Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin
e-ISSN : 2549-1999 No. : 4 Month : August
p-ISSN : 1693-5462 Volume : 21 Year : 2023

Article Processing Dates: Received on 2023-01-30, Reviewed on 2023-03-12, Revised on 2023-07-04, Accepted on 2023-07-04 and Available online on 2023-08-25

Techno-economic assessment of wind power generation feasibility in Sabang

Zulfaini[1], Adi Setiawan[1,2*], Muhammad Daud[2]
[1]Magister of Renewable Energy Engineering, Universitas Malikussaleh, Lhokseumawe, 24352, Indonesia
[2] Mechanical Engineering Department, Universitas Malikussaleh, Lhokseumawe, 24352, Indonesia
*Corresponding author: adis@unimal.ac.id

Abstract

Utilization of renewable energy in Aceh is still limited mainly to small-scale electricity through micro-hydro and solar power plants, accounting for less than 1% of the energy composition. Sabang stands out as a region with significant wind energy potential, boasting a speed of 8 m/s and an average power density of 537 W/m^2 for the windiest 10% of the region. Therefore, to explore the viability of harnessing wind energy, a pre-feasibility study is needed. This study aimed to assess the techno-economic feasibility of constructing a wind power plant for electricity generation in Sabang by evaluating the region's wind energy. The statistical method of the Weibull distribution probability density function was employed to evaluate Wind Power Density (WPD), wind turbine capacity factor, and energy output. Additionally, economic feasibility analysis involved calculating Net Present Value (NPV), Benefit Cost Ratio (BCR), Internal Rate of Return (IRR), Discounted Payback Period (DPP), and Levelized Cost of Energy (LCOE). The results showed that Sabang exhibited favorable wind characteristics with a shape parameter (k) of 1.6, average wind speed (Vm) of 7.9 m/s, and scale parameter (c) of 9 m/s. These features classified Sabang as wind power class 6 with a WPD of 735 watts/m^2 at a height of 50 m, and the results were categorized as excellent. The study concluded that constructing a wind power plant in Sabang using the Enercon E-70 turbine at a hub height of 100 m was technically feasible. The shape parameter (k) was 1.6, the average wind speed (Vm) was 9.3 m/s, scale parameter (c) was 11 m, and the WPD reached 1213 W/m^2, leading to a turbine capacity factor of 0.53 and an annual energy production (AEP) of 64,876,560 kW. The economic analysis yielded promising results for wind power projects. The DPP value was estimated at 5.6 years, the BCR at 1.96, the NPV amounted to USD 14,434,994, the IRR reached 17.9%, and the LCOE was assessed at USD 32.50/MWh. Considering all these economic indicators, it was evident that constructing a wind power plant in Sabang was highly feasible and financially viable.

Keywords:
Weibull distribution, technical feasibility, economic feasibility.

1 Introduction

The world's energy demand is on a continuous rise, and the International Energy Agency (IEA) estimates a 45% increase or an average annual growth of 1.6% by 2030. Additionally, fossil fuels currently supply approximately 80% of the global energy demand [1].

In 2020, Indonesia experienced the installation of a newly built Wind Power Plant with a total capacity of approximately 135 MW, distributed between 75 MW and 60 MW in the Sidrap and Janeponto regions respectively. To promote renewable energy, the Government Regulation No. 79 of 2014 sets a target of at least 23% for the share of new and renewable energy mix by 2025, and 31% by 2050. Aligned with the above, the target capacity for Wind Power Plant in 2025 is set at 255 MW [2].

One of the regions in Indonesia, Aceh province, boasts an extensive coastline spanning 1,865 km and is adorned with 119 islands that face both the Andaman Sea and the Indian Ocean. The electricity system consists of two parts which include a 150 kV North Sumatra-Aceh interconnected and a separate isolated structure operating at 20 kV distribution voltage. The primary source of electricity stems from the 150 kV North Sumatra-Banda Aceh interconnected system, supplying power to various regions, including the East Coast, Meulaboh, and surrounding areas. However, certain regions such as the West Coast, Central Aceh, and the islands continue to rely on Diesel Power Plants through a 20 kV network [3].

