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Suitable Locations of Ocean Renewable Energy (ORE) in Indonesia Region – GIS Approached

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Abstract

The purpose of this research is to find areas that are potential to produce energy from ocean with different level. Approach used was by looking at the current technological capabilities and characteristics of the currents, winds, waves, and tides. This research developed four dynamic oceanographic, combining with technologies use Geographic Information System (GIS) approach. The results elucidated that for the larger currents in eastern Indonesia with velocity up to 3 $m \cdot s^{-1}$. For the wind was in the south of Java, Papua, and West Sumatra. Tidal range that can be utilized in the area of Nusa Tenggara Timur, northern Sumatra and Papua had a height up to four meters. Waves were in the area directly facing the ocean, especially in the south of Java with a range of 1.4 m to 2.4 m. These results elucidated that Ocean Renewable Energy (ORE) in Indonesia can develop for one up to four farming in one place.

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Keywords: Blueprint; Indonesian seas; mapping; ocean renewable energy; suitable locations

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Nomenclature

GIS	computer system that provides spatial data entry, management, retrieval, analysis, visualization functions and present all types of geographical data
NOAA	federal agency of America which focused on the condition of the environment from the sun to the depths of the ocean floor
NTB	one of province in Indonesia which comprises the western portion of the Lesser Sunda Islands, with the exception of Bali
NTT	one of province in Indonesia which located in the eastern part of Lesser Sunda Islands and included West Timor
ORE	abbreviation of Ocean Renewable Energy
mile	$1 \text{ mi} = 1.6093440 \times 10^3 \text{ m}$

1. Introduction

Energy plays an important role in achieving social, economic, and environment for sustainable development as well as a support for the national economy. Energy use in Indonesia has increased considerably in line with economic growth and population growth [1]. However, this increasing demand has not been accompanied by increasing production, as Indonesia has limited proven reserve of oil and gas. A solution of this discrepancy must be sought. Renewable energy has the potential to add Indonesia energy supply. One of the biggest trends in the world now is using the ocean as renewable energy resources (ORE). The choice of using ocean as the renewable energy resources is dictated by the fact that exploiting land renewable energy resources often resulting in conflicts over land use [2].

Ocean covers seventy percent of the Indonesia archipelago and represents an enormous amount of energy in the form of wave, wind, tidal, ocean current and thermal resources [3]. Some paper showed that wind and currents can support energy to lighthouse [4] and give potential energy from small to big scale [5]. From the utilization will depend on the technology and local characteristic of potential areas. Some of The challenges are often found in the operating principles, the status, and the efficiency and cost of generating energy associated with each technology [6]. But, now the national capacity explored ocean energy and developed the suitable technology have been enhanced significantly [7]. Indonesia has a target to utilize the wind energy at 125 MW installed capacity on grid, 10 x 1000 MW of ocean currents, 5 MW on grid of wave. As a comparison in Europe, ocean energy is planned to represent 0.15 % of electricity consumption and wind expected to produce 495 TWh or about 14 % of total electricity consumption in 2020 [8].

2. Material and method

2.1. Data collections

The data was collected from some sources, such as National Oceanic and Atmospheric Administration (NOAA) Coastwatch which provided weekly ocean surface geostrophic current and wind speed data, NOAA Wavewatch III (NWW3) with hourly modelled-result wave height data, and Tide Model Driver (TMD) which predicted tidal range for each station (45 stations in total). The three years-data was used for each parameter to get the pattern and more reliable mean value with standard deviation as well. Data was filtered at first to remove the unreliable values based on common ocean condition in Indonesia water. Mean value and standard deviation divided into monthly and seasonally basis to see the pattern of time series data.

2.2. Mapping analysis

Mapping ocean energy potential was analyzed by using GIS approach. The mapping area was along the coast of Indonesia at a distance as far as 12 miles out to the sea as it was the management area of regency. The mean value from each parameter was calculated from three years data, then mapped and combined it all to get the overlaid-map of potential ocean energy. Each parameter of ocean energy sources has its own minimum value in order to be categorized as a potential area. The minimum value of each parameter was based on recent technology on energy harvesting which have been conducted on ocean energy production. Table. 1 shows the minimum value for each parameter of ocean energy sources used to categorize the potential area.

