Determination of Factors and Location of Wave Power Generating for Islands in Indonesia

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Abstract

To support the Indonesia Government in achieving SDGs' target No. 7, developing environmentally friendly alternative energy is necessary. This research seeks to support the development of a wave energy power plant with great potential in Indonesia as an archipelagic country. The factors are collected from previous research to be considered in developing the design of a sea wave energy power plant. Determination of the location begins by collecting several locations that have been recommended by previous researchers, generally from the consideration of the magnitude of the potential for ocean wave energy. Simeuleu, Nias, Siberut, and Enggano islands have an essential local cost of providing electricity higher than the electricity tariff generated by ocean wave energy power plants, which is economically advantageous. Considering the criteria for potential wave resources, the essential cost of providing electricity, and potential replacement of existing D/G power plant, the Analytic Hierarchy Process (AHP) method synthesizes Nias island as the best location for ocean wave energy power plants. All locations with a significant potential for ocean wave energy are located in earthquake and tsunami-prone areas. Therefore, the design of power plants must be resistant to earthquakes and tsunamis.

Keywords
Sustainable Development Goals (SDGs), Renewable, Energy, Ocean Wave, Analytic Hierarchy Process (AHP)

1. Introduction
As an archipelagic country with 17,504 islands and a water area of 6,400,000 km² (62.89%), Indonesia has an enormous enough marine energy potential. Air pollution increases along with increased energy needs, where most of the energy is met from fossil energy. Several new and renewable energies have been developed to reduce this pollution to replace fossil-based energy. According to (Luhur et al., n.d.), electricity from ocean current-based generators costs Rp. 1,268/kWh, ocean wave energy costs Rp. 1,709/kWh, and tidal energy costs Rp. 2,048/kWh. The energy that utilizes the difference in seawater temperature (OTEC) shows a substantial cost, reaching Rp. 4.030/kWh. Compared with the production costs of conventional electricity generated by PT (Persero) PLN of Rp 1.163/kWh, it is suggested that marine energy development focuses on ocean current energy, ocean wave energy, and tidal energy.

The cost of electricity from sea wave-based plants ranks second but has advantages in distribution where almost all islands have sea waves converted into electricity. Because ocean wave power plant technology is still nascent, it needs to be developed to replace fossil-based power plants that pollute the environment. Globally, there is a potential for ocean wave energy of about 32 PWh/year, dominated by Asia at 6,200 TWh/year and Australia at 5,600 TWh/year (Institute of Electrical and Electronics Engineers, n.d.). Power generation from ocean wave energy is still not included in the planning because no power plant can last up to 5 years (Minister of Energy and Mineral Resources of the Republic of Indonesia, 2019).

1.1 Objectives

Determination of Factors needed in developing the design of ocean wave energy power plants and deciding the location for ocean wave energy power plants in Indonesia to support the Indonesian Government achieve the target of the renewable energy mix according to the targets of the Sustainable Development Goals (TPB/SDGs).

2. Literature Review

The literature study was conducted by looking for research journals related to renewable energy development from the marine sector. According to (A Rahman et al., 2021), air pollution due to burning fossil energy in 2019 reached 1,150.77 mtCO2 and showed an increase from year to year. In addition to causing environmental pollution, it turns out that fossil energy also gets a large subsidy from the Indonesian Government because energy needs must still be met. Under the Sustainable development goals (SDGs) program launched by the United Nations until 2030. In goal no seven related to clean and affordable energy, in 2018, only 21% of energy consumption was fulfilled from renewable energy, and the trend is declining. According to (Mukhtasor 2012), the potential for ocean wave energy in Indonesia is around 1,200 MW. According to (Rahman et al., 2021), the potential for ocean wave energy in Indonesia is 17,989 MW, and only 0.002% is utilized. Under the geographical area of Indonesia, which 62.89% is water, it is necessary to develop a sea wave energy power plant to meet future electrical energy needs under the United Nations program in the SDGs. From the power plants that have been made, several things need to be learned in developing future ocean wave energy power plants. According to (Institute of Electrical and Electronics Engineers, n.d.), several problems of ocean wave energy power plants, are 1. Severely damaged by storms; 2 and permanently damaged due to the brunt of ocean waves; 3. Damaged by flood; 4. Stranded on the beach; 5. Leaks in the tank; 6. The project is terminated. In addition to the above problems, according to (Minister of Energy and Mineral Resources of the Republic of Indonesia, 2019) Chapter 3.2.7 regarding marine energy, it was written that until now there had been no manufacturer of marine energy conversion technology into electricity that has proven reliability for commercial operations for five years. To obtain a sea wave energy power plant that can be developed to the commercialization stage, it is necessary to identify the influencing factors and proper location.