Sabang City currently requires an additional electricity capacity of approximately 10 megawatts (MW) to supplement the existing 8 MW capacity. This increase is essential to meet the growing electricity demand driven by the development of the tourism industry on Weh Island [4]. Electricity generated by Diesel Power Plant in the city comes at a relatively high average price of IDR 3,064/kWh [5]. In contrast, the community's selling price stands at IDR 1,444.70/kWh [6], making the current electricity cost economically burdensome. The utilization of Renewable Energy Sources in Aceh is still limited, accounting for less than 1% of the energy mix as of 2019. It mainly involves small-scale power plants such as Micro-Hydro Power and Solar Power Plant operating in various districts and cities [7].

Sabang presents promising wind potential with a zephyr velocity reaching 8 m/s and an average power density of 537 W/m^2 for the windiest 10% of the area [8]. This substantial wind resource offers an excellent opportunity for the development of a Wind Power Plant in the city, allowing a reduction of dependency on Diesel Power Plants as electricity sources. On average, the fuel consumption of power plants is approximately 0.33 L/kWh, and the emissions from diesel generators range from 0.8 to 0.93 kg CO^2/kWh [9].

In a study conducted by Himri et al. (2020) on wind energy in the southwest region of Algeria, wind data collected by the Algerian Meteorological Office showed good wind energy potential. The study identified important wind characteristics such as average speed, dominant direction, frequency, and Weibull distribution parameters (scale and shape factors). The Adrar location demonstrated strong potential for economically feasible wind energy projects, boasting a Capacity Factor of 36%. Moreover, it exhibited a competitive levelized Cost of Electricity (COE) at 3.25 US cents/kWh and a relatively short payback period of 3.9 years [10].

Ismail et al. (2015) conducted a feasibility study for the wind power plant in the Southern Coastal Region of Purworejo. The study employed a comprehensive method involving economic analysis and evaluation, which covered three types of analyses namely economic scenarios, risk assessment, and sensitivity. The most favorable outcome, observed under scenario 1, showed a significant Net Present Value (NPV) of USD 70,422,642.29 and an impressive Internal Rate of Return (IRR) of 11.38% [11].

B.S. Premono et al. (2017) conducted a comprehensive study to assess the wind energy potential and performance estimation of Selected Wind Turbines in the Northern Coastal Area of Semarang. The study utilized wind statistics obtained from the Semarang Meteorological Station, which provided ten-minute average time series data for one year at a height of 10 meters. The Weibull distribution was employed to assess wind power and energy density, yielding shape parameter (k) and scale parameter (c) values of 3.37 m/s and 5.61 m/s, respectively. The study showed an annual average and maximum energy wind speeds of 5.32 m/s and 6.45 m/s, respectively. The annual energy density at the location was calculated to be 103.87 W/m^2, leading to a Capacity Factor of 29.79%. This high Capacity Factor led to an impressive energy production of 261 MWh per year [12].

2 Method

The specific methodology employed in this study was based on a techno-economic analysis of wind fields. The method involved evaluating wind data collected by BMKG and utilizing statistical techniques, such as the Weibull probability density function. This method ensured the most accurate verification for classifying wind fields according to the IEC 61400 standard which facilitated the selection of turbines suitable for wind characteristics in the field. Consequently, it formed an economic basis for choosing the most appropriate turbines.

The step-by-step sequence of the methodology was summarized: 1) wind speed conditions in the Sabang Island region were measured and technically evaluated, 2) the Weibull distribution was used to obtain wind characteristics at the location, 3) turbines that were suitable for wind characteristics at the location were selected, 4) Wind Power Density (WPD), Wind Turbine Capacity Factor, and Energy Output were calculated for technical feasibility analysis, 5) NPV, Benefit Cost Ratio (BCR), IRR, Discounted Payback Period (DPP), and Levelized Cost of Energy (LCOE) were calculated for economic feasibility analysis.

Wind speed data from the Sabang Meteorological Station was collected using an anemometer placed at a height of 10 meters above ground level. The data was collected over one year, spanning from October 2021 to September 2022. Accurate calculations were ensured by extrapolating wind speed data to the turbine hub height considering the surface roughness. Wind speed at a specific height was calculated using Eq. 1 [12].

$$V(Z_r) = V(Z)\frac{\ln\left(\frac{Z_R}{Z_0}\right)}{\ln\left(\frac{Z}{Z_0}\right)} \quad (1)$$

The variables are defined as follows, Z represented the height of wind data, Z_0 denoted the surface roughness height, represented the hub height, $V(Z)$ denoted wind speed at the height of Z, and $V(Z_R)$ represented wind speed at the height of Z_R.

