WIND FARM LOCATION SELECTION AT THE SOUTHERN COAST OF YOGYAKARTA PROVINCE FOR ENERGY SUPPLY OF HYDROGEN FUEL PRODUCTION

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Abstract

The depletion of non-renewable energy reserves and increased awareness of environmental damage caused by fossil-based fuel use have encouraged the world's efforts to develop and utilize new and renewable energy sources, including in Indonesia, especially in the special region of Yogyakarta. The potential for wind power plants can be developed in 3 districts in the southern part of Yogyakarta, bordering the Java Sea, to be converted into hydrogen through an electrolysis process. The three research locations were Bugel Beach in Kulon Progo, Pandansimo Baru Beach in Bantul, and Baron Techno Park at Baron Beach in Gunung Kidul. The selection of the most optimum location was made employing the Analytic Hierarchy Process (AHP) method by considering three factors, namely technical, location, and socio-economic factors.

The first factor includes the potential for electricity generation from wind power and the available land area. The second one consists of sub-factors, namely access to the location and the distance to the PLN electricity distribution line. Then the last one includes conflicts with tourism and the economic activities of the surrounding community. After obtaining the most suitable location, planning is carried out for the wind farm that is built, the amount of electrical energy produced, the cost of generating electricity, and the cost of producing hydrogen from the electrolysis process. Pandansimo Baru Beach is an ideal location, with an average wind speed of 4.833 m/s. Five Vestas V80 2000/80 wind turbines were selected according to the available land. The annual electrical energy that can be produced from this system is 161,677,216 kWh/year with a generation cost of 0.118 USD/kWh and is capable of producing 230,960 kgH2 of hydrogen at 4.35 USD/kg.

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1. Introduction

Massive utilization of fossil energy sources and the lack of discoveries of new oil and gas fields has led to an energy crisis, including in Indonesia. The use of fossil energy on a large scale that leads to environmental damage by Green House Gas (GHG) emission is getting serious attention. The Indonesian government takes a role in reducing GHG emissions by issuing Government Regulation No. 79/2014 concerning National Energy Policy, containing a commitment to increase the power generation mix from renewable energy by 23% in 2025 and 31% in 2050.

Indonesia has great potential in generating renewable energy that can produce up to 200 GWatt (Suprayogi et al., 2016). However, many obstacles face its development, such as inconsistent and intermittent production, expensive Investment, and the limited number of technologies available in the market. The location with high renewable energy potential is mostly located in a remote area, with a significant distance from the electric grid and industry area.

In this situation, energy storage methods are critical to making renewable energy can compete with fossil energy. Types of energy storage currently used worldwide are electrochemical (in the form of batteries), mechanical, thermal, and hydrogen fuel energy storage (Jubaedah & Budiman, 2013). The most rapidly growing energy storage today is the battery, which, on the other hand, has several drawbacks, including a loss of storage capacity of 1-5% per hour and excess temperature released into the environment. These make batteries have low effectiveness for long-term use. Besides, many of them are available in relatively small capacities with a limited lifetime, which means batteries will create another environmental issue regarding hazardous waste handling (Khalilnejad et al., 2014).

An alternative to energy storage that is very environmentally friendly and has high energy density is hydrogen fuel. Hydrogen can be used directly in transportation as fuel in combustion engines, thereby serving as a substitute for fossil fuels. It can also be a fuel cell, which converts chemical energy into electrical energy and a medium for sending large amounts of energy. Currently, 95% of its production still comes from fossil fuels, and its use is still limited to the chemical, refinery, and steel industries (Emanuele Taibi et al., 2018).

International organizations such as the European Commission, International Energy Agency (IEA), and the International Partnership for Hydrogen and Fuel Cell in Economy predict that shortly fuel cells will dominate the transportation sector, distribution of energy generation, and other micro applications . Hydrogen is a colorless, odorless, and non-toxic gas. It also has a high energy coefficient of around 120 MH/kg, and its excess combustion produces H_2O, making it very environmentally friendly.

The South Coast of the Special Region of Yogyakarta in Indonesia can develop renewable energy to convert wind into hydrogen. It has a wind speed intensity of averagely above four m/s with an unlimited water source as a base for hydrogen fuel. This recent research focused on Bugel Beach in Kulon Progo Regency, Pandansimo Baru Beach in Bantul Regency, and Baron Techno Park at Baron Beach in Gunung Kidul Regency. These three studies' locations are quite far from the center of industrial activities and power plants, so the conversion of wind energy to hydrogen is an attractive alternative in the distribution. Transportation of energy to be used later as electricity, fuel calls electric vehicles (FCEV) or directly into the industrial combustion engine. The selection of the ideal wind farms and the locations for installing electrolyzer units was made using the Analytic Hierarchy Process (AHP) method by considering three criteria, namely technical, location, and socio-economic factors.

2. Methodology

Based on The Indonesian Wind Map issued by ESDM in 2017 and the measurement of wind speed in 120 regions in Indonesia by LAPAN showed that the wind speed on land in Indonesia ranges between 3 and 7 m/s. Indonesia's wind energy potential reaches 978 MW, with the highest potential up to 200 MW at Sidrap and Janeponto regencies in South Sulawesi. PLTBs (wind power plants) have been developed in these two regions, which generate 75 MW and 72 MW electricity, respectively. Meanwhile, the South Coast of the Special Region of Yogyakarta can generate energy reaching 60 MW in Bantul Regency and Gunung Kidul Regency (Prasetyo et al., 2019).

