Determining potential location for development planning of ocean current energy for electricity resources in Bengkulu

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Abstract. This study aims to determine the potential locations for alternative energy sources from waves and currents. Located in the Indian Ocean, the hydrodynamics potential of Bengkulu waters is quite high. In this study, we used data obtained from the OSCAR satellite series and bathymetric data obtained from Dishidrosal. The data series for currents are 5-year from 2019 to 2023 and were analyzed to classify the distribution values of ocean currents and bathymetry to generate the seabed topography profile. The method used in this study employ Inverse Distance Weighting and Fuzzy Logic. The sea surface current velocity is represented by the distribution of the average current speed (cm/s), which is divided into three classes slow (3.08–3.50), medium (3.5-7.84), and fast (7.84 – 12.65). The fuzzy analysis results show the estimation of suitable sites using defuzzification results at approximately 12 m. The classes for sea depth (m) were shallow (0.13-5.0), medium (5.0-20), and deep (20-315.35). The potential location is in the northern part of the province, specifically in North Bengkulu, Central Bengkulu, Bengkulu City, Seluma, and South Bengkulu, which topographically allows energy accumulation. These three districts can be designated as locations for the development of alternative electrical energy using ocean waves and currents.

1 Introduction

Energy is one of the most crucial factor of social development, economic growth, and human well-being [1]. It is predicted that by 2050, the world's energy consumption will rise by 50% over its current level [2]. Ocean energy is currently among the world's top exploitable renewable energy resources, along with solar and wind energies [3]. The energy policy target in indonesia, produced from various power plants and ocean electricity called (PLTAL). Ocean currents are driven by wind, water density differences, and tides [4]. The wave velocity is fast but unstable, whereas the ocean current energy has the characteristics of slow flow velocity but stable electrical energy transmission and a small impact on the power grid

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[5]. Compared with tidal range plants, current plants have a lower environmental impact and are potentially less disruptive to marine ecosystems. Both types of energy utilize the motion of water to generate power, and tidal energy depends on predictable tidal cycles, whereas current energy captures energy from ocean currents, which are driven by a broader set of forces, including the Earth's rotation and temperature gradients in the water. While reviewed from a geographical perspective, ocean currents can be constructed in open ocean environments and often in deeper waters. Current energy can be captured in many coastal regions, even when tides are not particularly strong. This gives the current energy a potentially wider geographic range than tidal energy. Location selection is an important issue in contradictory criteria, or so-called complex multi-criteria decision-making [6][7].

Located on the coast of the Indian Ocean, Bengkulu Waters surface currents range from 0,2 -0,5 m/s and in 20 m depth range from 0,2 - 0,4 m/s [8]. What differentiates the concept of current and tide is the movement of water to propel the turbine. The generator converts the kinetic energy into electrical energy [9]. However, physical characteristics and hydrodynamic factors make the study area potentially vulnerable to disaster navigational risks. Therefore, it is essential to determine locations that are topographically safe, allow energy accumulation, and pay attention to shipping traffic safety.

Feasibility studies and power plant installations are expensive. An alternative approach can be conducted using available data, such as the data provided by the OSCAR. The raw data are computed using a simplified physical model for geostrophy, Ekman, and thermal wind dynamics from satellite-sensed sea surface height gradients, ocean vector winds, and sea surface temperature gradients. A global 0.25° × 0.25°-grid is used to display the daily averaged surface currents across an estimated well-mixed top 30 meters.

The satellite data approach has the advantage of providing a wide coverage. Previous research [10] has shown the potential of ORE (Ocean Renewable Energy) throughout Indonesia, including in Bengkulu Province, using satellite data and GIS analysis. This study intends to further examine one of the previously studies energy sources. Therefore, the purpose of this study is to produce a map of depth and ocean current distribution, and to produce a map of potential locations based on suitability values using Fuzzy Logic.