3. Methods

An essential initial step is determining the factors that affect the wave power plant to be planned. By knowing and determining the factors considered in planning a wave power plant, it is hoped that the final result will be as planned. The process of determining these factors is as follows: 1. First, literature studies from journals, papers, theses, dissertations, and others are carried out to collect data and experiences written by other researchers in developing ocean wave energy power plants; 2. Classification and tabulation are carried out from the data obtained to make the candidate factors easier to read and analyze. The factors that have been obtained will be taken into consideration in designing a sea wave energy power plant so that it can reach the commercialization stage.

Determination of locations process begins by collecting data from previous researchers who can support the determination of locations such as the potential, ocean wave energy, natural disasters, costs, environmental impact, competition with other power plant technology. After determining the factors, the research selected locations for ocean wave energy power plants. Previous researchers have recommended several locations for ocean wave energy power plants. A comparison is made between the essential local cost of providing electricity with electricity rates from ocean wave energy power plants for each recommended location. Locations with the essential local cost of providing electricity above sea wave energy power generation rates were selected for further processing using the AHP method. AHP analysis uses wave resources, the essential cost of providing electricity, and potential replacement of the Existing D/G Power plant. The synthesis results from AHP are the recommended locations while still considering natural disasters in developing the design of the ocean wave power plant that will be made.

4. Data Collection

Resource assessment

Considering their stability and wave power density throughout the year, there are six potential areas to develop into a power plant. According to (Habibie et al., 2021), as shown in figure 1, the most stable area based on significant wave height is open-sea and requires a wave power density of at least ten kW/m to develop power plant reliability. This area has a power density of more than ten kW/m throughout the year and high stability. The locations are Enggano, Lampung, West Java, DIY, East Java, and Bali.