Table 1. Minimum values of ocean energy source for ORE suitability categories

Ocean energy source	Minimum value	Data source
Current speed	$0.5\ m \cdot s^{-1}$	Yuningsih et al. [9]
Wind speed	$4.0\ m \cdot s^{-1}$	Khaligh and Onar [10]
Wave height	1.6 m	Cruz [11]
Tidal range	2.0 m	Charlier and Finkl [12]

2.3. Converted energy estimation

Estimation on the amount of energy power was using some equations which have been used commonly in energy conversion. The estimation used for each ocean renewable energy sources were different. Each source has different variables in order to get the energy power. Besides that, the generator or turbine used for each source was also different. Firstly, the ocean surface current was converted by using the Fraenkel Equation and based on T-Files Turbine characteristics [9]:

$$P = \tfrac{1}{2} \times \rho \times v^3 \times \eta \tag{1}$$

where:
P = the power of the ocean current in Watt
ρ = the density of water, in $kg \cdot m^{-3}$ ($1\ 025\ kg \cdot m^{-3}$)
v = speed (velocity), in $m \cdot s^{-1}$
A = plane broad of turbine = turbine height x turbine diameter = $1.2\ m^2$
η = generator coefficient (%) = 79.07 %

Secondly, wind is one of ocean renewable energy which popular nowadays because of it has been used in several countries and has a good result. Wind energy has the kinetic power and it depends on some parameters like the blade length and air density. The energy power estimation of the ocean surface wind expressed with the formula [10]:

$$P = \frac{1}{2} \times \rho \times R^2 \times \pi \times v^3 \tag{2}$$

where:
P = the power of the wind in Watt
ρ = the density of air, in $kg \cdot m^{-3}$
R = blade length (m), based on Enercon E-33
v = wind speed (velocity), in $m \cdot s^{-2}$

The third was the wave energy power which carried both kinetic and gravitational potential energy. The total energy of a wave depends roughly on two factors, which are height (*H*) and its period (*T*). In this case, the period was defined as 5 s because it was the average wave period in Indonesian Seas. The equation was came from the general equation of wavetrain energy, $E=\rho g H^2$, where ρ is the density of the water and *H* the root mean square wave height ($H^2 = a^2/2$). More crucially for the present purposes, the oscillations move energy in the direction of the wavetrain and this energy flux, i.e. power per unit width, is *E* multiplied by the group velocity *U*/2, resulting at [11]:

$$E(kW/m^2) = c \times H^2 \times T \tag{3}$$

where:
c = constant given by $\rho g^2/4\pi$ ($\cong$ 7.87 kW · m^{-3}· s^{-1})
H = wave height (m)
T = wave period (s) = 5

The fourth was the tidal energy which can be estimated approximately by the formula [12]:

$$E(kW) = A'mgI\int_0^H h\frac{dh}{T} = \frac{\frac{1}{2}(103\times10^3)H^2(A\times10^6)}{60\times60\times62} = 225AH \quad (4)$$

where:
A = basin surface area in km^2
A' = basin surface area in m^2
g = gravity acceleration (m^2 · s^{-1})
H = tidal range (m), head (m)
m = mass of seawater

3. Results and discussion

3.1. Ocean energy sources

Ocean currents, wind, wave, and tide are among common energy sources from the ocean. Each of those energy sources has a different energy production pattern, in Indonesia as well as in other places. This belongs to force that generate the water bulk. Ocean surface current has minimum speed to generate substantial electricity which is about 0.5 m · s^{-1}. In the Fig. 1a, it is shown that there are still many locations which are suitable to harvest ocean surface current energy in Indonesia. Current speed could reach as high as 3 m · s^{-1} in North Sulawesi and it may vary in range of 0.5 m · s^{-1} to 2 m · s^{-1} to the west of Sulawesi Island like Moluccas, West Papua, Ternate, and Seram Island. The comparison on two sides of Indonesia (eastern and western side) has a significant result, namely in that eastern part of Indonesia has a stronger current speed than the western part.

