An assessment Indonesia's Ocean Thermal Energy Conversion (OTEC) as an electrical energy resource

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Abstract. The primary source of Indonesian electricity still has a dependence on the availability of fossil energy, which is limited in its presence and has non-renewable properties. It is necessary for alternative energy research as a renewable source of electrical power to replace energy sources that cannot be renewed. The one of energy is ocean thermal energy conversion, in which the technology is based on the thermal energy difference between surface temperatures and deepsea water to produce electricity. The research aimed to assess the power potential generated by utilizing the vertical sea temperature in some Indonesian waters. The survey method was used to collect secondary data from the HYbrid Coordinate Ocean Model. The process was completed with the conversion of OTEC to produce the electric base on the model applied by Rauchenstein. This model calculated the net power production of an OTEC plant as a function of water temperature and chilled water pipe length with the potential OTEC power generated for a closed cycle power plant of 100 MW / 150 MW gross power. The study found an average temperature difference of 20 °C at a depth of ≥500 m. Based on the seasonally mean, the highest potential of power was in the Papua of 174 MW during transitional season 2. The lowest value was assessed in Southeast Sulawesi of 82.09 MW in the southeast season. The highest electricity potential for annual average has been obtained in Papua with 168.33 MW and the lowest around 97.69 MW in North Sulawesi.

1. Introduction
Several studies and activities have been conducted that propose the potential for the utilization of ocean sustainable energy in Southeast Asia [1]. The utilization of marine resources aims to meet the needs and improve human welfare [2]. Marine resources such as tidal, wave, wind, and temperature can be empowered as renewable energy [2]. Sustainable energy is a source of energy derived from natural resources that continuously exist and can replace fossil energy that will gradually be extinct or depleted [3]. In case temperature refers to the study [2], ΔT between shallow and deep-sea tropical water stretches equitably constant over an area of 100 x10⁶ km². Indonesia, which has a vast sea with a striking temperature difference, has the opportunity to be converted as alternative energy.

The application for transforming thermal slope among surface and deep water is higher than 20 °C is known as ocean thermal energy conversion (OTEC) [2,4], and it can be used as a source of electrical energy [5]. Review in Kusuma [6], theoretically Indonesia has 4247.39 GW and practically is 41 GW an OTEC resource. OTEC is the method of altering sensible heat stored in the top of mixed layers of low and mid-latitude oceans into electricity, vaporizing the fitting liquid working in a Rankine cycle.
between warm surfaces and cold deep-water temperatures [3]. The source of cold water used in constricting liquid fittings is a mass of water carried through the thermohaline circulation, which flows from high latitude waters as deep flows towards the equator [3]. The difference in temperature of deep water with the surface forms a strong stratification because the mass of cold, salty water has a greater density than warm surface water [1, 7, 8]. The construction and deployment of OTEC systems at sea have yet to become economically competitive. Still, future energy markets and increased concerns about energy independence and environmental impacts may soon make the vast OTEC resources attractive [1, 2]. This research aimed to assess the power potential generated by utilizing the vertical sea temperature difference as an electrical resource in some Indonesian waters.

2. Materials and methods
The method used in this study is the survey method, in which the data has been retrieved from www.hycom.com. Daily temperature start from December 2016 to November 2017 with a spatial resolution of 1/12° across the water column [8]. We used those data because it is proven close to observational data [9, 10]. The research location is the Indonesian waters of Southeast Kalimantan, North Sulawesi, Morotai, Southeast Sulawesi, and Papua (Figure 1). Determining the research area was done by looking at bathymetry with a maximum depth of 1000 m [3].

![Figure 1. Map site of study.](image)

The temperature gradient was analyzed based on the difference value of temperature between layer 20 m and deep layer [3]. To calculate the potential of electrical resources, the OTEC generator assumption used in this study refers to the model applied by [3, 11]. This model calculates an OTEC plant's net power production as a water temperature function and chilled water pipe length. The potential OTEC power is generated for a closed cycle power plant of 100 MW / 150 MW great capacity. For this plant model, the OTEC net power production ($P_{\text{net}}$) is calculated using three components: gross power ($P_{\text{g}}$), based on the governing thermodynamic equations of a Rankine cycle; variable losses ($L_{\text{var}}$), associated with cold water pumping; and fixed losses ($L_{\text{fixed}}$), associated with all other pumping and transmission within the plant,
The formula for $P_G$ is modified from an equation given by Nihous [4] to accommodate propriety assumptions made by Lockheed Martin [12] ($P_G^{LM}$), and then simplified to a linear equation [11]:

$$P_G^{LM}(MW) = \frac{106.22 + 2 \Delta T^2}{T_s - 0.25 \Delta T + 273.15} \approx P_G (MW) = 13.89 \Delta T - 149.71$$