The Weibull distribution was widely used as a model to characterize wind speed variation. This distribution involved two functions, namely the probability density and the cumulative distribution function. Wind speed variation was represented using two parameters, namely the shape (k) and the scale parameter (c). The shape parameter (k) was obtained by utilizing actual wind speed data from the field and was found sufficient in representing distribution. Eq. 2 was applied to calculate the value of k, and the process necessitated the use of the mean and variance of the data. The findings were determined from Eq. 3 and Eq. 4 [13].

$$k = \left(\frac{\sigma_v}{V_m}\right)^{-1{,}090} \quad (2)$$

where, σ_V represented the standard deviation of wind speeds, and V_m denoted the average wind speed.

$$V_m = \left(\frac{\frac{1}{n}\sum_{i=1}^{n} f_i V_i^3}{\sum_{i=1}^{n} f_i}\right)^{\frac{1}{3}} \quad (3)$$

$$\sigma_v = \sqrt{\frac{\sum_{i=1}^{n} f_i (V_i - V_m)^2}{\sum_{i=1}^{n} f_i}} \quad (4)$$

where f_i represented the frequency, and V_i was the midpoint value of the wind speed interval.

WPD was the most significant indicator for wind, which described the quantity of energy generated by various speeds at a specific location. It was calculated based on Eq. 6 using Weibull distribution parameters as described by [14]. With the knowledge of WPD, the Wind Turbine Generator (WTG) was selected to match the WPD value at the chosen location.

$$WPD = \frac{P}{A} = \int_0^{\infty} \frac{1}{2}\rho V^e f(V)dV = \frac{1}{2}\rho\, c^3 \Gamma\left(\frac{k+3}{k}\right) \quad (5)$$

$$WPD = \frac{1}{2}\rho\, c^3 \Gamma\left(\frac{k+3}{k}\right) \quad (6)$$

where ρ represented the air density, and c denoted the scale parameter of the Weibull distribution, which was obtained using Eq. 7 [13].

$$c = \frac{2V_m}{\sqrt{\pi}} \quad (7)$$

For greater accuracy, c was calculated using Eq. 8.

$$c = \frac{V_m k^{1.6674}}{0.184 + 0.816 k^{2.73855}} \quad (8)$$

The Capacity Factor (CF) was crucial for evaluating wind turbine field performance. It represented the ratio of the actual energy developed by the Wind Energy Conversion System (WECS) at a specific location which was generated when the machine operated at the rated power continuously [13]. The Capacity Factor depended on wind resources and the type of turbine used, with typical ranges from about 25% and 40% in low and high wind speed locations respectively. A higher value indicated a highly favorable location [15]. The calculation of the Capacity Factor was described by [16].

$$C_f = \frac{E}{T\,(P_r)} x\ 100\% \quad (9)$$

During the early phase of project identification, information about the turbine's Capacity Factor at a specific location was not available. In such situations, it was recommended to calculate the Rough Capacity Factor (RCf) using Eq. 10 as demonstrated by [13].

$$RC_f = \frac{P_{Vm}}{P_r} \quad (10)$$

where P_{Vm} represented the Rated Power of the turbine at the average wind speed, while P_r denoted the turbine's Rated Power. With the known RCf, the Annual Energy Production (AEP) of wind turbine was calculated using Eq. 11. The results represented the total amount of electricity generated by the turbine in one year as stated by [17].

$$AEP = RC_f\ x\ P_r\ x\ 8760 \quad (11)$$

To conduct the investment feasibility analysis, it was essential to possess knowledge of the value and assumptions for the input data as shown in Table 4. The percentages used were based on references that evaluated market conditions and data from projects installed in a specific year. This information was crucial for understanding the total land-based Capex, Annual Energy Production (AEP), Annual OpEx for newly installed projects, and representative turbine technology (Stehly et al., 2020).