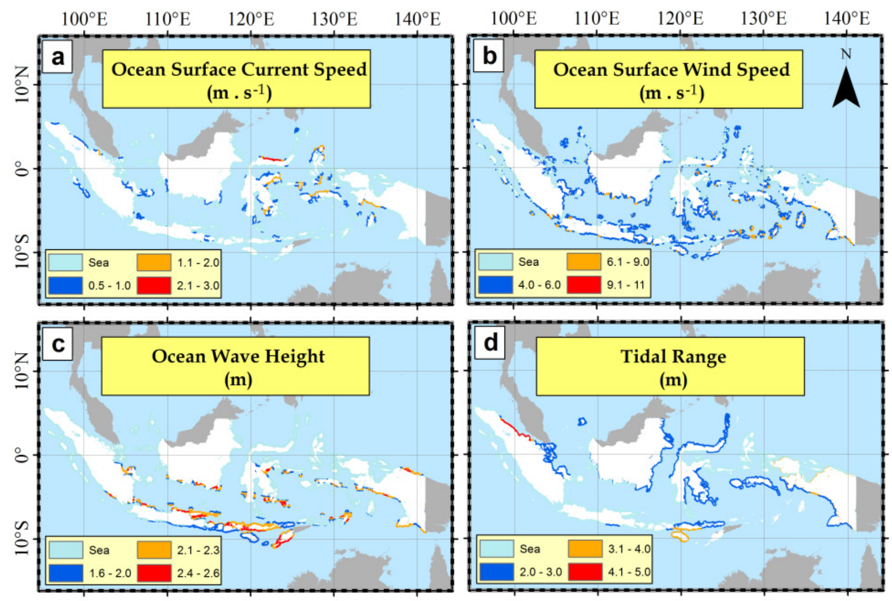

Fig. 1. Map of suitable location for each ORE source.
(a) ocean surface current, (b) ocean surface wind, (c) ocean surface wave height, and (d) tidal

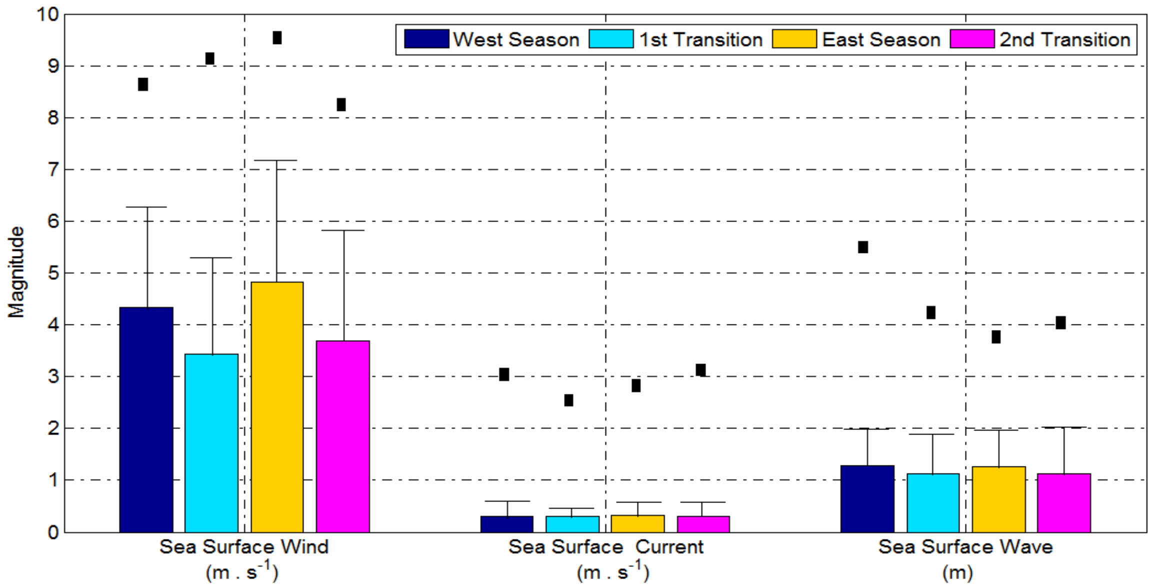

Fig. 2. Seasonal pattern of wind, currents, and waves magnitudes at overall in Indonesia