(2)

The value of $L_{\text{fixed}}$ is based on the model OTEC assumption using the property loss OTEC due to cold water intake, condenser and distribution pump, evaporator, and distribution of the pump, and the ammonia pump is calculated [3]. The derivation of each of these components is presented in [11], producing a total fixed loss:

$$L_{\text{fixed}}(MW) = 42.7$$

(3)

Variable loss, $L_{\text{var}}$ represents the sum:

$$L_{\text{var}}(MW) = L_{pf} + L_{sh}$$

(4)

$L_{pf}$, pipe friction losses and $L_{sh}$ define a static heat loss.

The loss of pipe friction is calculated based on pipe smoothness, pipe diameter, and water velocity. Static heat loss is calculated as a loss of pump power, static heat bias correction, and simplified static heat loss. Loss of pipe friction and static heat loss are respectively calculated as:

$$L_{pf} = \frac{hfmg}{\eta} = \frac{f(m \pi A)^2 mg}{2Dg\eta}z = 0.0038z$$

(5)

and

$$L_{sh} = \left( L_{pp} \times L_{ssh} \times C_{shb} \right)$$

(6)

Where $L_{pp}$ is a loss of pump power, $L_{ssh}$ is a simplified static heat loss, and correction of $C_{shb}$ static heat bias. These are calculated from:

$$L_{pp} = \frac{mgz}{\eta} = 4.488z$$

(7)

$$L_{ssh} = \frac{-0.00599 T_s^2 + 0.031 T_s + 1025}{-0.00599(T_s-\Delta T)^2 + 0.031(T_s-\Delta T) + 1025} - 1$$

(8)

$$C_{shb} = 5.234 \times 10^{-10} z^3 - 1.378 \times 10^{-6} z^2 + 1.313 \times 10^{-3} z - 0.6541$$

(9)

Equation (1) until (9) above are used in each study location to predict the power potential value. Average electric power production from December 2016 to November 2017, $P_N$, was assessed at each point of latitude/longitude for all depths evaluated until it found the depth of cold water at each location producing maximum power.

3. Results and discussion

3.1. Seasonal temperature difference

The seasonal difference in surface and depth temperature of the assessed region, $\Delta T$, is listed in Table 1. In general, $\Delta T$ values above 20 °C were found in East Kalimantan for all stations and seasons. The highest seasonal value of $\Delta T$ is obtained at stations 1 and 2 with the same amount of 23.42 °C in transition season 2, in the deepest cold-water isobath of 900 m and 800 m, respectively. The lowest value in the northwest monsoon is 22.54 °C at 800 m isobath at station 2. In station 3, $\Delta T$ below 23 °C has been found only during the northwest season.

The value of $\Delta T$ less than 20 °C has been found consistently for all seasons in station 1 for North Sulawesi, the maximum depth of cold water at 400 m. The lowest $\Delta T$ value is at station 1 in the northwest
monsoon, while the highest is in the southeast monsoon at station three, about 20.84 °C with the deepest isobath of cold water 500 m. The ΔT under 20 °C was found only at station 3 in transitional season 1 in Morotai. This value is located in the deepest 700 m isobath of cold water. At the deepest 500 m cold water isobath, ΔT is measured more than 20 °C for stations 1 and 2 in all seasons, while the highest value is 22.64 °C at station 2 in transition season 1. In the Southeast Sulawesi area, the lowest ΔT of all stations was found at station 3 in the southeast monsoon, 18.95 °C. This value is the lowest value of all the regions that were the location of this study. The highest ΔT was measured at 24.17 °C at station 1 in the northwest monsoon. The huge ΔT of more than 24 °C had counted in uniform isobath 1000 m on Papua for all seasons. These values represent the most significant value of the entire study area. The highest values are in transitional season 2 and lowest in the northwest monsoon, and higher in the southeast than in transitional season 1.