The calculation on these areas found that the average wind speed and specific powers are 5.8 m/s and 117 Watt/m^2 at Baron Gunung Kidul Beach and 4.1 m/s and 42 Watt/m^2 Pandansimo Baru Beach, Bantul. The wind speed of less than five m/s at Pandansimo Baru Beach is suitable for developing small-scale power plants with the vertical axis wind type. Simultaneously, in Baron Gunung Kidul Beach, it is appropriate for large-scale Horizontal Axis Wind Power Plant (Prasetyo et al., 2019). In 2017, Multazam conducted research using the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) in East Java. Selection of the proper locations for wind farms is substantial to determine the ideal location, both in terms of electricity production capacity, economics, and location factors.

The research took place at six different locations in the East Java region. Decision-making was done using the Fuzzy AHP method, based on seven sub-criteria, namely, the estimation of electricity production, grid access, road access, distance to settlements, emissions, and electromagnetic inferences. The decline of oil production and price prompted research on the potential for wind energy in Algeria. Another factor that affected this research's importance was that new and renewable energy has a significant limitation. It is especially its intermittent production, thus requiring conversion to facilitate storage and distribution. From the latest wind maps in Algeria, the wind power potential is available in three provinces to convert the wind power to hydrogen by electrolysis. The wind power conversion studied has four wind turbine capacities, namely 600, 1250, 1500, and 2000 kW, which were then evaluated for their ability to produce hydrogen. From this research, it could be concluded that the turbine type "Wind D7" can produce hydrogen at an economical cost in Adrar Province.

(Dutton et al., 2000) stated that the wind power generation system used as an energy source to process water into hydrogen is very appropriate to develop in areas with an average wind speed above 12 m/s. With this wind speed, the wind-to-hydrogen system is considerable can compete with fossil fuels in terms of production costs. However, it is not easy to find a location with a wind speed of more than 12 m/s, so detailed calculations and planning of the generation potential are required to produce maximum hydrogen output.

In this study, the researchers used the Analytical Hierarchy Process (AHP) method to select the optimal location for developing wind farms among the three alternative areas in the South Coast of Yogyakarta Special Region. Some criteria were arranged in a matrix, following a hierarchical arrangement, weighted quantitatively and qualitatively using the Level of Interest Scale under predetermined priorities. With this method, it is possible to produce an ideal alternative location for converting wind energy into hydrogen fuel. The stages carried out in this study are as follows:

A. Selection of the location where the research would take place

In this study, the chosen locations were the South Coast of Java in the Special Region of Yogyakarta, namely, Bugel Beach in Kulon Progo Regency, Pandansimo Baru Beach in Bantul Regency, and Baron Techno Park at Baron Beach in Gunung Kidul Regency, as seen in Figure 1.

Figure 1. Research location

B. Determination of criteria and collection of data required for evaluation of predetermined criteria and sub-criteria.

The criteria used in this study were technical factors consisting of sub-criteria for electrical energy and land availability. Location factors including sub-criteria for access to the location, distance to the grid, and disaster risk. Socio-economic factors are consisting of conflicts with tourism and conflict with fishermen. The sub-criteria selected in this study:

- Production of electricity by wind power plants (PLTBs)

The electricity generated by the wind turbine at each location was calculated based on the average wind speed obtained. The average wind speed was calculated using the equation (Hau, 2006).

$$V = \frac{\sum_{i=1}^{n} Vi.ti}{\sum_{i=1}^{n} ti} \qquad (1)$$

Where,
V = average wind speed (m/s)
Vi = rated wind speed (m/s)
ti = duration of wind blowing at speed Vi
n = number of data measured

The kinetic energy generated by the wind speed, which was used to rotate the turbine blades, was calculated by the equation (Hau, 2006).

$$E = \frac{1}{2} m V^2 \tag{2}$$

Where,
E = kinetic energy (joule)
m = air mass (kg)
V = average wind speed (m/s)

Then, the wind energy generated per unit time was obtained using the equation (Hau, 2006).

$$Pw = \frac{1}{2} A V^3 \rho \tag{3}$$

Where,
Pw = wind energy per unit time (watt)
A = swept area of windmill = πD^2 (m^2)
V = average wind speed (m/s)
ρ = air density ($\mathrm{kg/m^3}$)

The mechanical power generated by the wind turbine was obtained from the equation (Hau, 2006).

$$Pm = \frac{1}{2} cp \, \rho \, A \, V^3 \tag{4}$$

Where,
Pm = mechanical power generated by a windmill (watt)
cp = power coefficient
ρ = air density ($\mathrm{kg/m^3}$)
A = swept area of windmill = πD^2 (m^2)
V = average wind speed (m/s)

Furthermore, the wind energy conversion system to generate electrical energy was obtained by the formula (Hau, 2006).

$$P_{syst} = cp \, \eta_{tr} \, \eta_g \, \eta_b \, \frac{1}{2} \, \rho \, A \, V^3 \tag{5}$$

Where,
Pm = electric power generated by windmill system (watt)
cp = power coefficient
η_{tr} = transmission efficiency
η_g = generator efficiency
η_b = battery efficiency
ρ = air mass ($\mathrm{kg/m^3}$)
A = swept area of windmill = πD^2 (m^2)
V = average wind speed (m/s)

Although formulas for calculating wind turbines' power are available, it is challenging to get a definite figure regarding the power, transmission, generator, and battery coefficient or efficiency. In this study, the selection of wind turbines that are suitable for the research location is assisted by using the Wind Turbine Power Calculator software. In this software, there are several choices of wind turbine brands with various power specifications and dimensions. The average electric power will have obtained in the result column by inputting the average wind speed and selecting wind turbine type.