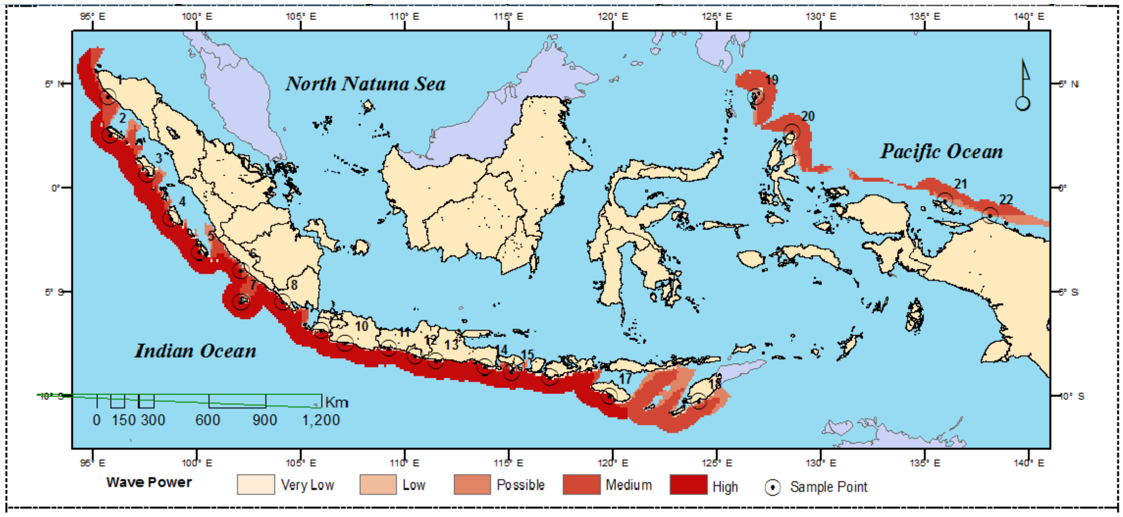

Figure 1. Wave energy flux climate in Indonesia (1991 – 2015) (Habibie et al., 2021)

Natural disasters (earthquake, tsunami, volcano eruption)

The increased seismic activity throughout Indonesia (1900-2016) was recorded, as shown in Figure 2. The areas with the highest tsunami hazard are the west coast of Sumatra, the south coast of Java, West Nusa Tenggara, East Nusa Tenggara, the north coast of Papua, Sulawesi, Seram, and North Maluku. Areas with low tsunami hazards are the north coast of Java, the east coast of Sumatra, the west and south coasts of Kalimantan, and the south coast of West Papua.

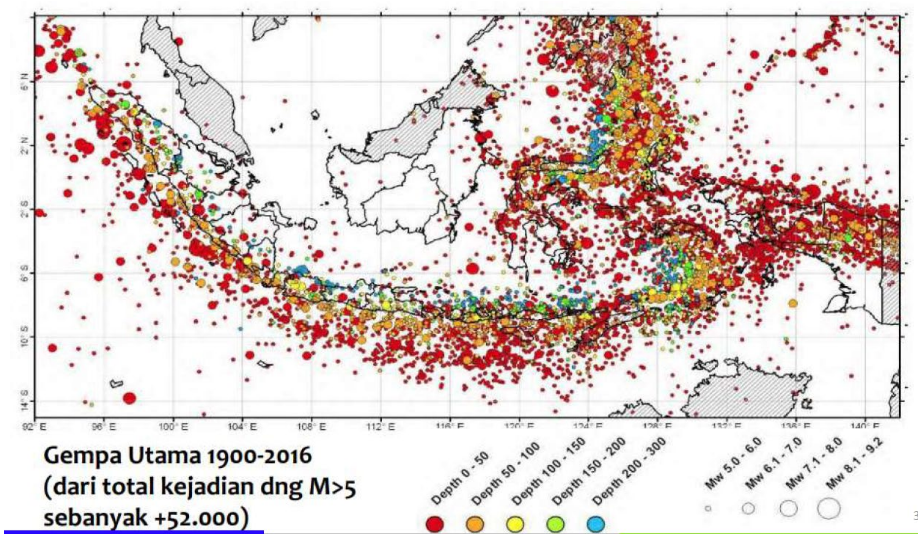

Figure 2. Increased seismic activity throughout Indonesia
A TSUNAMI EAST JAVA AND READINESS FOR RESPONSE, n.d.).)

Areas affected by the tsunami in Indonesia are marked in red in Figure 3. The black line represents the global ring of fire in Indonesia. Movement at the Indo-Australian and Eurasian tectonic plates is the cause of several large earthquakes in Indonesia.