NPV was determined as the difference between the discounted cash inflows and outflows, utilizing the social opportunity cost of capital as the discount factor. NPV was calculated using Eq. 12 [13].

$$NPV = \sum_{i=0}^{L} \frac{cf(i)}{(1+r)^i} \quad (12)$$

where cf represented the net cash flow, r denoted the discount rate, and i represented the operational lifetime of the wind Power Plant.

BCR was utilized in the cost-benefit analysis to summarize the relationship between the relative costs and benefits of the proposed project. BCR was calculated using Eq. 13 [13].

$$BCR = \frac{NPV_{BA_{1-n}}}{C1 + NPV_{CA_{1-n}}} \quad (13)$$

where NPV_{BA} represented the benefits, NPV_{CA} denoted the fixed cost, C_1 signified the capital cost, and n symbolized the operational lifetime of the wind Power Plant.

DPP referred to the time required to recover the investment outlay with the discount rate of cash flows expected or the time needed to reach the break-even point of the investment. DPP was calculated using Eq. 14 [13].

$$DPP = \frac{\ln\left(1 - \frac{C_1 r}{\{B_A - C_1 m}\right)}{\ln(1+r)} \quad (14)$$

where m represented the difference between Operation and Maintenance costs and capital costs per year. Eq. 15 was used to calculate m.

$$m = \frac{C_{om}}{C_1} \quad (15)$$

where C_1 represented the capital cost, B_A denoted the revenue of wind Power Plant, r signified the discount rate, C_{om} is the operation and maintenance cost.

IRR was frequently employed to assess investments and served as a measure of profitability. A higher IRR indicated a more favorable economic performance of the wind Power Plant project. IRR was defined as shown in Eq. 16 [13].

$$NPV = r \ for\ NPV\ is\ equal\ to\ zero \quad (16)$$

where r represented the discount rate.

LCOE measured the energy cost generated by wind turbines in dollars per kilowatt-hour. LCOE served as an industry-standard in power plants to calculate the life-cycle COE. It was calculated using Eq. 17 [13].

$$LCOE = \left(\frac{C_1}{AEP} \times fcr\right) + \left(\frac{C_{om}}{AEP}\right) \quad (17)$$

where, fcr represented the Fixed Charge Rate (routine expenses such as rent, taxes, or interest need to be met), and AEP denoted the Annual Energy Production of the wind turbine.

3 Results and Discussion

Based on wind speed records obtained from the meteorological station, along with data from the atlas application and other studies in Sabang City (as shown in Table 1), the average wind speed at a height of 50 meters was determined to be v_m7.91 m/s. Additionally, WPD was calculated to be 735 $Watt/m^2$.

Based on the information shown in Fig. 1 for 2021-2022, it was observed that the prevailing wind direction was from the west, with wind velocity exceeding 8 m/s. Due to the surrounding semi-forested areas, the most suitable turbine type for wind power plants was the Horizontal Wind Axis Turbine (HWAT). The location Cot Pawang complied with IEC 61400-1 and fell under Wind Turbine Class II (medium wind) with average wind speeds of 9.07 m/s and 9.30 m/s at heights of 85 m and 100 m, respectively. After evaluating several turbine options available in the market (as shown in Table 2), only the Enercon E-70 model was deemed suitable for the Sabang location.

Table 1. Wind speed data from Wind Atlas, Meteorological Station, and Sabang City Manual Station

Data	Wind Speed	WPD
Meteorological Station	7.91 m/s	735 W/m²
Wind Atlas	7.62 m/s	595 W/m²
Sabang City Manual	9.15 m/s	-