2 Methods

In this study, two variable inputs contributed to the determination of potential sites for power plant installation development planning. The bathymetry profile was obtained from the Dishidrosal and current velocities from satellite data. Satellite altimetry is an essential remote sensing technique for monitoring dynamic ocean conditions, including major ocean currents. Ocean currents are determined by satellite synthetic aperture radar (SAR). The data processing mechanism is shown in Figure 1, and an explanation is provided below.

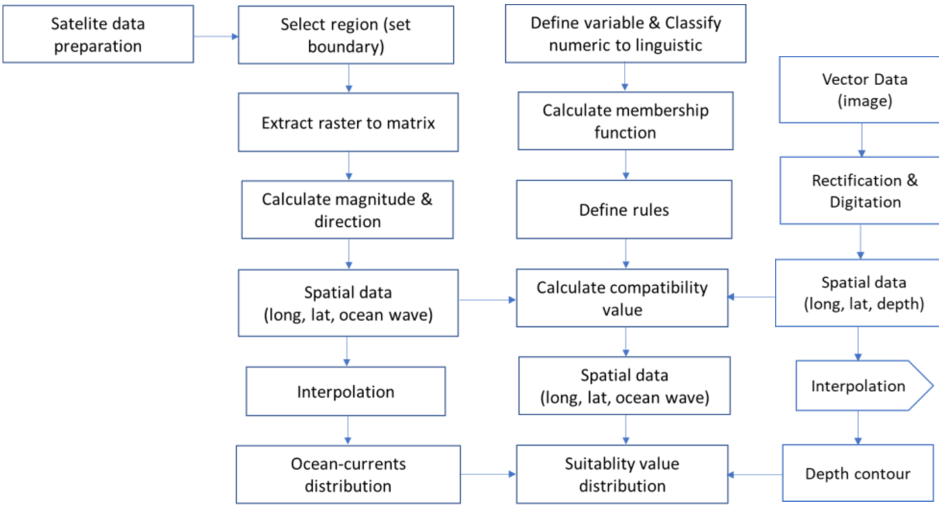


Figure 1. Research Workflow

2.1. Depth

Most available bathymetric charts are processed from echosounder data through digitizing and plotting to provide batchymetry chart contain with coordinate data and depth values. This value later proceeds with the fuzzy-logic process. The spatial distribution was interpolated using Inverse Distance Weighting (IDW).

2.2. Sea-surface Currents

Ocean surface currents are driven by global wind systems, which draw energy from the sun. The patterns of these surface currents are influenced by the wind direction, the Coriolis effect resulting from the Earth's rotation, and the geographical features that interact with the currents [4].

Vector represents the current velocity. With the north serving as a zero and clockwise measurement, its direction refers to the flow direction and uses degrees (°) as a unit. The water flowing through the columns moved more slowly than at the surface. Pressure and density are the two physical characteristics of water that affect it. Currently the u and v components have data. Two vectors were computed using Eq. (1) to determine the magnitude:

$$|v| = \sqrt{(u^2 + v^2)} \quad \text{(1a)}$$

$$\Theta = \left(\frac{v}{u}\right) \Big/ 180 * \pi \quad \text{(1b)}$$

$|v|$ is the magnitude representing the speed of the current or vector's length in the horizontal plane.
u is an east-west component of the current-velocity; the value indicates flow direction, positive means east, and negative means west.
v is a north-south component of the current velocity, the value indicates flow direction, positive means north, and negative means south

Ɵ is direction represented as degree of angle
π is a mathematical constant representing the ratio of the circumference of a circle' to its diameter.