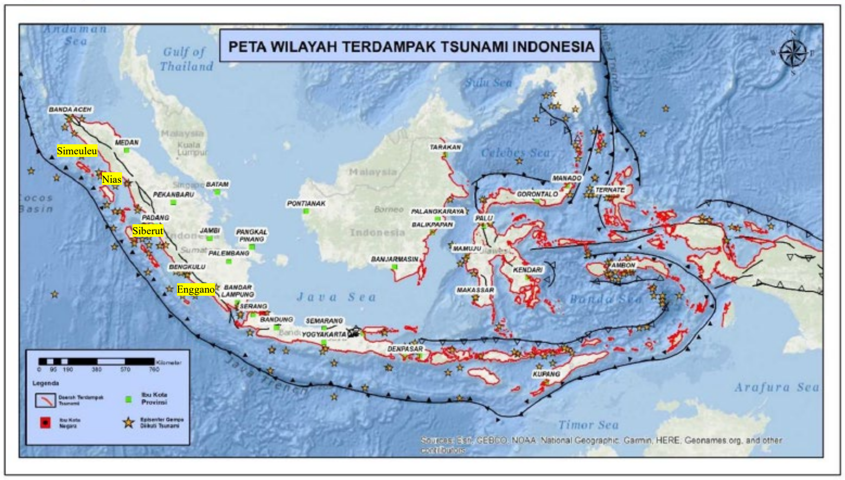

Figure 3. Map of areas affected by the tsunami in Indonesia
(A TSUNAMI EAST JAVA AND READINESS FOR RESPONSE, n.d.))

Cost

Indonesia's energy sector provides two incentives for renewable energy, while four incentives are given for coal and six for oil and gas (Rahman et al., 2021). Current status the electricity tariff for wave energy is Rp. 1,709/kWh compared to conventional energy of Rp. 1,163/kWh (Non-subsidized)(Luhur et al., n.d.).

Environmental impact

According to (Wang & Lu, 2018), Point Absorber (PA) WECs are considered environmentally friendly and have obtained interests from academic research and industrial prototypes.

Competition with other power plant technology

Approximately 74% of the total capacity of the national power station is located in Java-Bali, 16% in Sumatra, 3% in Kalimantan, and other islands (Sulawesi, Maluku, NTB-NTT, Papua) (Sugiyono, 2016).

5. Results and Discussion

Determination of factors

Wave energy harvesting is still in the nascent stage. Some problems occurred during the development process, and lessons learned were already taken. In order to increase the effectiveness of development, it is required to identify factors that affect the wave energy conversion and support the commercialization of the electric power generated. Some papers have been reviewed and collected factors as table 1. Resource assessment is the leading and essential factor to consider and recommend by a most minor seven previous researchers. When designing wave energy power plants, wave energy potential, variability, wind speed, water depth, and energy demand are sub-factors.

The second main factor is the wave energy converter itself, how ocean waves energy converts and distributes to the end-user. We need to consider also our design objective. Different design objectives will influence the result. For example, if we need to give power to navigation buoys in the middle of the sea, the decision will be point absorber technology. Even this type of converter is not the cheaper one. Other factors related to the conversion of the wave to be electric power are Wave energy converter (WEC) efficiency, extreme loading capability, light in weight, low maintenance, long life cycle, reliable structure & mooring system, type of WEC, PTO, storage system, Loading characteristic, Time required to start/stop, Possibility to electric Export/Import, Construction & Installation time required, Availability & Integration to Electric Grid, prototype to commercial scale, Resistant to corrosive, Well space for Operation & Maintenance, and Transmissions from sources to users.

The third factor related economic view is the power plant cost. Financial incentives from the Government in tax reduction or credit support will influence the financial calculation. How much cost of investment is required needs to be considered. The private sector can bear low investment costs, but considerable investment costs only the

Government can afford to support. Most of the sea wave energy power plant development projects are still funded by the Government. Operation and maintenance cost also influence the feasibility analysis of the power plant. It is necessary to design low operation & maintenance costs for the power plant. The life cycle of the power plant will affect the feasibility analysis. Even though in some studies, ocean wave energy power plants are calculated at the age of 15 years, according to (Menteri ESDM Republik Indonesia, 2019), no technology can last more than five years. It is necessary to conduct an in-depth study of the reliability of each wave energy converter and its supporting systems to ensure a life cycle of more than five years. Return on investment is a factor to be considered when investors finance WEC. The discount rate will influence the financial analysis, and the cost reduction will occur according to the economies of scale of mass production of WEC.