The western part of Indonesia has only one location which had strong current in a range of 1.1 $m \cdot s^{-1}$ until 2 $m \cdot s^{-1}$ and it is located in Malacca Strait. Other locations are like Bangka and Belitung Island, Seribu Island, Mentawai Island, East Kalimantan, and also Aceh. The domination of eastern part to produce greater ocean current's speed may be resulted by the Indonesian Through Flow (ITF) passage which is also influencing water movement in the surface, as there is also exist a water masses mixing around the ITF passage.

The second ocean energy resource examined in this study is wind. Strong wind speeds (4.0 $m \cdot s^{-1}$ to 6.0 $m \cdot s^{-1}$) are known to exist in almost every location in Indonesia. This potential is very strong if compared with wind potential in the land based on ESDM data (2.2 $m \cdot s^{-1}$ to 6.4 $m \cdot s^{-1}$). Fig. 1c shows the blue colour (denoting strong wind speed) dominantly spread throughout Indonesia starting from Sabang (Aceh) to Merauke (Papua). But, there is a significant dominancy in the spreading pattern which is more suitable location for developing ocean surface wind in the region below Equatorial line than in the region above Equatorial line. The other colour, orange and red, represent stronger speed of ocean surface wind which can be found in West Java, South Kalimantan, Flores, Papua, and Moluccas. The wind speed could reach 9.0 $m \cdot s^{-1}$ to 11 $m \cdot s^{-1}$. In view of the newest wind farming technology, which requires wind speed as low as 3 $m \cdot s^{-1}$ to start generating electricity, this high wind speed represent great potential source of energy.

Ocean surface wave is the third ocean energy resource examined. To generate power significantly, ocean surface wave must have a minimum height about 1.6 m. The result of this research shows the location of sufficient wave height in Indonesia. All of locations which have sufficient wave height are located below the Equatorial line. As the wind generates the surface wave, so the result is related with the previous result, as in Fig. 1d shows the wave height range about 1.6 m to 2.6 m. Those mean values along the year could generate enough power in some locations like Java Island, Bali, Lombok, NTB, until Flores and Papua.

The fourth ocean energy source which could be utilize as renewable energy is tidal. The minimum value of tidal range is 2.0 m and the higher range, the higher power generated. Fig. 1b shows that eastern part of Indonesia is having higher tidal range than the western part. The commonly found tidal range is below 2.0 m in the western part of Indonesia, such as in Java Island and West Sumatera. The tidal type generally belongs to semidiurnal type, therefore the tidal range is not high. But, the eastern part of Indonesia has the diurnal type tidal and it is common to find the tidal range above 2.0 m, and even 4.0 m. However, there is one location in western side of Indonesia which has the highest mean tidal range in the country (up to 5 m), located in North Sumatera (Medan).

The time series data also calculated to produce mean values for each season in order to see the pattern of each parameter along the year. Fig. 2 shows that the Sea Surface Wind (SSW) has the highest mean value in the east season ($4.7\ m \cdot s^{-1} \pm 2.5\ m \cdot s^{-1}$) and then followed by the west season ($4.3\ m \cdot s^{-1} \pm 2.0\ m \cdot s^{-1}$). In the east season, wind speed could be up to 9.5 m/s. Second highest maximum wind speed is $9.2\ m \cdot s^{-1}$ in the first transition season or along March-May. Wind speed data in Indonesia is a proof that there is a wind speed change along the season. Meanwhile, the Sea Surface Current (SSC) and Waves had no significant value difference along the season's change. The SSC average for whole Indonesia is still below $0.5\ m \cdot s^{-1}$, but there is also maximum value of up to $3.6\ m \cdot s^{-1}$ in the west season and second transition season. It is likely only occur in the eastern part of Indonesia as already discussed. The similar pattern found in the value of surface wave which had no significant difference between the seasons. The mean value is at 1.3 m ± 1.2 m which also has the maximum value of up to 5.5 m in the west season.