This software can also simulate wind power economic analysis by using initial Investment such as capital expenditure of wind turbine and operational and maintenance in specific lifetimes—revenue of the wind turbine obtained from the amount of produced power and electricity tariff.

- Land area

The available land under these sub-criteria includes the land required to build a wind farm optimum for converting wind energy into electrical energy, sufficient land to build a seawater processing unit into hydrogen, and a storage system for the generated hydrogen fuel.

- Access to location

One of the most striking problems of new and renewable energy is to store the energy produced. Thus the ease of distribution and transportation of hydrogen fuel are considered in this research.

- Distance to grid

The main purpose of electrical energy from wind farms is to be used as an energy input for the hydrolysis process. However, if there is an excess of electrical energy, it can be supplied to the electricity distribution network.

- Risk of disaster and abrasion

These are essential considerations in designing a wind farm to avoid problems in the facility's operation, including safety problems due to the threat of earthquakes, tsunamis, floods, and abrasion on the Southern Coast of Yogyakarta.

- Conflict against tourism

The three beaches used as research locations are popular coastal areas in Yogyakarta. For this reason, it is necessary to consider the conflicts that may arise in the tourism sector from the construction of the wind farm and other units.

- Conflict against fishermen

At the research location, fishing activities are the livelihoods of several local communities, including the Fish Auction Place (TPI), which accommodates the fishermen's catch to be sold at culinary stalls beach or sent outside the area when exceeding the target. Also, the shrimp pond and farm are significant economic sectors in the research location.

C. Constructing the AHP method

To solve the problem in selecting the best location for a wind farm, including the processing and storage unit of the hydrogen produced, the AHP method was taken based on the above criteria and sub-criteria. Troubleshooting using this method includes the following steps:

- Arranging a hierarchy of the problems at hand

The AHP structure on the problems in this study can be seen in Figure 2.

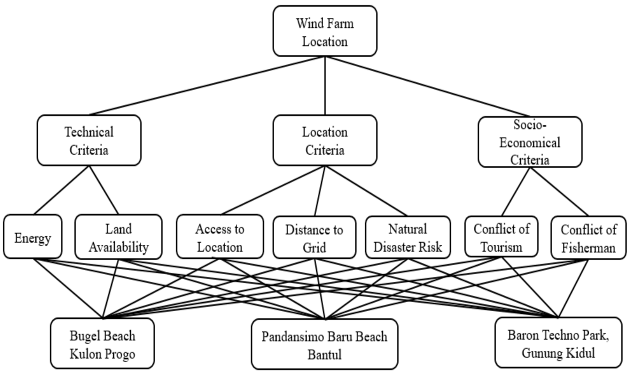


Figure 2. AHP structure of determining wind farm location

- Determining the priority of each element

The value scale was calculated using Table 1. The more important the criteria covering technical, location, and socio-economic factors, the higher the scale is given. The values on this scale range from the numbers 1-9.

Table 1. Importance-level scale

Importance Level Scale	Definision
1	Equal importance compare to other
3	Moderate importance compare to other
5	Strong importance compare to other
7	Very strong importance compare to other
9	Extremely strong importance compare to other
2, 4, 6, 8	Level between two scale

- Synthesizing to get the overall priority level

The next step was to synthesize the matrix obtained to get an overall priority level. In this study, after weighing each element's priorities, the Analytical Hierarchy Process construction was carried out using Expert Choice software. A paired weighting was carried out for the three research locations. For technical factors, the greater the electrical energy per year and the wider the land area available at the study site, the higher the weight given.

As for the location factor, the closer the research location is to National Road and the closest distance to the PLN grid, the higher the weight given. As for the sub-disaster factor, the lower the potential for disaster to occur in the research location, the greater its weight. Meanwhile, social and economic factors were taken into account; the greater the possibility of tourism and fishermen's products, the less the weight.

D. Calculating Hydrogen Production

Hydrogen can be produced by splitting water with an electrochemical process called electrolysis (Khalilnejad et al., 2014). In this process, water is decomposed into H_2 and O_2 with the help of electricity, according to the following equation.

$$2H_2O\ (l/g) \rightarrow 2H_2\ (g) + O_2\ (g) \qquad (6)$$

This reaction is an endothermic reaction that requires external energy and only occurs at high electrical voltages. The required voltages can come from renewable energy, which more environmentally friendly and does not produce CO_2 exhaust gas. In general, the electrolysis scheme is present in Figure 3.