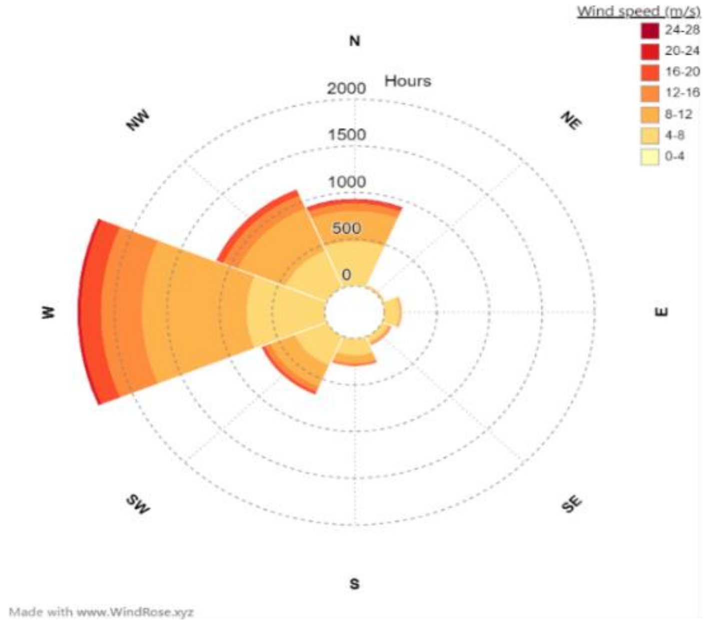

Fig. 1. Wind rose throughout the year.

Table 2. Wind turbine type HWAT

Turbine model	Rated power	WPD (W/m²)	Wind class IEC
Enercon E-40	600 kW	394.5	III
Enercon E-48	800 kW	442.1	II
Enercon E-70	2000 kW	526.2	II
Enercon E-101	3050 kW	380.7	I

The requirements for constructing a wind Power Plant in Sabang City were fulfilled by selecting a turbine that matched wind characteristics in the area. Therefore, the Enercon E-70 turbine, a German-made wind with a capacity of 2 MW, was chosen. Table 3 presented detailed specifications.

Table 3. Specifications of the Enercon E-70 Turbine [18]

Model	Enercon E70
Rated power	2,000.0 kW
Cut-in wind speed	2.5 m/s
Rated wind speed	15.0 m/s
Cut-out wind speed	34.0 m/s
Diameter	71.0 m
Swept area	3,959.0 m²
The number of blades	3
Rotor speed, max	21.0 U/min
Top speed	78 m/s
Material	GRP
Manufacturer	Enercon
Power density 1	581.0
Hub height	100 m

The Enercon E-70 wind turbine was initially tested in Aurich, Lower Saxony, Germany, back in 2002. With a rotor diameter of

71 m, the turbine had a minimum and maximum hub height of 64 m and 113 m, respectively. Wind coverage for the turbine ranged from a cut-in speed of 2.5 m/s to 34 m/s [18].

After selecting the Enercon E-70 wind turbine at a hub height of 100 m, wind speed in July 2022 was observed to be 12.72 m/s. The lowest wind speed was recorded in April 2022, reaching 6.76 m/s, and the annual average velocity was calculated to be 10.58 m/s. Fig. 2 presented the detailed data for the entire year.

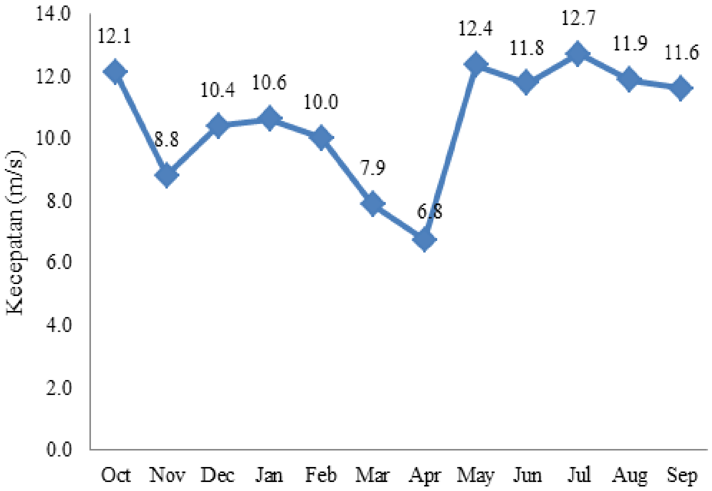

Fig. 2. Average Wind Speed (m/s) for the previous year's period (2021-2022).

Based on the data presented in Fig. 2, the highest wind velocity at the height of 100 meters occurred in July 2022, measuring a speed of 12.72 m/s, while the lowest was recorded in April 2022, reaching 6.76 m/s. The annual average wind speed was 10.58 m/s.

In this study, wind speed data was collected from the Maimun Saleh meteorological station in Sabang, measured every hour throughout the year from October 2021 to September 2022. Based on the selection of the Enercon E-70 turbine and using Eq. 2, Eq. 3, and Eq. 5, the parameters were obtained, namely shaped factor $k = 1.6$, average wind speed $V_m = 9.30$ m/s, and scale factor $c = 11$ m/s, as depicted in Fig. 2 and Table 3.