The fourth factor is the environmental impact of the power plant. Ocean wave energy power plants preserve the environment by reducing air pollution produced by conventional power plants. With the support of the United Nations and the Indonesian Government, this renewable energy power plant development program can continue to preserve the environment. The socio-economic impact will be considered related to permits in the construction program. Other environmental factors that need to be considered are minor or no greenhouse gas produced, have little or no adverse effect on the aquatic plant and marine life, reduced shoreline erosion, Impact during construction and installation, and WEC performance reduction because of seaweeds or biofouling.

Table 1. Factors influencing the development of ocean wave energy power plants

No.	Factors collected	Journals references									
		(Institute of Electrical and Electronics Engineers, n.d.)	(Aderinto & Li, 2018)	(Aderinto & Li, 2019)	(Sheng, 2019)	(Ode et al., n.d.)	(Habibie et al., 2021)	(Nugroho Sugianto et al., 2017)	(Wang & Lu, 2018)	(Alifdini et al., 2018)	(Alkhayyat et al., n.d.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
A	**Resource assessment**										
1	Wave energy potential	✓	✓	✓		✓				✓	✓
2	Wave energy variability (Height, period, direction)	✓	✓	✓		✓	✓			✓	✓
3	Wind speed	✓									
4	Water depth							✓		✓	✓
5	Energy demand					✓				✓	
B	**Wave energy converter**										
6	Design objective			✓							
7	Efficiency			✓	✓	✓					
8	Extreme loading conditions (storm, hurricane, harsh weather)	✓	✓								✓
9	Should not have an excessive weight	✓									
10	Should require reduced maintenance	✓									✓
11	Long life cycle (more than five years)	✓				✓					
12	Reliability of structure & Mooring system	✓	✓		✓						
13	WEC location (Coastal, nearshore, offshore)		✓								
14	Capacity					✓					✓

15	WEC Type					✓			✓		✓
16	Power Take-Off (PTO)								✓	✓	✓
17	Storage								✓		

Tabel 1. Factors influencing the development of ocean wave energy power plants (continued)

No.	Factors collected	Journals references									
		(Institute of Electrical and Electronics Engineers, n.d.)	(Aderinto & Li, 2018)	(Aderinto & Li, 2019)	(Sheng, 2019)	(Ode et al., n.d.)	(Habibie et al., 2021)	(Nugroho Sugianto et al., 2017)	(Wang & Lu, 2018)	(Alifdini et al., 2018)	(Alkhayyat et al., n.d.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
18	Loading characteristic (Including load adjustment)					✓					
19	Time required to start/stop					✓					
20	Possibility to electric Export/Import					✓					
21	Construction & Installation time required					✓					
22	Integration to Electric Grid		✓						✓		✓
23	Availability of electric grid		✓								
24	Laboratory prototype to commercial scale		✓								
25	Resistant to corrosive condition		✓								
26	Well space for Operation & Maintenance activities		✓								
27	Transmissions from sources to users							✓			
C	**Economic (Cost)**										
28	Financial incentive										✓
29	Investment cost					✓		✓			
30	Operation & Maintenance cost		✓			✓		✓			
31	Lifecycle cost		✓			✓		✓			
32	Return on investments		✓	✓		✓					
33	Discount rate					✓					
34	Cost reduction										
D	**Environmental impact**										
35	Political support										✓
36	Socio-economic issues and permits	✓	✓								✓
37	Produces little or no greenhouse gas	✓	✓								✓
38	Have little or no adverse effect on the aquatic plant and marine life	✓	✓								✓
39	Reduce shoreline erosion	✓	✓								✓
40	Impact during construction and installation	✓	✓								✓

41	WEC performance reduction because of seaweeds or biofouling		✓								

In order to contain more comprehensive considerations related to WEC development, several factors were added, such as 1. Competition aspect with other power plants; 2. Power plant scale; 3. WEC Array configuration; 4. Risks related to natural disasters (Earthquake, Tsunami, Volcano eruption); 5. The local component of the power plant; 6. Site characteristics (Bathymetry, tide, soil). In the process of planning a good ocean wave power plant, an in-depth study is needed to quantify each of the factors found in table 1.