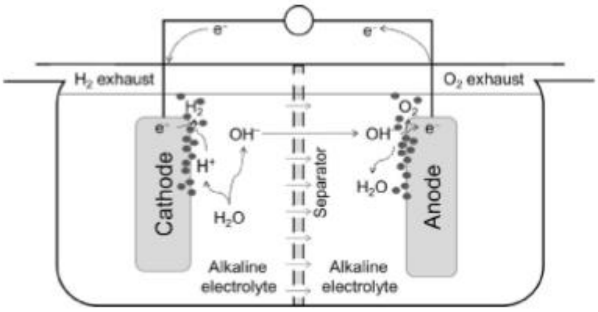


Figure 3. Electrolysis process in the electrolyzer unit

This electrochemical reaction process takes place in an electrolyzer cell, which consists of two electrodes. The electrode's positive pole called the anode serves as an oxygen evolution reaction (OER), while the negative one called the cathode does as the hydrogen evolution reaction (HER). The two are separated by a membrane that separates hydrogen gas and oxygen gas (Hosseini et al., 2010). The diagram of a hydrogen production facility utilizing wind turbine as an energy source and seawater as the primary raw material is shown by the following scheme (Dutton et al., 2000).

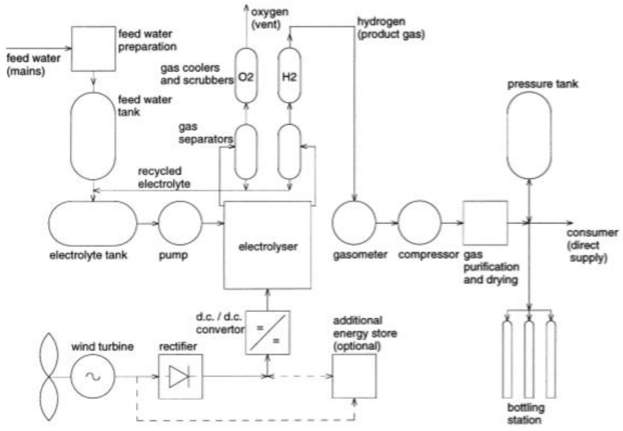


Figure 4. Wind to hydrogen production process

The generation of electricity from wind energy is an energy conversion with the least environmental impact than other new and renewable energy sources. Countries that have made considerable use of wind energy are America, China, Germany, Spain, and India, which account for 73% of wind-generated electricity worldwide (Tavan et al., 2015). In 2009, the United States, through the National Renewable Laboratory Energy (NREL) agency, conducted a test connecting wind turbines with a capacity of 100 kW to hydrogen units with the type of Polymer Electrolyte Membrane (PEM) with a hydrogen output capacity of 20 kg/day.

A more detailed economic calculation said that the cost required to produce hydrogen from wind power is 5,5 USD/kg. Electricity from wind farms will later be used as an energy source from the electrolysis process shown in Figure 4. In the research conducted by Douak and Settou in 2105, an electrolyzer with a capacity of 52,5 KWh/kg and an efficiency of 75% was used. The amount of hydrogen produced from a wind farm system is indicated by the following formula.

$$M_{H2} = \frac{\eta_{el} W}{LHV_{H2}} \tag{7}$$

Where,

M_{h2} = mass of hydrogen produced from wind turbines (kgH_2/year)
η_{el} = electrolyzer efficiency
LHV_{H2} = electrolyzer capacity (kWh/kg)

The critical factor of the economic parameter in the production of hydrogen from wind energy is the cost required for hydrogen production, which can be calculated using the equation,

$$C_{H2} = \frac{C_{ele} + C_w}{M_{H2} T} \tag{8}$$

Where,

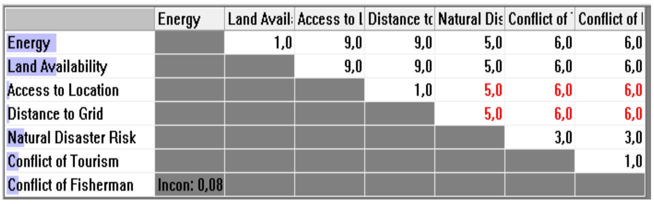
C_{H2} = Hydrogen production costs (USD/kg)
C_{ele} = Start-up capital and operations and maintenance costs of the electrolyzer unit (USD)
C_w = Energy Cost (USD)
M_{H2} = The mass of hydrogen produced (kgH_2)
T = Generation system lifetime (years)

3. Results & Discussion

The first step in making AHP is determining the priority of each element. In this study, the most crucial criterion is technical factors, namely the energy possible to generate at the three research locations. It combines the selected wind turbines' energy potential and the available land area in the research locations. The larger the wind turbine capacity and the more available land area, the greater the energy produced. So, energy and land sub-elements have the same priority. The next priority element is the socio-economic factor, consisting of the sub-criteria of conflicts with tourism and conflicts with fishermen and farmers.

This element is important for showing the relationship between the wind farm and the hydrogen unit with the community's social and economic aspects around the research locations. The last element is the location factor. The hydrogen fuel product will later be distributed by road mode. The excess of electrical energy that is not used or absorbed in hydrogen production is channeled to the PLN electricity distribution line (on-grid). Moreover, the risk of natural disasters is taken into account. Furthermore, the priority of these three elements and their sub-elements was weighted using Table 1. Importance-level Scale, into the Expert Choice software, as shown in Table 2.