2.3. Fuzzy logic

Fuzzy set theory is among the most preferred theories in decision making introduced by Zadeh (1965) for dealing with uncertainty and imprecision information associated with another. There are two potential sources for generating a fuzzy membership function, expert knowledge and real data [11]. The three steps of a fuzzy-logic system are Rule Evaluation, Defuzzification, and Fuzzification. Membership functions are used in the fuzzification and defuzzification processes to transfer non-fuzzy input values to fuzzy linguistic concepts and vice versa. A function called the membership degree indicates how much an input fits into a set [12][13][14]. A trapezoidal membership function for two variables represents fuzzy sets in a two-dimensional space. This function is useful in fuzzy logic systems for defining the degrees of membership of various inputs. The formula for trapezoidal membership is as follow:

$$\mu \text{ membership } [x, y] = \begin{cases} 0; & 0; \\ \frac{x-a}{b-a}; & \frac{y-a}{b-a}; \\ 1; & 1; \\ \frac{d-x}{d-c}; & \frac{d-y}{d-c}; \end{cases} \tag{2a}$$

α = smallest domain value with a zero membership level
b = smallest domain value that has a membership degree of one
c = value of the largest domain with a degree of membership of one
d = the value of the largest domain that has zero membership degree

As a result of normalization, all input and output variable values fell within the range [0,1]. The most popular methods are (i) min–max normalization, (ii) Z-score normalization, and (iii) decimal scaling normalization [15].

2.4. Spatial Analysis

Currents can be synoptically detected by satellite remote sensors [16] processed and visualized by geographic information systems (GIS). Calculating the statistical features and performing geoprocessing operations included how interpolation was performed. This method, known as Inverse Distance Weighting (IDW) interpolation, uses deterministic mathematical functions to assume a closer value that is more closely related than a further value. The IDW formula can be expressed as follows:

$$FZ_x = \sum_{i-1}^{n} W_i Z_i \tag{3a}$$

$$W_i = \frac{\left(\frac{1}{d_i}\right)^p =}{\sum_{j=1}^{n}\left(\frac{1}{d_j}\right)^p} \tag{3b}$$

$$\sum_{i=1}^{n} W_i = 1, p > 1 \tag{3c}$$

The IDW process in this study can be classified as a preprocessing step to fill in missing data gaps and increase the spatial resolution. The processed parameters include the depth and current components (u and v). After the empty values are filled in, the magnitude of the current velocity and direction of the current at each point are calculated as show in Table 1.

Table 1. Matrix format for parameters processed by IDW and example

Longitude (x)	Latitude (y)	Depth (m)	u	v	Magnitude ($\|v\|$)	direction (Θ)
102.7895	-4.4420	3.92746	5.4245	11.4339	12.6554	25.3939
101.7005	-3.3022	4.00431	-0.4001	-0.7638	0.8622	-152.4291

The idw process was conducted for each year from 2019 to 2023. A composite process must be carried out to determine the average of the 5-year data.

3 Result and Discussion

There are 2 (two) main results in the form of spatial information and graphs. Spatial information contained in the bathymetry chart, sea surface currents, and suitable value distribution. Graph as a result of data analysis to interpret the physical properties.

3.1 Depth Distribution

Most available bathymetric charts are processed from echo-sounder data using a digitizing and plotting procedure to produce digital data-sets [22]. Depth is an important factor for determining the optimal location for generator installation. If it is too shallow, it is affected by sedimentation, which can reduce the water capacity and damage the turbine [18] [19]. The depth distribution represents in seven districts and divided in 3 classes as shown in Table 2.

Table 2. Depth data 2019-2023

	Muko muko	**North Bkl**	**Central Bkl**	**Bkl City**	**Seluma**	**South Bkl**	**Kaur**
Minimum	1.76	1.31	3.65	3.33	3.34	0.13	0.32
Maximum	41.97	17.50	19.67	44.54	39.53	29.35	315.34
Mean	10.25	9.69	10.56	19.03	16.30	13.11	89.37

*Bkl: Bengkulu

This depth distribution provides information on the topographic conditions of a body of water. This information is directed at considerations of navigation safety and the protection of the power plant itself. The depth distribution and bathymetric chart are shown in Figure 1.

Figure 1. Depth Distribution

Shallow waters, especially near the coast, tend to have predictable ocean current patterns, making energy production more reliable. Shallow waters also allow the use of fixed bottom structures (turbines mounted directly on the seabed), which are simpler and more stable than floating systems. This can lead to more efficient energy extraction, as the velocity of the currents tends to be faster in shallow coastal areas. However, in areas with very shallow depths, the flow speed of the currents may be reduced, thereby limiting the energy extraction potential. In such locations, energy generation may be less efficient than in deeper water areas, where currents are faster.