Location of Wave Power Generating for Islands in Indonesia

As stated in Presidential Regulation No. 22/2017 (RUEN), waves energy has 17.989 MW potential capacity and only utilized 0,002% (0,3 MW) (Rahman et al., 2021). To generate power significantly, ocean surface waves must have a minimum height of about 1.6 m (Joao Cruz, 2008). (Purba et al., 2015)said that ocean surface waves range from about 1.6 m to 2.6 m in some locations like Java Island, Bali, Lombok, NTB, until Flores and Papua, those mean values along the year could generate enough power. The mean value is at 1.3 m ± 1.2 m which has the maximum value of up to 5.5 m in the west season. The highest tidal range was found in Riau Province and West Kalimantan as the tidal range is 1.3 m until 3.7 m, and the maximum value could reach 5.7 m. The smallest one was located in West Sumatera, followed by Java and Bali. (Amiruddin et al. l, 2019) said that The highest wave power was found in JJA season (June to August), in which about 30–40 kW/m (the 90th percentile: 40–60 kW/m, the 99th percentile: 50–70 kW/m) on average is expected around the south of the Java Island, south of Bali, south of West Nusa Tenggara and also East Nusa Tenggara. Other locations, which are also promising, are around the southwest of Sumatera Island, particularly for small islands such as Simeulue Island, Nias Island, and Siberut Island. Other researchers have already performed some studies and recommended 9 locations based on the magnitude of the potential for ocean wave energy. Under the latest study, the recommended location is narrowed into 3, namely the western part of Sumatra, the southern part of Java, and the southern part of Bali, as shown in Tabel 2.

Tabel 2. Recommended locations for ocean wave energy generation

No	Recommended Location	(Purba et al., 2015)	(Alifdini et al., 2018)	(Amiruddin et al., 2019)	(Ribal et al., 2020)	(Habibie et al., 2021)
1	West of Sumatera		✓ Meulaboh	✓ Simeuleu, Nias, Siberut	✓	✓ Enggano, Lampung
2	South of Java			✓	✓	✓ West Java, DIY, East Java
3	North of East Java	✓				
4	Bali	✓	✓ South Kuta	✓	✓	✓
5	West Nusa Tenggara	✓		✓	✓	
6	East Nusa Tenggara	✓		✓		
7	South of Sulawesi	✓				
8	South of West Papua	✓				
9	North of West Papua		✓ Manokwari			

Table 2 summarizes some of the potential locations that we will choose to apply ocean wave energy power plants, and it is an essential cost of providing electricity, as stated in table 3.

Tabel 3. Summarize a potential location and its essential cost of providing electricity

No	Recommended Location	The essential local cost of providing electricity *

		cent US$/kWh	Rp/kWh
1	Meulaboh (Aceh)	9,26	1.349,37
2	Simeuleu island	14,75	2.149,37
3	Nias island	19,25	2.805,11
4	Siberut Island	15,92	2.319,86

Tabel 3. Summarize a potential location, and its essential cost of providing electricity (continued)

No	Recommended Location	The essential local cost of providing electricity *	
		cent US$/kWh	Rp/kWh
5	Enggano island	19,25	2.805,11
6	Lampung	6,83	995,27
7	West Java	6,23	907,84
8	DIY/Central Java	6,23	907,84
9	East Java	6,26	912,21
10	South Kuta	6,23	907,84
11	Manokwari	11,00	1.602,92

Source : * (*Kepmen No. 169.K.HK.02.MEM.M.2021*, n.d.) 1 US $ = Rp 14.572
National basic cost of providing electricity in Indonesia is 7,05 cent US$/kWh (Rp 1.027,70/kWh)