Table 2. Weighting of priorities



	Energy	Land Avail:	Access to l	Distance tc	Natural Dis	Conflict of ˈ	Conflict of l
Energy		1,0	9,0	9,0	5,0	6,0	6,0
Land Availability			9,0	9,0	5,0	6,0	6,0
Access to Location				1,0	5,0	6,0	6,0
Distance to Grid					5,0	6,0	6,0
Natural Disaster Risk						3,0	3,0
Conflict of Tourism							1,0
Conflict of Fisherman	Incon: 0,08						

The priority order of the seven sub-criteria was obtained as shown in Figure 5.

Figure 5. Sub-criteria priority chart

Each sub-criteria energy generated from the wind farm and the land area available in the research locations had a scale of 0.341, followed by the sub-elements vulnerability to natural disaster risk exposure with a scale of 0.123. The conflict in the development of wind farms and fuel cell generation units with tourism and the community's economic activities had a scale of 0.075. Meanwhile, the sub-elements location access and distance to the PLN electricity distribution line weighted 0.022. The above calculation's inconsistency value was 0.08, where a value below 0.1 is sufficiently consistent in the weighting.

A. Technical Factor

- Wind energy calculation

The calculation of the energy output from wind turbines in this study used the Wind Turbine Power Calculator's help developed by the Danish Wind Industry Association.

- Pandansimo Baru Beach, Bantul

With an average wind speed of close to 5 m/s, the most optimal wind turbine was the Vestas V80 2000/80, which has a capacity of 2000 kW, a tower height of 80 m, and a rotor diameter of 80 m. A calculation simulation for each wind speed was performed, as shown in Table 3.

Table 3. Wind speed and electrical energy output at Pandansimo Baru beach

Month	Speed_Wind (m/s)					Monthly Energy Output (kWh/month)
	0-3	3-6	6-9	9-12	>12	
January	0,263441	0,58871	0,115591	0,02957	0,002688	2552084,353
February	0,29321	0,632716	0,074074	0	0	2101410,988
March	0,275538	0,662634	0,05914	0,002688	0	2097361,817
April	0,356944	0,540278	0,043056	0,026389	0	1928631,416
May	0,270161	0,454301	0,162634	0,107527	0,005376	3266830,255
June	0,276389	0,356944	0,168056	0,1625	0,036111	3859680,173
July	0,165323	0,33871	0,219086	0,254032	0,022849	4827000,013
August	0,188172	0,209677	0,202957	0,227151	0,107527	4976866,615
September	0,263889	0,276389	0,266667	0,173611	0,019444	4244463,976
October	0,276882	0,361559	0,232527	0,120968	0,008065	3645449,835
November	0,334722	0,397222	0,238889	0,029167	0	2875765,685
December	0,351389	0,534722	0,119444	0,025	0,002778	2425775,171
					Annual Energy Output (kWh/year)	38801320,2969

- Bugel Beach, Kulon Progo

Bugel Beach is located about 10 km east of NYIA Airport and is based on SNI 03-7112-2005 concerning Aviation Operation Safety Area (KKOP). The maximum height of the building in a radius of 10 km should be 100 m. So the wind turbine NEG Micon 1000/60, having a capacity of 1000 kW, a tower height of 59 m, and a rotor diameter of 60 m, was selected. With the same average wind speed as at Pandansimo Baru Beach, the results are as shown in Table 4.

Figure 6. SNI 03-7112-2005

Table 4. Wind speed and electrical energy output at Bugel beach

Month	Wind Speed (m/s)					Monthly Energy Output (kWh/month)
	0-3	3-6	6-9	9-12	>12	
January	0,2634	0,5887	0,1156	0,0296	0,0027	1221208,1129
February	0,2932	0,6327	0,0741	0,0000	0,0000	1015814,0525
March	0,2755	0,6626	0,0591	0,0027	0,0000	1014664,1196
April	0,3569	0,5403	0,0431	0,0264	0,0000	928346,4993
May	0,2702	0,4543	0,1626	0,1075	0,0054	1541367,9671
June	0,2764	0,3569	0,1681	0,1625	0,0361	1803679,9660
July	0,1653	0,3387	0,2191	0,2540	0,0228	2247232,0847
August	0,1882	0,2097	0,2030	0,2272	0,1075	2300766,9738
September	0,2639	0,2764	0,2667	0,1736	0,0194	1982392,1444
October	0,2769	0,3616	0,2325	0,1210	0,0081	1713199,2413
November	0,3347	0,3972	0,2389	0,0292	0,0000	1366374,6611
December	0,3514	0,5347	0,1194	0,0250	0,0028	1161087,1569

Annual Energy Output (kWh/year) 18296132,9796

- Baron Techno Park, Baron Beach, Gunung Kidul

NYIA airport regulations did not restrict the choice of the wind turbine used at Baron Beach. This location has an average wind speed higher than the other two research locations. Therefore, the Nordex N90/2300 wind turbine with a capacity of 2300 kW, a rotor diameter of 90 m, and a tower height of 80 m was used. The simulation results are as shown in Table 5.