Eq. 5 of the Weibull distribution function was used to plot the probability density of wind speed at the height of 100 meters as shown in Fig. 3. The function value at both 100 and 85 meters was found to be 6 m/s. Based on power curve of the Enercon E-70 turbine, a wind speed of 6 m/s resulted in a power output of 240 kW. The shape factor (k) values at 100 and 85 meters were identical, both being 1.6. Additionally, the scale factor (c) values at 100 and 85 meters were 11 m/s and 10 m/s, respectively.

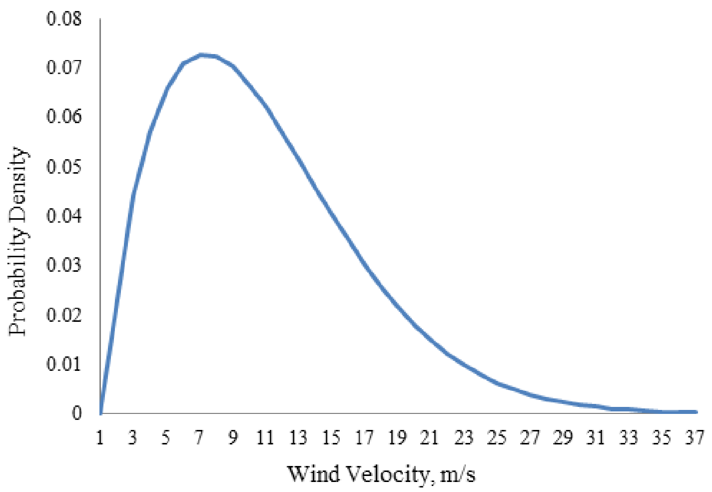

Fig. 3. The Weibull distribution for the previous year's period 2021-2022.

Wind speeds were derived from data obtained from BMKG, as illustrated in Fig. 2. The air density was considered to be the standard value of 1.2 kg/m^3. The WPD at the height of 100 meters was calculated using Eq. 6. The highest value, reaching 2064 watts/m^2, was observed in October 2022. It was evident that power output increased with higher wind speeds. Conversely, the lowest WPD was recorded in April 2022, amounting to 341 watts/m^2. Further detailed data throughout the year was presented in Fig. 4.

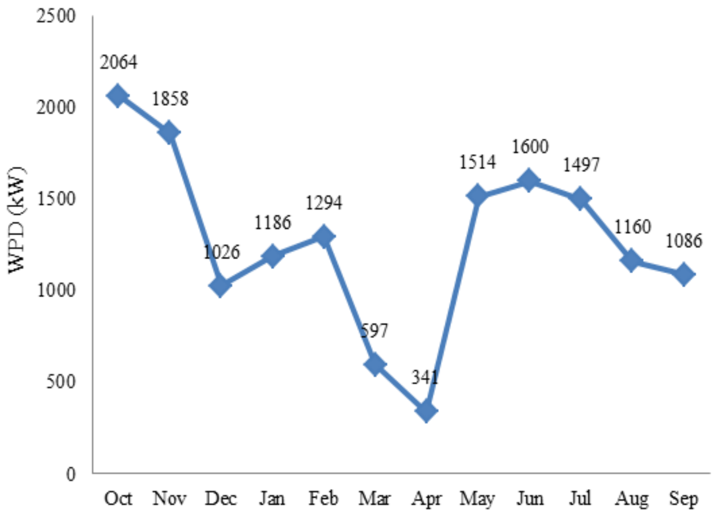

Fig. 4. WPD (kW) for the previous year 2021-2022.

The Enercon E-70 wind turbine, which operated at a hub height of 100 meters with an average wind speed, achieved a Capacity Factor of 0.53 for the entire year. Detailed information about the Capacity Factor throughout the year was provided in Table 4, showcasing fluctuating values for each month due to varying wind speed conditions.