The essential local cost of providing electricity for Lampung, West Java, DIY/central Java, East Java, and South Kuta is below the National essential cost of providing electricity USD 0.0705 per kWh. The electricity supply for this location has been quite efficient compared to other regions in Indonesia and is much cheaper than the electricity tariff generated by the ocean wave energy power plant, which is 11,7 cent US$/kWh (Rp. 1,709/kWh). In two locations, namely Meulabooh and Manokwari, although the essential local cost of providing electricity is higher than the essential national cost of providing electricity, it is still below the electricity tariff for ocean wave energy. These locations will be removed from the selected location. 4 potential locations met the availability of wave resources and essential local cost of providing electricity which was still higher than the electricity tariff for ocean wave energy, namely 11.7 cents US$/kWh (Rp. 1.709/kWh). These locations are Simelue Island, Nias Island, Siberut Island, and Enggano Island. To choose the best location to be used in the ocean wave energy power plant, the Analytical Hierarchy Process Method (AHP) was used in selecting the location. Some data were collected to support the pairwise comparison of the AHP analysis according to table 4.

Tabel 4. Supporting data for pairwise comparison AHP

No	Recommended Location	Wave energy means (kW/m)*	Basic cost of providing electricity (cent US$/kWh)**	Existing capacity of D/G in the location (MW) ***	Depth (m)*	SWH (m)*
1	Simeuleu island	37,07	14,75	13,8	67,55	1,48
2	Nias island	40,87	19,25	44,3	71,12	1,53
3	Siberut Island	42,96	15,92	9,3	96,51	1,61
4	Enggano island	42,14	19,25	1,5	42,26	1,75

Source : * (Rizal & Ningsih, 2020)
** (*Kepmen No. 169.K.HK.02.MEM.M.2021*, n.d.)
*** (Menteri ESDM Republik Indonesia, 2019)

The hierarchy for AHP has been made with a decision model, namely location for wave energy harvesting. There are three criteria, namely: 1. Wave resources; 2. The essential cost of providing electricity; 3. Potential replacement of Existing D/G Power plant as shown in Figure 4. There are four alternatives, namely: 1. Simeuleu Island; 2. Nias island; 3. Siberut Island; 4. Enggano Island. Priority and pairwise comparisons were compiled based on table 4. The consistency ratio (CR) was calculated and maintained below 10%. The results of the AHP synthesis for the Location for Wave energy harvesting decision model are in Table 5.