Table 5. Wind speed and electrical energy output at Baron Techno Park, Baron beach

Month	Wind Speed (m/s)					Monthly Energy Output (kWh/month)
	0-3	3-6	6-9	9-12	>12	
January	0,225483	0,538296	0,181102	0,048676	0,006442	3773086,659
February	0,414764	0,510654	0,06621	0,008371	0	2322941,105
March	0,46933	0,455064	0,067047	0,005706	0,002853	2180914,757
April	0,334694	0,346939	0,198834	0,091545	0,027988	4080900,166
May	0,175439	0,196594	0,278122	0,22033	0,129515	6774151,127
June	0,227495	0,227495	0,316047	0,222114	0,006849	5798091,482
July	0,161611	0,301343	0,409249	0,121333	0,006464	5634410,091
August	0,128546	0,301147	0,439348	0,13096	0	5893166,064
September	0,282871	0,324777	0,329492	0,061289	0,001572	4398864,783
October	0,224219	0,414063	0,346875	0,014844	0	4264227,684
November	0,582364	0,333333	0,071705	0,00969	0,002907	1926659,42
December	0,223116	0,21608	0,541374	0,01675	0,00268	5253931,48

Annual Energy Output (kWh/year) 52301344,82

- **Land Availability**

At Pandansimo Baru Beach, the land area available is vast, reaching 24 hectares (Setyawan, 2015). Based on the Regional Regulation of Kulon Progo Regency Number 1 of 2012 concerning the Spatial Layout of Kulon Progo Regency in 2012-2013, Bugel Beach has 16 hectares. In Baron Techno Park, Baron Beach, Gunung Kidul, the location is in the form of soil and limestone with an area of 9 hectares (Rohmah et al., 2017). Based on (Ackermann & Soder, 2005), the ideal distance between turbines installed at the wind farm is ten times the turbine blades' diameter and five times the turbine blades' diameter when in an orthogonal position, as shown in Figure 7.

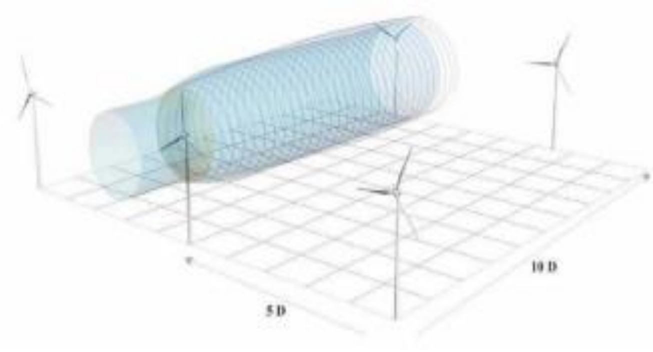


Figure 7. Ideal distance between wind turbines

Based on the available land area, the ideal distance between turbines and energy output based on simulated wind speed at each research location is presented in Table 6.

Table 6. Land area and energy output

Location	Large (m2)	Lenght (m)	Width (m)	Tipe of Turbine	5 x Diameter	Installed Wind Turbine	Total Energy Output (kWh/year)
Bugel Beach	160000	1500	106	NEG Micon 1000/60	300	5	7623388.74
	Selected Turbine	Hub (m)	Diameter (m)	Annual Energy Output			
	NEG Micon 1000/60	59	60	1524677.748			
Pandansimo Baru Beach	240000	2000	120	Vestas V80 2000/80	400	5	16167217
	Selected Turbine	Hub (m)	Diameter (m)	Annual Energy Output			
	Vestas V80 2000/80	80	80	3233443.358			
Baron Tekno Park	90000	1000	90	Nordex N90/2300	450	2	8716890.80
	Selected Turbine	Hub (m)	Diameter (m)	Annual Energy Output			
	Nordex N90/2300	80	90	4358445.402			

B. Location Factor

- Distance to Grid

Based on the Decree of the Board of Directors of PT PLN Number 0357.K/DIR/2014 regarding guidelines for connecting renewable energy power plants to the PLN distribution system and according to the road map for the development of PLTB Bantul, electricity generated from new and renewable energy power plants with a capacity of less than 2 MW should be connected to a 150 kV voltage distribution network. Based on the Map of 150 kV Electricity Distribution in DI Yogyakarta, the distance of research location to the PLN gird is shown in Table 7.

- **Access to location**

Hydrogen fuel produced from the three research locations will then be distributed using land transportation distribution, thus requiring road access to accommodate these interests. The parameter used is the National Road's location distance in DI Yogyakarta based on the DIY Governor Decree No. 118 of 2016. The distance of the research location to the national road is shown in Table 7.

- **Risk of Disaster**

Data on potential disasters in earthquakes, tsunamis, and floods were obtained from maps of earthquake-prone areas for the Special Region of Yogyakarta issued by the National Disaster Management Agency (BNPB). The disaster risk of the research location based on BNPB map are shown at Table 7.

C. Socio – Economy Factor

- Conflict with Tourism

Conflict with tourism was also considered in this study because the three beaches where the research took place were quite popular in Yogyakarta. Based on Department of Tourism and Culture data in 2019, each location was visited by tourists and generated fee income.