3.2 Sea-surface Currents Distribution

Water currents initially involve at least two dimensions. A current measurement can be expressed as the direction of the current's movement or as its flow speed [20]. Sea surface current distribution is represented by the magnitude obtained from vector data.

Table 2. Sea-surface currents velocity (cm/s) for year 2019-2023

	2019	2020	2021	2022	2023	2019-2023
Minimum	1.00	1.89	0.65	1.28	0.60	0.60
Maximum	8.54	2.18	1.29	2.88	2.32	8.54
Mean	4.12	1.99	1.04	2.26	1.11	4.57

Sea surface currents distribution 5 years range from 1- 8.54 cm/s for 2019, 1.89 - 2.18 cm/s for 2020, 0.65 - 1.29 cm/s for 2021, 1.28 - 2.88 cm/s for 2022, and 0.60 - 2.32 cm/s for

2023. This means that from 2019-2023 to the current velocity range from 0.60 - 8.54 cm/s. Ocean currents are the culmulative of both local and distant influences, such as tides, winds, buoyancy fluxes, and various wave types; these forces have a significant impact on ocean currents [21] as shown on Figure 2.

Figure 2. Sea-surface Current Distribution

The power of the current is proportional to the cubed velocity and flux. Minimum values of ocean energy source for ORE (Ocean Renewable Energy) ideally have to reach a value of 0.5 m/s [10]. The higher the speed, the more valuable is the ocean current [24]. The faster the current is, the more energy that can be extracted. Ocean currents must sufficiently fast to be economically viable for power plants. However, in places where ocean currents are generally slow but constant, weak-current power plants can still be implemented. Weak current power plants can also be useful in remote coastal regions, islands, and off-grid communities, where other forms of energy generation may be too costly or impractical.

3.3 Determining the Suitable Site

Building mathematical models while considering the element of uncertainty in decision -making process can enhance the adequacy, thereby increasing the validity and factual efficacy of the conclusions drawn from their analysis [22]. When determining a suitable site, it is possible to identify two main situations requiring a multi-criteria approach using the fuzzy logic system [23]. A fuzzy inference system (FIS) implements a nonlinear mapping from an input space to an output space [15]. In this process, we must define the membership function applied to the current velocity and depth. Both variables were divided into 3 groups, as shown in Table 3.

Table 3. Data range and membership

Currents		Depth	
range (cm/s)	**class**	**range (m)**	**class**
3.08 –3.50	slow	0.13 - 5.0	shallow
3.50 –7.84	medium	5.0 - 20.0	medium
7.84 – 12.65	fast	20.0 - 315.35	deep

Currents variable range from 3.08 – 12.65 cm/s and depth range from 0.13 – 315.35 m. Membership for currents consists of 3 class that is slow, medium, and fast. The depth consists of shallow, medium, and deep layers. In this case, a suitable membership function is the trapezoidal function. The trapezoidal membership function formula for the current and depth variables is as follows:

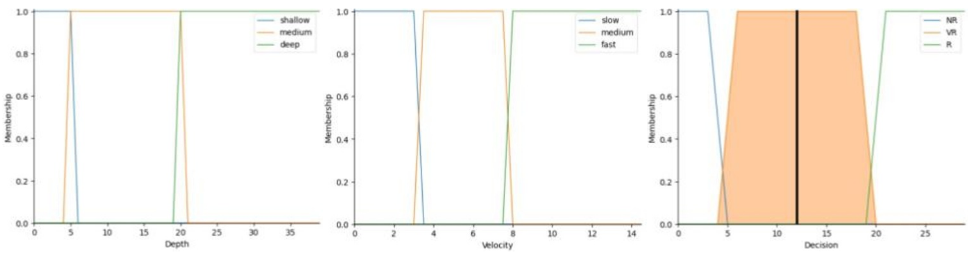
$$\mu \text{ membership } [\mathrm{x}, \mathrm{y}] = \begin{cases} 0; & 0; \\ \frac{x-0.308}{0.35-0.308}; & \frac{x-0.13}{5-0.308}; \\ 1; & 1; \\ \frac{0.784-x}{0.784-0.783}; & \frac{315.35-x}{315.35-19}; \end{cases}$$