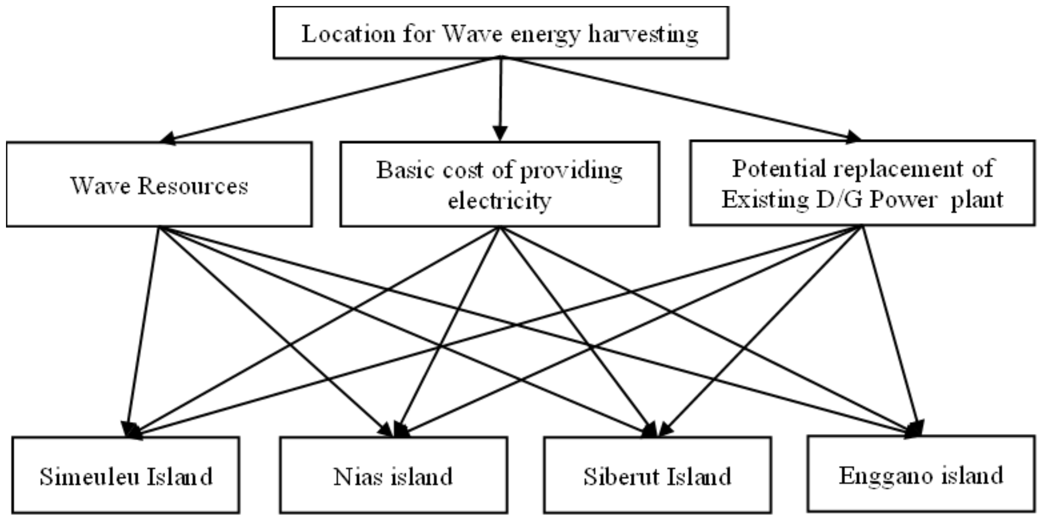

Figure 4. A hierarchy for the AHP decision model

Tabel 5. Result of AHP synthesis for Location for Wave energy harvesting

Criteria	Weight	Location			
		Simeuleu	Nias	Siberut	Enggano
Wave Resources	33,33%	4,24%	13,56%	52,00%	30,20%
Basic cost of providing electricity	33,33%	5,17%	42,09%	10,64%	42,09%
Potential replacement of Existing D/G Power	33,33%	22,81%	61,45%	10,82%	4,92%
Total	100 %	10,74%	39,03%	24,49%	25,74%

According to the results shown in table 5, the first rank for the location of wave energy harvesting is Nias Island, with a score of 39.03%. This choice is dominated by the magnitude of the potential wave energy and the large capacity of diesel power plants that can be replaced by ocean wave energy power plants. Building a sea wave energy power plant on Nias Island will obtain several advantages, such as 1. It is obtaining an environmentally friendly power plant; 2. Lowering the cost of the Basic cost of providing electricity; 3. Lowering fuel subsidies; 4. Reducing carbon emission pollution; 5. Support the achievement of SDGs targets; 6. They are reducing dependence on imported fuel. Building wave energy power plants on the islands of Enggano, Siberut, and Simeuleu also remain profitable because the essential cost of providing electricity is still higher than the tariff for electricity from ocean wave energy power plants. According to the data in Figure 2 and Figure 3, the location with the most significant potential for ocean wave energy in Indonesia is in an area prone to earthquakes and tsunamis. Because the earthquake and tsunami can cause a total loss for the investment to be given, mitigation is needed in the form of preventive action to minimize the impact of the earthquake and tsunami on the ocean wave energy power plant to be built. It is recommended not to use the Wave energy converter (WEC) design in onshore locations because it is prone to damage during an earthquake or tsunami. WEC designs at nearshore and offshore locations also need to be studied in-depth related to their resistance to tsunamis with wave heights up to 5m.

6. Conclusion

Based on the data analysis above, the conclusion is:

1. Several factors need to be considered in the development of ocean wave energy power plants, as shown in Table 1.
2. Some areas are recommended for ocean waves energy harvestings in the resources potential view, such as West Sumatera, South of Java, and South of Bali.
3. All areas that will contain a high potential for ocean wave energy are located in areas prone to earthquakes and tsunamis. It can be a challenge for the development of ocean wave energy converters.
4. In terms of the level of competition with other power plants, the development of ocean wave energy power plants on the islands of Java and Bali will face stiff competition against hydropower plants. Due to power plants in Indonesia, 74% are located on the islands of Java and Bali.
5. In terms of the level of competition with other power plants and energy demand, the development of ocean wave energy power plants should be carried out in:
   a) Sumatra Island, for the following reasons: 1. The level of energy demand is relatively high; 2. The highest ocean wave energy potential; 3. 16% of Indonesia's power plants in Sumatra.
   b) The northern part of the islands of Maluku and Papua. Because of the following reason: 1. Most of the power plants that fill the area use diesel power plants, which are expensive and pollute the environment; 2. The potential for ocean wave energy is quite enormous; 3. Geographical conditions with many small islands separated by the deep sea.
6. Under the results of the synthesis of the AHP method, it was found that Nias Island is the most suitable location for ocean wave energy power plants. Locations on the islands of Enggano, Siberut, and Simeuleu also remain profitable for ocean wave energy power plants because the essential cost of providing electricity is higher than the electricity tariff for ocean wave energy.

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