Generally from three sources of ocean energy found high magnitude of each parameter in the west season and east season. It is also on the tidal range, it could not be any differences between the seasons because they are changed to the lunar and solar condition not to the season or monsoon. So, another graph shows in the Fig. 3 about tidal range in some regions which has been divided into six regions. 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 and then followed by Java and Bali. Other eastern region like East Kalimantan, Sulawesi, and West Papua has sufficient value for renewable energy development. There are rarely found any high value of tidal range in area of equatorial line. This may related to the moon elevation as the moon orbiting in the Equatorial line. Astronomical factor is affecting tidal range, so there is the difference value between area in the Equatorial line and the area above or below them.

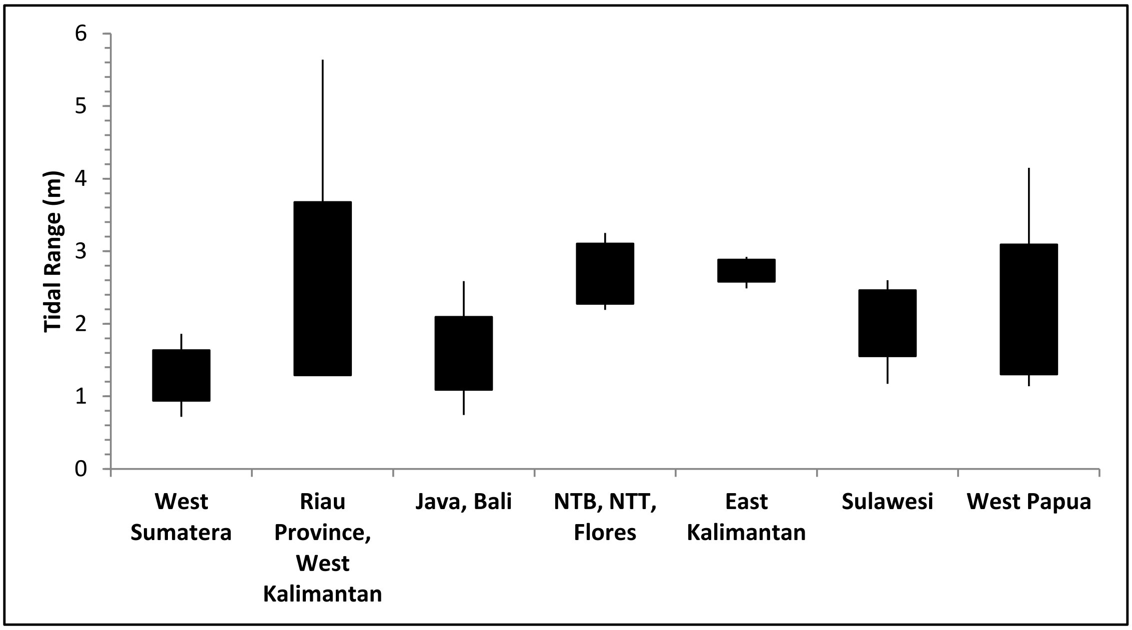

Fig. 3. Tidal range Standard Deviation (black box) and minimum maximum values (black line) in different areas

3.2. Mapping of suitability on combined sources of ocean energy

Some regions in Indonesia have potential to develop several ocean energy sources at the same time and places. In Fig. 4 almost every parts of Indonesia has its own ocean energy development suitability. In the western part of Indonesia, Mentawai Island has its potential to develop ocean current and tidal energy. This is similar to Aceh and Bangka Island. In other area, such as the Riau province, there is a suitable condition to develop wind and tidal energy. In the West Java, it is suitable for wave, wind, and tidal energy utilization. The eastern part of Indonesia has more various areas with its own suitable characteristics to develop ocean renewable energy. The space between one area to another one is not great. One island could have some different area to develop different kind on ocean energy sources like in Sulawesi and Moluccas. In Bali and Lombok there are suitable characteristics to develop wave, tidal, and current energy. While in Flores and NTT is suitable for wave and wind energy.