A Trapezoidal is a type of membership function to describe values that fall within a certain range, with varying degrees of membership. In fuzzy inference systems, trapezoidal membership functions help evaluate how strongly an input value belongs to a particular fuzzy set, which is then used in rules to make decisions or predictions. After normalizing the available data of the case study and determining the linguistic variable, the next step is to contrive the rules that define the relationship between the input variables and output. The use of linguistic variables while formulating the ‘if-then’ rules to implement the knowledge base in the system [15]. The linguistic variable from the case study data consists of velocity members that should be associated with depth members and then combined with rule results to form a fuzzy output that represents the overall decision made by the fuzzy system. At this stage, fuzzy rules are applied to the fuzzified inputs, the degree of satisfaction of each rule is calculated, and the results are combined to create a final fuzzy output set as shown in Table 4.

Table 4. Relationship between velocity and depth variable with decision

Velocity\ Depth (input)	shallow	medium	deep	Decision/output
slow	NR	NR	NR	NR = Not Recommended R = Recommended VR = Very Recommended
medium	NR	R	R	
fast	NR	VR	R	

In defuzzification, fuzzy output is converted to a crisp value as the decision to generate a precise value from a fuzzy set. Figure 3 illustrates the relationship between the input and output applied to the graph of the trapezoidal function. The output is the decision of the site represented by a specific depth.



a) Depth membership b) Velocity c) Decision

Figure 3. Graph of membership function

The sea-surface current velocity is represented by the distribution of the average current speed, which is divided into three classes: slow, medium, and fast. Respectively 3.08 –3.50 cm/s, 3.5 - 7.84 cm/s, and 7.84 – 12.65 cm/s. The classes for sea depth are shallow, medium, and deep. Respectively is 0.13 - 5.0 m, 5.0 - 20 m, and 20 - 315.35 m. A suitable site can be estimated using the value of the defuzzification results obtained. At a depth of approximately 12 m.