- Conflict against Fishermen

The data used in quantifying conflicts against fishermen and farmers use data obtained from a study by (Musrowati Lasindrang, 2015) entitled Study of the Distribution of the Economic Potential of Marine Resources at the South Coast of DI Yogyakarta as an Effort to Accelerate Investment, as presented in Table 7.

Table 7. Sub-criteria data for each location

Criteria	Sub-Criteria	Location	Obtained data
Techincal	Annual Electric Power (MWh/year)	Bugel Beach	7623.4
		Pandansimo Baru Beach	16167.2
		Baron Tekno Park	8716.90
	Land Availability (Ha)	Bugel Beach	16
		Pandansimo Baru Beach	24
		Baron Tekno Park	9
Location	Access to Location (km)	Bugel Beach	5
		Pandansimo Baru Beach	7
		Baron Tekno Park	18
	Distance to Grid (km)	Bugel Beach	4
		Pandansimo Baru Beach	6
		Baron Tekno Park	20
	Natural Disaster Risk	Bugel Beach	High
		Pandansimo Baru Beach	High
		Baron Tekno Park	Low
Socio-Economi	Tourism Conflict (IDR Billion)	Bugel Beach	0.18
		Pandansimo Baru Beach	1.3
		Baron Tekno Park	8
	Fisherman Conflict (IDR Billion)	Bugel Beach	19
		Pandansimo Baru Beach	23
		Baron Tekno Park	4

- **Weighting Criteria**

a) Techincal factors

Technical factor is achieved by calculating the amount of energy produced by a series of wind turbines that make up a wind farm system. This factor consists of the sub-criteria for the energy produced by each wind turbine and the location to build a wind farm. The greater the wind turbines' annual electricity production, which is selected based on wind speed data at each research location. The availability in challenging land areas can be used as a wind farm installation location. The weighting given is also getting more significant. Weighting quantitatively the sub-criteria for electric energy production per year uses the data in Table 7.

Bugel Beach has the same average wind speed as Pandansimo Baru Beach because its radius is inside the KKOP area. The wind turbines installed have limited dimensions of poles and diameters. Pandansimo Baru Beach and Baron Techno Park have a higher electricity production per year than Bugel Beach, so the weighting at Pandansimo Baru Beach is given a value of 8. If weighted by Baron Techno Park, it is given a value of 9. While the annual electricity production at Baron Techno Park is the largest, it is given a value of 2 when paired with Pandansimo Baru Beach. The weighting of electrical energy in the three research locations is presented in Table 8. Meanwhile, based on the available, challenging land area, Pandansimo Baru Beach has the largest area, followed by Bugel Beach and Baron Techno Park.

b) Location factor

The location factor consists of 3 sub-criteria, namely access to the location, distance to the grid, and disaster risk. The research location access to the national road and the PLN 150 KV network distance is not much different. Bugel Beach has the closest space to the two sub-location criteria, followed by Pandansimo Baru Beach, Baron Techno Park's farthest location. The weighting of the access to Bugel Beach location is given a value of 2 to Pandansimo Baru Beach because it is only 1 km away, while Baron Techno Park is given a weight of 6. The comparison of Pandansimo Baru Beach to Baron Techno Park is assigned a value of 5.

Not much different from the location access weighting, the distance to the grid is given the same value as the national road's distance. It is except for Pandansimo Baru Beach's weighting compared to Baron Techno Park because the grid distance from Baron Techno Pack is 1 km closer to Baron Techno Park's distance to the national road.

The next sub-criteria are natural disasters from the three research locations. Baron Techno Park has the lowest natural disasters, while Bugel Beach and Pandansimo Baru Beach have the same risk. The comparison between Bugel Beach and Pandansimo Baru Beach is given a value of 1, while for Baron Techno Park, it is given 5.

c) Socio-Economic Factors

The sub-criteria that compose the socio-economic factors are conflicts over the development of wind farms and hydrogen electrolysis. These units against the community economy around the research location, consisting of conflicts against tourism and fishermen's conflicts. Retribution from tourist visits to Baron Beach reaches six times the Pandansimo Barum Beach visitors and almost 44 times compared to Bugel Beach.

For the sub-criteria for conflict against fishermen, data on fisheries' income and fishermen and fish cultivation are used on the three beaches. Pandansimo Baru Beach has an enormous income from the fisheries sector, followed by Bugel Beach and Baron Beach.

Table 8. Weighing criteria for each sub-factor

Criteria	Sub-Criteria	Location	Bugel Beach	Pandansimo Baru Beach	Baron Tekno Park
Techincal	Annual Electric Power (MWh/year)	Bugel Beach		8	9
		Pandansimo Baru Beach			2
		Baron Tekno Park			
	Land Availability (Ha)	Bugel Beach		4	3
		Pandansimo Baru Beach			2
		Baron Tekno Park			
Location	Access to Location (km)	Bugel Beach		2	6
		Pandansimo Baru Beach			5
		Baron Tekno Park			
	Distance to Grid (km)	Bugel Beach		2	6
		Pandansimo Baru Beach			4
		Baron Tekno Park			
	Natural Disaster Risk	Bugel Beach		1	5
		Pandansimo Baru Beach			5
		Baron Tekno Park			
Socio-Economi	Tourism Conflict (IDR Billion)	Bugel Beach		3	8
		Pandansimo Baru Beach			3
		Baron Tekno Park			
	Fisherman Conflict (IDR Billion)	Bugel Beach		3	5
		Pandansimo Baru Beach			7
		Baron Tekno Park			

From the data and weighting above, a graph obtained using Expert Choice software shows the analysis of the three alternative wind farm locations available for later use as energy input in the electrolyzer unit, as presented in Figure 8.

