be calculated using Eq. 6 and Eq. 11 if the parameters for both distributions using wind speed data on random test dates have been calculated/estimated beforehand. After the value of the average wind speed ($\bar{v}$) of the two distributions for each location is calculated, and the next step is to calculate the value of Wind Energy Production (*WEP*) for each location. The results of comparing *WEP* values can be seen in Figure 5 below.

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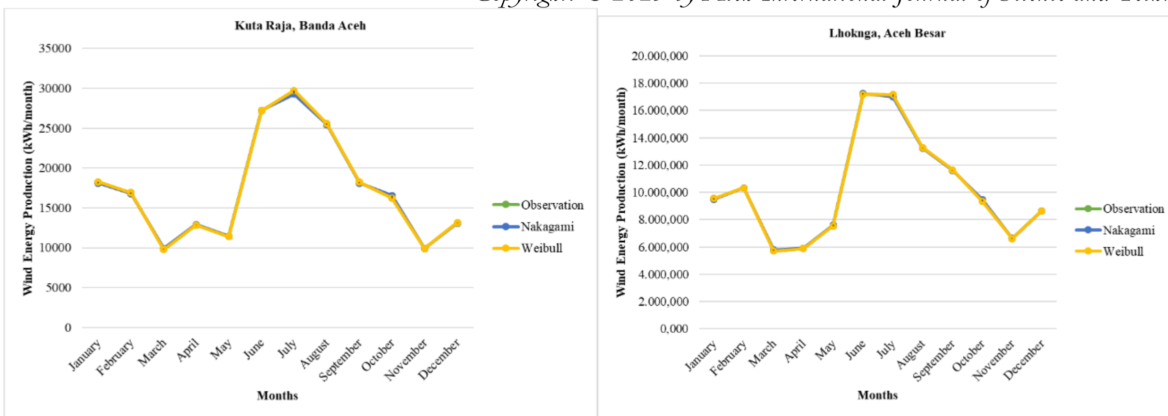

(a) **(b)**

Figure 5. Comparison of the *WEP* value of observation data with distribution data of Nakagami and Weibull (a) Location of Kuta Raja, Banda Aceh (b) Lhoknga, Aceh Besar.

In Figure 5. it can be seen clearly that the *WEP* value of the Weibull distribution managed to adjust the results very well to the *WEP* value of the actual/observed data. Meanwhile, the *WEP* value of the Nakagami distribution experienced a slight discrepancy at several points, especially in July, so the Weibull distribution was superior to the Nakagami distribution in calculating the *WEP* value in Kuta Raja, Banda Aceh. The total *WEP* value for one year at the Kuta Raja location, Banda Aceh, calculated using actual/observational data, is 209,346.51 kWh/year, the same as the *WEP* value of the Weibull distribution. While the *WEP* value at this location using the Nakagami distribution is 208,887.87 kWh/year. Based on Figureure 4.8, it can be seen that the *WEP* value of the two distributions gives a perfect match to the *WEP* value of the observation/actual data in Lhoknga, Aceh Besar. The total *WEP* value for one year at the Lhoknga location, Aceh Besar, calculated using observation/actual data, is 122,919.57 kWh/year, the same as the *WEP* value of the Weibull distribution and the *WEP* value using the Nakagami distribution was 123,010.01 kWh/year. The *WEP* value produced by the two distributions at these locations does not differ much from the actual/observation data.

Discussion

In this study, calculating the potential for wind power for the location of Aceh Besar (Lhoknga) has a higher potential value than the location of Kuta Raja, Banda Aceh. However, the calculation of the *WEP* value for the location of Kuta Raja, Banda Aceh, has a higher total energy than the location of Lhoknga, Aceh Besar. It is shown in the analysis result that the potential wind value at the Kuta Raja location, Banda Aceh, based on the PDF value of the Nakagami distribution, is higher than the Weibull distribution, which only reaches 62,73%. Likewise, for the Lhoknga location, Aceh Besar, the Nakagami value reaches 73.60%. The potential is still low because the calculation is limited to wind speeds of 3-5 m/s only.

Between these two locations, Aceh Besar (Lhoknga) has the highest potential, which is ± 74%, and has wind speed characteristics that are represented by shape parameters m of 2.144840 (Nakagami distribution) and k of 3.100242 (Weibull distribution), that resulting probability/potential wind speed value that is greater than Kuta Raja, Banda Aceh. When the Nakagami and Weibull shape parameter values are $m \geq 1$ and $k \geq 2$, it shows a variation in wind speed that is less than the average wind speed.

Nakagami distribution also shows good results based on the Goodness of Fit Test, which is 0.0048 and 0.0098 in the R^2 test, 0.9772 and 0.9860 in the *RMSE* test for both Kuta Raja (Banda Aceh) and Lhoknga (Aceh Besar) which is not that bad. However, the Weibull distribution shows better results for the Goodness of Fit Test (R^2 and *RMSE*). In the R^2 test, the better results are shown when the value is closer to 0, but in the *RMSE* test, the better results are shown when the value is closer to 1.

Although Weibull distribution shows a good fit for *WEP* calculation towards actual data, which is 209.346,51 kWh/year and 122.919,57 kWh/year for both Kuta Raja (Banda Aceh) and Lhoknga (Aceh Besar), Nakagami distribution produces a *WEP* value that not much different from the actual/observational data where *WEP* value is 208.887,87 kWh/year and 123.010,01 kWh/year. The calculation of the potential for wind power for the location of Aceh Besar (Lhoknga) has a higher potential value than the location of Kuta Raja, Banda Aceh. However, the calculation of the *WEP* value for the location of Kuta Raja, Banda Aceh, has a higher total energy than the location of Lhoknga, Aceh Besar. The calculation of the *WEP* value, including wind speed categories from 2 m/s to 9 m/s (small wind turbine starts generating energy at 2 m/s), so that the shape and scale parameters produced by two distributions can characterize the wind speed for each month well.

Conclusion

The potential wind value for the Kuta Raja location, Banda Aceh, based on the *PDF* value of observation/actual wind speed data, is 63.55%, based on the Nakagami distribution *PDF* value of 64.16%, and based on the Weibull distribution *PDF* value of 62.73%. In contrast, the potential wind value for the Lhoknga location, Aceh Besar, based on observation/actual wind speed data, is 74.98%, based on the Nakagami distribution *PDF* value of 73.60%, and based on the Weibull distribution *PDF* value of 73.28%.

Comparing these two distributions results in the Weibull distribution being superior to the Nakagami distribution for both locations. The Weibull distribution has a lower error value than the Nakagami distribution for both locations, so the Weibull distribution excels in the Goodness of Fit Test. The Weibull distribution also excels in calculating *WEP* values for both locations compared to the Nakagami distribution.

The Weibull distribution produces annual *WEP* values that are in accordance with data/actual observations for the two locations, namely 209,346.51 kWh/year in Kuta Raja, Banda Aceh, and 122,919.57 kWh/year in Lhoknga, Aceh Besar. The Nakagami distribution produces a *WEP* value whose appearance is not much different from the actual/observations data and the Weibull distribution for the two locations, where the *WEP* value is 208,887.87 kWh/year in Kuta Raja, Banda Aceh, and 123,010.01 kWh/year in Lhoknga Aceh Besar.

This study showed that the Nakagami distribution is an effective alternative to the Weibull distribution since it fits low-speed wind speed data in two locations. Nakagami distribution can be used in the future as a comparison for Weibull distribution to modeling wind speed distribution data. However, more evaluations on the effectiveness of the Nakagami distribution should be conducted in future studies. More case studies with different wind speed characteristics should also be evaluated to achieve this.

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