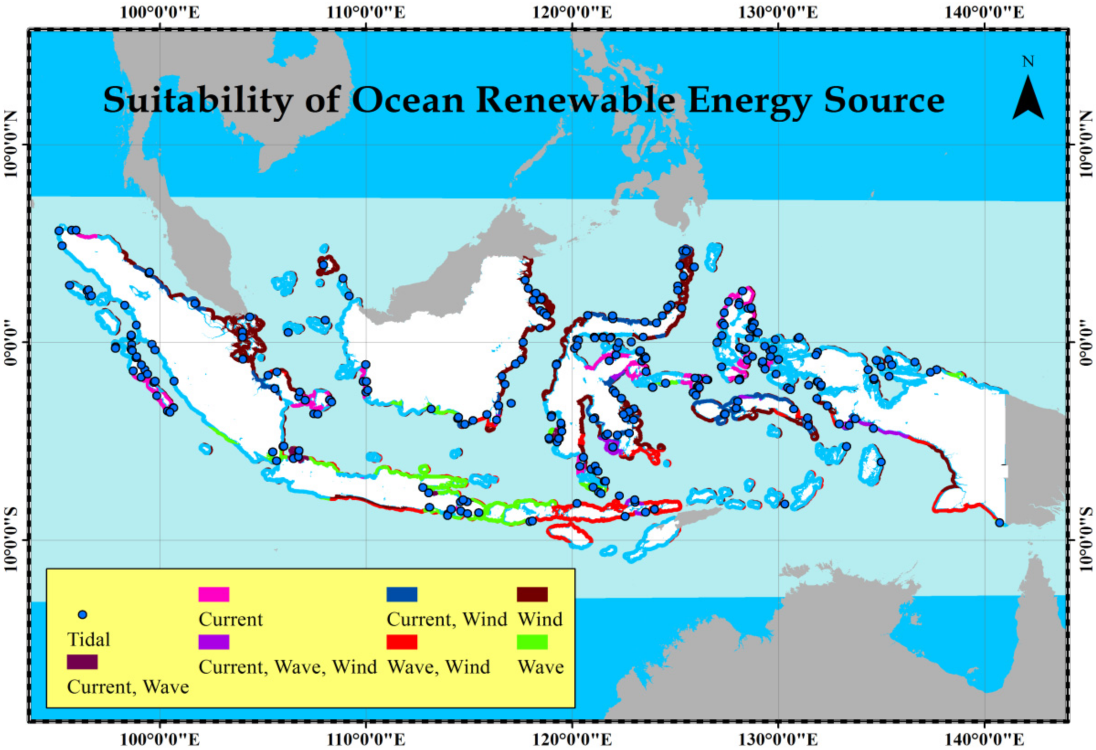

Fig. 4. Map of potential locations of whole ORE sources

3.3. Energy power estimation

Estimated energy powers from each ORE source were nearly the same. As shown in Fig. 5 there is a scattterhist graph indicating higher magnitude of ORE sources resulted higher energy power as mentioned by other research [9,10]. The difference was from the percentage of suitable points to generate enough power. In Fig. 5a, it shows that ocean current energy mostly generated (0.004-7 000) Watt because of the dominant current speed was below $0.5\ m \cdot s^{-1}$. The results were different to wind and wave energy power as shown in Fig. 5c and 5d which dominantly generated higher energy power up to 0.1 MW (wind) and 0.05 MW (wave). Tidal energy power also had different result which indicated stable power values. In Fig. 5b, it shows that tidal range in Indonesia is mostly about 2 m which is minimum value to generate enough energy power about 1.0 MW.