3.2. Seasonal power
Seasonal electrical power production is evaluated at each latitude/longitude location. Temperature differences in Table 1 were involved in equations 1 to 9 To create a power assessment. The seasonal values of $P_{N}$ East Kalimantan is more than 100 MW (Figure 2.1, right), indicates that all stations have potential as a source of electrical energy. The high power of about 147 MW was assessed in both transition seasons. The value of $P_{N}$ more than 140 MW is steadily found in station 1 for all seasons, which has a distance of 16 km from the coastline (Table 1). The net power of stations 1 and 2 tend to unstable in all seasons despite the fact that the distance was about 10 km from the land. The lowest electrical power was generated in station two during the Northwest season of 133 MW. Compared to the calculation results which were done in the north of Makassar Strait [10], our results were higher due to differences in the basic assumptions of net $P_{N}$ calculations.

The highest OTEC power of North Sulawesi was produced in station 3 with a value of about 108 MW during the southeast season (Figure 2.2, right). According to ΔT in Table 1, station 1 was insufficient as an energy source due to the temperature gradient between warm water at 20 m and cold-water isobath (400m) less than 20 °C. More than 100 MW as high power was accounted for in station two on southeast and transition season 2.

The power generated in Morotai exceeds 100 MW except station 3 in transition season 1 (95 MW) (Figure 2.3, right). The net power production in this station for all seasons was lower than the other stations. Station 1 is the only station whose energy production tends to increase with the changing seasons, was reached the highest in transition season 2. During transition season 2, station 1 and 2 were produced a net $P_{N}$ of 135.03 and 135.22 MW, respectively. These values were represented the high category of all the power produced at Morotai. Station 2 can be considered the most potential source of electrical energy than stations 1 and 2 because the production tends to be high and a short distance from the nearest coastline.

Overall, station 1 in Southeast Sulawesi has the most potential to be used as a source of electrical energy (Figure 2.4, right). Its net production is the highest compared to other stations for all seasons, even the nearest coastline shortest (Table 1). Station 2 has occupied the second position as a source of electrical energy, although it is still further away than station 1, but its $P_{N}$ production is stable above 100 MW for all seasons. The most significant electrical power has been generated in station one throughout the northwest season, which values about 159 MW. Meanwhile, in the same season, station two only achieved the highest net production of around 138 MW. Station 3 has been noted as the station that produces the lowest electrical energy compared to the previous two stations. The highest value is around 105 MW, and the lowest is about 82 MW.
Figure 2. Location of station (left) and net electrical power (right). Area of East Kalimantan (2.1); North Sulawesi (2.2), Morotai (2.3), Southeast Sulawesi (2.4), and Papua (2.5).
The power generated in each station’s Papua waters and season exceeds 100 MW (Figure 2.5, right). The seasonally maximum values of $P_N$ of station one until 3 in transition season 2 are 173.86, 174.18, 174.85 MW, respectively. Although all stations have high electrical power if the distance is considered, station 3 is a more advisable location. The length is only 4 km from the Papua mainland, which is regarded as a short distance compared to other stations. The potential electrical energy at all stations is closely related to $\Delta T$ between the temperature at a depth of 20 m and the deep layer of 1000 m, which reaches more than 24 °C. The temperature gradient is significantly affecting the power produced, which was in line with Nihous [2], which is every increment of 1 °c difference between the warm and cold-water resources used. This power can be extracted increases by about 15%. The electric energy production pattern at all stations showed an increasing trend from the northwest season to the second transition. The values have great potential to be developed as a source of electrical energy.

3.3. Mean annual power

The annual electrical power generated within one year for each station can be seen from the seasonal average. The mean yearly variations of each station's net power output for all locations were pronounced in Figure 3a. At the same time, the mean annual for each area is shown in Figure 3b. The point of annual $P_N$ was found uniformly in East Kalimantan (Figure 3b), particularly in station 3. Simultaneously, the electrical power in stations 3 and 2 was lower than station 1, which has a mean value of 142.41 MW (Figure 3a). Contrary to East Kalimantan, the North Sulawesi has the most insufficient electrical power (88.68 MW) compared to all locations for all stations. However, the deviation is small in contrast to Southeast Sulawesi and Papua.