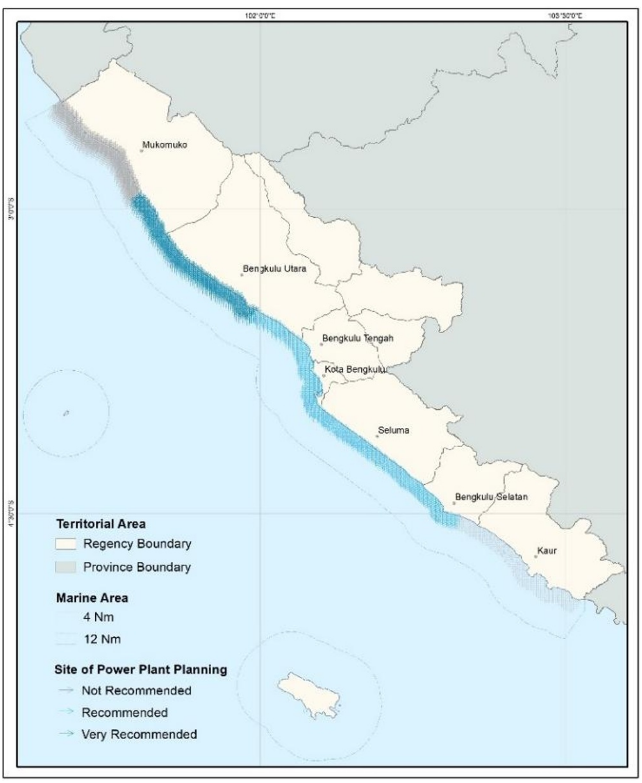


Figure 3. Site of Power-plant Planning

Mukomuko has the fastest velocity, but approximately 75% of the area classified as not recommended. It is considered that a strong current will affect the performance and increase the need for high maintenance for power-plant installation. However, this is approximately 25% of area that is recommended with approximately 75% of North Bengkulu Regency. Meanwhile, 25% of remaining area is classified as highly recommended along with Central Bengkulu, Bengkulu City, Seluma, and South Bengkulu Regency. Meanwhile, the Kaur Regency has the slowest velocity but a deeper slope than the others. Slow currents but large water masses can still produce sufficient energy to drive rotors and generate electricity, although the design and technology must be adapted to maximize efficiency under these conditions.

4 Discussion and Conclusion

The value of this ocean current distribution is the result of incoming and returning currents for one year. In coastal regions, incoming currents can be driven by ocean gyres (large circular ocean current systems), bringing water into the area. Returning currents can be driven by the Coriolis effect or tidal changes, where water returns to the open ocean. The resultant currents would describe the overall movement of the water within the coastal zone. Using this information, we can estimate the energy that can rotate the turbine through the mass of water that arrives and returns. The greater the speed of the ocean current, the greater the speed of the turbine to rotate and the greater the power obtained [24].

In shallow waters, currents tend to be more easily disrupted by the seafloor and may lose energy faster, especially near coastlines. Current energy plants are often deployed at depths ranging from a few meters to 50 m. Currently, the recommended depth for this case study is 5-20 m.

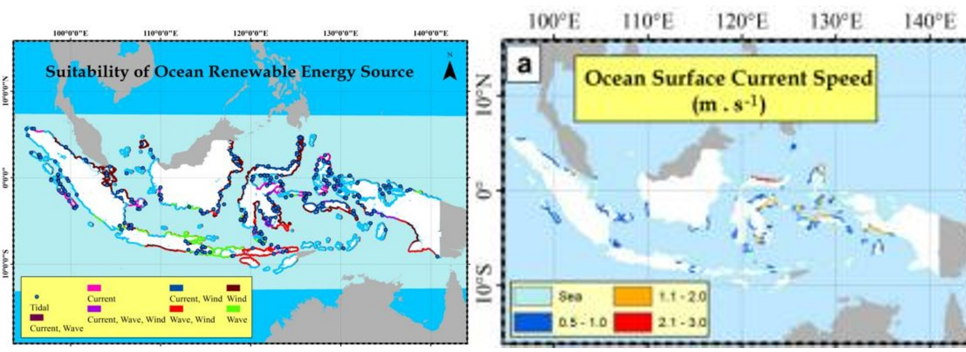


Figure 4. 1) Map of potential location of whole ORE sources, 2) Map of suitable location for current source [13]

The western part of Indonesia has only one location with a strong current in the range of 1.1 m/s until 2 m/s, and is located in the Malacca Strait [12] as shown in Figure 4. The Sea Surface Current (SSC) and waves had no significant value difference with the change in season. The average SSC for the whole of Indonesia is still below 0.5 m/s, but there is also a maximum value of up to 3.6 m/s in the west and second transition seasons. To verify the results study, we can compare with some expected data values or historical data from an established power plant. For example, computing using the MAE formula $= \frac{1}{n}\sum_{i=1}^{n}|\mathrm{y_i} - \hat{y}_i|$.

The distribution of value provides a sufficient illustration of the energy potential in the area but seems vague. This caused by the nature of the data, which have a low spatial resolution (big pixel: 4 km). This limitation has to make the dataset goes through interpolation process to fill in the data gaps and increase the spatial resolution.

It is recommended that in situ measurements be taken to calibrate and cross-validate satellite data. To be more rigid, it is necessary to collect field data by increasing spatial resolution. The steps are to add the number of data collection stations or collect data to cover the empty pixel areas. Future work will involve examining waves and tidal currents to compare the energy sources that can produce optimum power for prospective renewable electricity sources.

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