Table 4. Capacity Factor throughout the year

Month	V_m (m/s)	Capacity Factor
October	10.9	0.80
November	8.1	0.31
December	9.3	0.45
January	9.5	0.53
February	9.0	0.45
March	6.5	0.20
April	5.5	0.06
May	11.0	0.80
June	10.5	0.70
July	11.3	0.80
August	10.5	0.61
September	10.3	0.61

With the known cf average of 0.53 for the entire year, the AEP was calculated using Eq. 9. The AEP was determined to be 64,876,560 kW per year. To meet the electricity needs of Sabang City, a total of 7 wind turbines were installed.

The Enercon E-70 wind turbine was selected for installation in a wind Power Plant, with the potential location being Cot Pawang, Iboih Village, Weh Island, Sabang, and coordinates 05° 88' 69" N, 95° 21' 72" E, as depicted in Fig. 5. Table 5 presented the specific turbine installation costs sourced from National Renewable Energy Laboratory (NREL).

The economic feasibility analysis was conducted, encompassing calculations for NPV, BCR, IRR, DPP, and LCOE. Table 6 presented detailed results of the economic assessment. Fig. 6 illustrated that the IRR was twice as large as the discount rate, indicating the feasibility of wind Power Plant installation in Sabang City.

Fig. 5. Cot Pawang, Iboih Village, Sabang City.

Table 5. The installation costs for the Enercon E-70 wind turbine [41].

Wind Turbine Specification	Cost ($)
Rotor module	277
Blades	184
Pitch assembly	60
Hub assembly	44
Nacelle module	488
Nacelle structural assembly	98
Drivetrain assembly	192
Nacelle electrical assembly	167
Yaw assembly	32
Tower module	215
Total capital cost	991
Development cost	16
Engineering and management	18
Foundation	59
Site access and staging	44
Assembly and installation	44
Electrical infrastructure	145
Balance of system	326
Construction financing cost	34
Contingency fund	86
Financial costs	120
Total capital expenditures (kW)	1436
7 Wind Turbin x 14000 kW	20,104,000

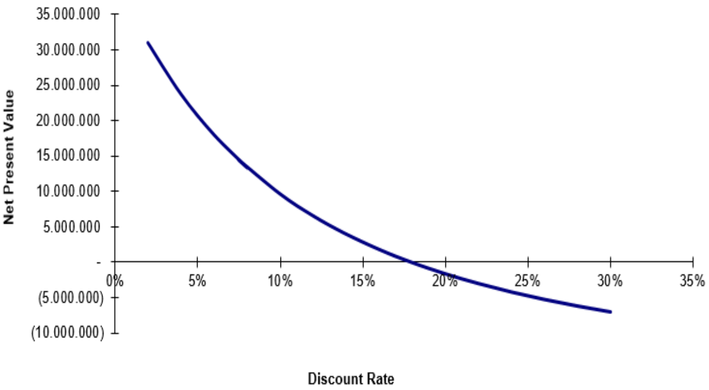

Fig 6. IRR of the 14 MW Wind Power Plant.

Table 6. Economic feasibility of the 14 MW Wind Power Plant

Item Description	0	1	10	20
Cash flow		6.656.335	6.656.335	3.989.908
Capex	-20.104.000			
Discount rate [11]	7.5 %			
Fcr [13]	6,5%			
Opex (O&M) [13]	746.080	746.080	746.080	746.080
Tax 20% [11]		1.021.219	1.021.219	487.934
Depreciation 20% [11]		804.160	804.160	804.160
NPV	14.434.994			
BCR	1,96			
DPP	5,6 year			
IRR	17,9%			
LCOE	USD 32,28 / MWh			

4 Conclusion

This study has assessed the techno-economic feasibility of developing wind power plants for electricity generation at Cot Pawang, Iboih Village, in Sabang. The location was deemed feasible after thorough measurements and calculations, showing wind power density of 735 Watt/m^2 and wind energy density of 6437.83 kWh/m^2/year respectively. The findings indicated an average wind speed of 7.91 m/s at a height of 50 m. To meet Sabang's electricity demand, 7 wind turbines of the HWAT type and Enercon E-70 model with a capacity of 2000 kW were recommended. Economic evaluation utilizing NPV, BCR, IRR, DPP, and LCOE methods confirmed the feasibility of proceeding with the construction of this wind power plant. Moreover, there are no economic risks associated with the development of wind Power Plants.