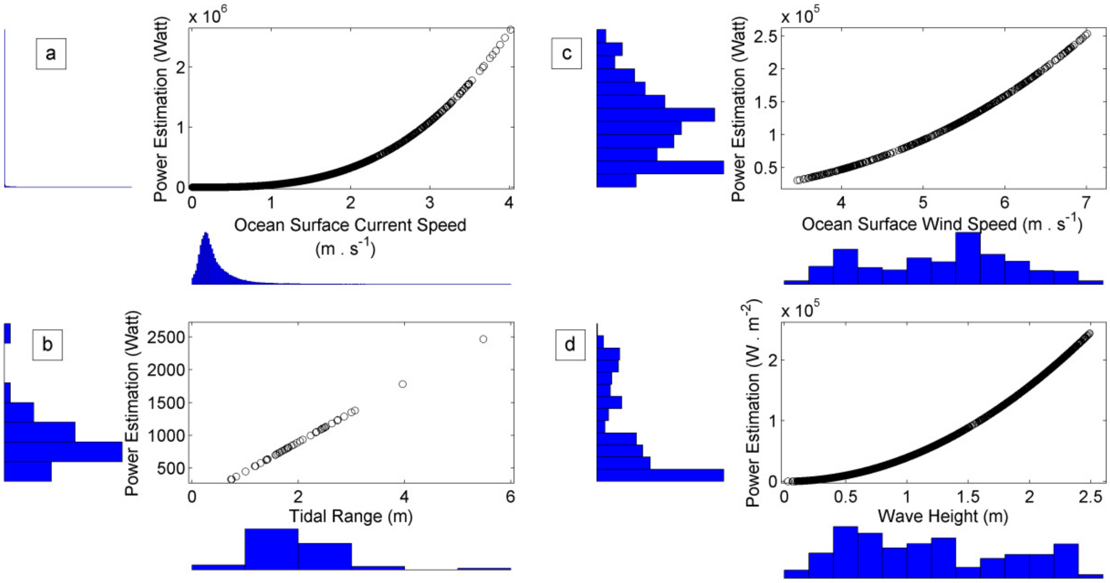

Fig. 5. Scatterhist graph of power estimation from each ORE source.
a) ocean surface current, b) tidal range, c) ocean surface wind, and d) wave height

The energy power which estimated was in some results showed high disparity between the minimum and maximum value. The disparity which shown in Table. 2 were clearly on energy power from current, wind, and wave. Refer to that situations, it shows that there are high different magnitudes to each ORE source in each region in Indonesia. Ergo, the potential region which has the maximum energy power was specified to some areas.

Table 2. Minimum, maximum, and mean values of energy power with its highest potential regions in Indonesia

ORE sources	Energy power			Highest potential regions
	Min	Max	Mean	
Ocean surface current	0.0041 W	2.6256 MW	7.1687 kW	North of North Sulawesi, Moluccas, South Sulawesi, Bali Strait, West Sumatera, Malacca Strait, Halmahera, Mindanao, Timor Strait.
Ocean surface wind	3.0427 W	0.2535 MW	11 kW	South of West Java, Arafura Sea, NTT, South of South Kalimantan, South of South Sulawesi.
Ocean surface wave	32.8655 W · m^{-2}	0.2440 MW/m^2	72 kW/m^2	Bali, Lombok, NTB, NTT, South of South Sulawesi, South of West Papua, North of East Java.
Tidal	0.33 MW	2.46 MW	0.89 MW	Medan (North Sumatera), NTB, NTT, Riau Province, West Kalimantan, North Sulawesi, Moluccas, West Papua.

Ocean surface current had the highest maximum value which up to 2.62 MW, but had the lowest minimum value either. Mean value of energy power was far from the maximum. But, there are best region to generate high energy power from ocean current like North and South Sulawesi, Moluccas, Bali and Malacca Strait which were dominantly located in the eastern part of Indonesia. Ocean surface wind energy power was not significantly high, but had enough power up to 0.25 MW. The best regions for wind are also dominantly in the eastern part of Indonesia like Arafura, NTT, and South Sulawesi. Ocean surface wave generated energy power per meter square up to 0.24 MW and the minimum value was 32.86 W. Tidal which mostly have higher tidal range in higher and lower latitudes had the highest mean energy power. The mean value was 0.89 MW and the minimum was not far from that, it was 0.33 MW. The four sources of ORE had the potential to help fulfilling energy needs and also could reduce the global climate threat which caused by fossil fuel energy [13].

4. Conclusion

Analysis of the four ocean characteristic parameters concluded that some locations may be a valuable source of renewable energy. This energy can be combined together or just one parameter in one place. Recommended location is in eastern Indonesia where oceanographic characteristics are very supportive. The challenge in this study suggests that further study is to promote the development of energy harvesting technology by combining farming the three to four potential energy

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