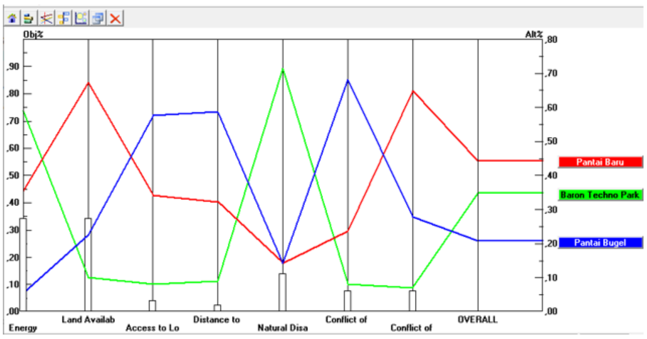


Figure 8. Results of simulation using expert choice

The Y-axis line on the left is a line showing the scale of importance following Figure 5. The amount of energy produced by a wind turbine and land availability is the top priority of 34.6%. Meanwhile, the sub-criteria with the second priority is the risk of natural disasters at 9.9%. In comparison, the next priority is 7.7%, namely access to the location, followed by tourism conflicts and fishermen conflicts at 5.6%, and the last priority is 2.0. % is the distance to the grid.

Meanwhile, the Y-axis on the right shows the weight of the alternative on each criterion and each option's overall weight. The results of Expert Choice software analysis (Figure 4.10) can be concluded that Pandansimo Baru Beach is an ideal location for a wind farm to meet the energy needs of the fuel cell unit with a weight of 44.7%. The next alternative site is Baron Techno Park which is on Baron Gunung Kidul Beach with a weight of 35%. Meanwhile, at the last alternative location, Bugel Beach, Kulon Progo weights 20.3%

- **Economical Factor**

Based on the manufacturer's website, the Vestas V80 2000/80 wind turbine's price is around 3 million USD. The cost of mobilization from Europe to Indonesia and installation is calculated at 40% of the wind turbine price. With a wind turbine lifetime of 20 years and the selling price of PLTB electricity in Indonesia based on Permen ESDM No. 17/2013, amounting to USD 0.12 per kWh. Economic calculations are carried out by entering the annual energy generated from the Wind turbine Vestas V80 2000/80 at Pandansimo Baru Beach, Bantul, which is 3,233,443 kWh.

Annual expenditure in the form of operational and maintenance costs every year is 1.5%, so the total income is obtained of USD 343,013.16 per year. By this assumption and simulation, it can be concluded that the installation of wind turbine type Vestas V80 2000/80 at Pandansimo Baru Beach will reach the Break Event Point (BEP) in the 13th year after installation.

- **Hydrogen Production**

The mass of hydrogen produced was calculated using Equation 7, with an electrolyzer capacity of 52.5 KWh/kg and an efficiency of 75%. The calculation obtained hydrogen's mass production at Pandansimo Baru Beach of 46.192 kgH_2 per year or 46,192 tons of hydrogen per year. The economic calculation of hydrogen production at Pandansimo Baru Beach in Bantul can be calculated using Equation 8. C_{ele} is the initial cost in the form of an initial investment in the construction of the electrolyzer unit along with the maintenance costs.

In research conducted by Jeffery Jacobs (2016), on a power plant with a power generation capacity of 40 MW/day, 20 electrolyzer units could be built at the cost of up to 20 million USD with large-scale wind farms like in Pandansimo Baru Beach. Meanwhile, the electricity cost was stated in USD/kWh or, based on the simulation with the Wind Turbine Power Calculator software, was 0.181 USD/kWh. Hydrogen production at Pandansimo Baru Beach reached 46.192 kgH_2 per year, and it was assumed that this system would have a lifetime of 20 years so that the cost of hydrogen production at Pandansimo Baru Beach was 22,068 USD/kg.

4. Conclusion

The highest electrical energy from a single wind turbine is at Baron Techno Park, Gunung Kidul. However, after considering land availability, the total amount of energy from the wind farm system becomes Pandansimo Baru Beach, Baron Techno Park, Gunung Kidul, and the last is Bugel Beach, Kulon Progo. Based on the analysis, by considering the technical criteria as a priority in determining the wind farm's location to supply energy to the fuel cell.

It is concluded by AHP methodology that the most considered alternative location for energy supply of hydrogen fuel producer is Pandansimo Baru Beach, Bantul. The wind farm economy calculation at Pandansimo Baru Beach with the wind type chosen by Vestas V80 2000/80 obtained BEP in the 13th year. Meanwhile, the amount of hydrogen fuel produced is 46.192 kg per year with an estimated 22,068 USD / kgH_2.

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