References

[1] K. E. dan S. D. M. ESDM, "Hingga 2030, Permintaan Energi Dunia Meningkat 45%," Jakarta, 2008. [Online]. Available: https://www.esdm.go.id/id/media-center/arsip-berita/hingga-2030-permintaan-energi-dunia-meningkat-45-

[2] D. J. E. B. T. dan K. E. EBTKE, "Potensi Energi Angin Indonesia 2020," Jakarta, 2021. [Online]. Available: https://p3tkebt.esdm.go.id/pilot-plan-project/energi_angin/potensi-energi-angin-indonesia-2020#:~:text=Sementara hingga tahun 2020 PLT,Indonesia masih menjadi tantangan nasional.

[3] K. M. dan S. D. M. ESDM, "Pengesahan rencana usaha penyediaan tenaga listrik PLN Tahun 2018 s.d. 2027," *Menteri Energi dan Sumber Daya Mineral Republik Indonesia*, 2018.

[4] Bakri, "Sabang Butuh Listrik 10 MW," *Serambi News*, Banda Aceh, p. 1, 2016. [Online]. Available: https://aceh.tribunnews.com/2016/02/09/sabang-butuh-listrik-10-mw

[5] L. O. M. A. Wahid, "Perbandingan Biaya Pembangkitan Pembangkit Listrik di Indonesia," *Pengemb. Sist. Kelistrikan Dalam Menunjang Pembang. Nas. Jangka Panjang*, pp. 58–68, 2006.

[6] PLN, "Penetapan Penyesuaian Tarif Tenaga Listrik April - Juni 2022," *Web.Pln.Co.Id*, 2022, [Online]. Available: https://web.pln.co.id/statics/uploads/2022/03/ttl-april-juni.jpg

[7] G. Aceh, "Qanun Aceh Nomor 4 Tahun 2019 Tentang Rencana Umum Energi Aceh," in *Qanun Aceh*, 2019, pp. 1–95.

[8] G. W. Atlas, "Center (Lat, Long): 5.894452°, 95.672241°, Sabang," https://globalwindatlas.info/, Sbang, Aceh, Indonesia, 2022.

[9] F. H. Jufri, D. R. Aryani, I. Garniwa, and B. Sudiarto, "Optimal battery energy storage dispatch strategy for small-scale isolated hybrid renewable energy system with different load profile patterns," *Energies*, vol. 14, no. 11, 2021, doi: 10.3390/en14113139.

[10] Y. Himri, M. Merzouk, N. Kasbadji Merzouk, and S. Himri, "Potential and economic feasibility of wind energy in south West region of Algeria," *Sustain. Energy Technol. Assessments*, vol. 38, no. January, p. 100643, 2020, doi: 10.1016/j.seta.2020.100643.

[11] Ismail, S. Kamal, Purnomo, Sarjiya, and B. Hartono, "Economic Feasibility of Wind Farm: A Case Study for Coastal Area in South Purworejo, Indonesia," *Energy Procedia*, vol. 65, pp. 146–154, 2015, doi: 10.1016/j.egypro.2015.01.049.

[12] 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," *AIP Conf. Proc.*, vol. 1788, no. January, 2017, doi: 10.1063/1.4968279.
[13] K. R. Rao, *Wind Energy for Power Generation*. 2019. doi: 10.1007/978-3-319-75134-4.
[14] A. Keyhani, M. Ghasemi-Varnamkhasti, M. Khanali, and R. Abbaszadeh, "An assessment of wind energy potential as a power generation source in the capital of Iran, Tehran," *Energy*, vol. 35, no. 1, pp. 188–201, 2010, doi: 10.1016/j.energy.2009.09.009.
[15] T. Ackermann, *Wind Power in Power Systems*. 2005. doi: 10.1002/0470012684.
[16] M. A. Abdelrahman, R. H. Abdel-Hamid, M. A. Abo Adma, and M. Daowd, "Techno-economic analysis to develop the first wind farm in the Egyptian western desert at Elkharga Oasis," *Clean Energy*, vol. 6, no. 1, pp. 976–990, 2022, doi: 10.1093/ce/zkac006.
[17] S. Mathew, *Windy Energy*. 2006.
[18] wind turbine Models, "Enercon E-70 E4 2.000," *Deutsche Windtechnik*, German, pp. 1–5, 2022. [Online]. Available: https://en.wind-turbine-models.com/turbines/827-enercon-e-70-e4-2.000