The highest annual net power in North Sulawesi was counted in station 3 of around 103.21 MW (Figure 3a). As seen in Figure 3b, Morotai can be developed as an OTEC based on its annual average for all seasons, which is about 120.53 MW. The $P_N$ of stations 1 and 2, almost equivalent are 128.44, 127.91 MW, serially. Highly divergence in electrical power between stations was seen in Southeast Sulawesi, where the highest value is around 145.85 at station one and the lowest at station 3, approximately 96.87 MW.

Like Morotai, mean energy along the year in Southeast Sulawesi is almost in the same range of 122.20 MW, although the annual fluctuation is still higher (Figure 3b). Sharply variation on each station of Southeast Sulawesi (Figure 3a) be the trigger of high disparity of annual $P_N$. Throughout the year, Papua’s electrical power has variation but has the highest electrical power for all stations compared to other locations. The maximum net $P_N$ was noted of 168.33 MW.
The study considers Papua as the first recommended location based on the amount of energy that has been calculated, especially in station three, since the shortest distance to the coastline. A consistent amount of energy in Papua over 100 MW available frequently throughout the year is necessary to ensure a sustainable supply.

4. Conclusion
Data on the temperature difference between the depth of 20 m and the deep layer generated by HYCOM were used to calculate the power generated with a nominal minimum of 100 MW (net), one progressive step to explore the great potential of renewable energy in Indonesian waters. We have calculated that to obtain $\Delta T$ that meets the minimum production value, OTEC is excellent when developed in a region with a depth of water 500-1000 m. The assessment of the one-year average electricity production from the five selected locations as a source of electrical energy can be sorted from the largest, namely Papua, East Kalimantan, Southeast Sulawesi, Morotai, and North Sulawesi, which are 168.33, 142.41, 122.20, 120, 53, and 97.69 MW, separately. Each selected location's resources fluctuate seasonally, with the potential for maximum net power production being the highest in transitional season 2 in Papua. We recommend that even if a location's potential is the most significant, uncompetitive distances will reduce its feasibility.
Table 1. Temperature differences (ΔT °C).

| Region          | Station | Distance from the nearest shoreline (km) | End Depth | Temperature differences (ΔT °C) |
|-----------------|---------|------------------------------------------|-----------|---------------------------------|
|                 | Num.    | Longitude | Latitude | | Northwest Season | Transition season 1 | Southeast season | Transition season 2 |
| East Kalimantan | 1       | 118.00    | -0.64    | 16 | 900  | 23.10 | 23.40 | 23.33 | 23.42 |
|                 | 2       | 118.00    | -0.56    | 10 | 800  | 22.54 | 22.78 | 22.70 | 23.42 |
|                 | 3       | 118.00    | -0.48    | 10 | 900  | 22.97 | 23.24 | 23.07 | 23.19 |
| North Sulawesi  | 1       | 123.28    | 1.04     | 17 | 400  | 19.13 | 19.28 | 19.67 | 19.61 |
|                 | 2       | 123.35    | 1.04     | 14 | 500  | 19.97 | 20.13 | 20.59 | 20.65 |
|                 | 3       | 123.44    | 1.04     | 16 | 500  | 20.04 | 20.26 | 20.84 | 20.75 |
| Morotai         | 1       | 128.40    | 2.64     | 14 | 500  | 22.03 | 22.06 | 22.08 | 22.63 |
|                 | 2       | 128.32    | 2.56     | 7  | 700  | 21.96 | 22.03 | 22.03 | 22.64 |
|                 | 3       | 128.24    | 2.48     | 15 | 700  | 20.50 | 19.93 | 20.78 | 21.26 |
| Southeast Sulawesi | 1    | 123.12    | -3.36    | 5  | 500  | 24.17 | 23.97 | 22.38 | 22.88 |
|                 | 2       | 123.12    | -3.44    | 14 | 700  | 22.88 | 22.65 | 20.79 | 21.26 |
|                 | 3       | 123.12    | -3.52    | 22 | 1000 | 20.70 | 20.58 | 18.95 | 19.91 |
| Papua           | 1       | 132.48    | 3.44     | 24 | 1000 | 24.06 | 24.60 | 24.99 | 25.01 |
|                 | 2       | 132.56    | 3.36     | 11 | 1000 | 24.06 | 24.63 | 25.01 | 25.03 |
|                 | 3       | 132.64    | 3.28     | 4  | 1000 | 24.07 | 24.63 | 25.03 | 25.07 |
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