EPI International Journal of Engineering
Volume 8, Number 1, February 2025, pp. 26-33
DOI: 10.25042/epi-ije.022025.04

pISSN 2615-5109
eISSN 2621-0541

Preliminary Design and Energy Production of a Mobile Floating Structure (MFS) for Offshore Wind Turbines in Indonesian Waters

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Abstract

The Mobile Floating Structure (MFS) is an innovative floating wind turbine concept that utilizes a catamaran hull design to enhance mobility and operational efficiency. Unlike stationary platforms, the MFS can relocate to areas with higher wind energy density, making it a promising solution for optimizing wind energy harvesting in offshore environments. This study focuses on the preliminary design and energy production of the MFS. Maxsurf is used to analyze hydrostatics and assess the hydrodynamic performance of the MFS hull after the dimension of the MFS is determine with key considerations including rotor diameter and the weight of the wind turbine. Furthermore, four wind turbines are installed in the MFS. Those aspect were integrated into the design process to ensure realistic operational adaptability. As result. the resulting dimensions of the MFS were determined utilizing Maxsurf. Moreover, different with the previous study that use satellite data, the present study employs reanalysis data to estimate the energy density and power production of MFS. the energy density map is also produced in the present study to determine the monthly location of the MFS. The energy production of the MFS with four turbines has been calculated, and the energy production map is also drawn. Finally, the energy production of the MFS in the chosen location has also been estimated. The energy production map can be utilized to develop MFS in other location.

Keywords: Floating wind turbine; MFS; platform design; energy production

1. Introduction

The global demand for sustainable energy solutions has driven significant advancements in renewable energy technologies, with wind energy emerging as a key contributor. Floating wind turbine platforms, particularly in offshore locations, offer a promising solution to harness wind energy more effectively [1]. Mobile Floating Structure (MFS) stands out as an innovative approach, leveraging the twin-hull or catamaran design for enhanced mobility and operational efficiency [2]. Unlike fixed or location-specific platforms, the MFS can relocate to areas with higher wind energy density, making it a versatile and effective option for energy harvesting [3].

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Mobile Floating Structure (MFS) is a concept for a floating wind turbine that adopts the catamaran hull design. Its primary advantage lies in its ability to relocate to areas with higher wind energy density, thereby enhancing the effectiveness and optimization of wind energy harvesting. Previous studies have analyzed the potential for wind energy in several Indonesian waters, identifying ideal locations for MFS installations, such as the Java Sea near Sulawesi Island, where optimal wind conditions are observed during January and February [4], [5].

While wind energy conversion systems have been extensively explored in prior research—including land-based systems [6], and sea-based systems [7], [8], many existing prototypes remain confined to specific locations. This limitation can lead to efficiency losses due to seasonal variations in wind speed and distribution. The MFS addresses this issue through its mobility, which allows it to access areas with consistently higher wind energy density. A similar approach has been implemented in Japan with the concept of a Very Large Mobile Offshore Structure (VLMOS) [9]. The initial concept and primary design of the MFS have been developed [2]. However, further refinements are required to adapt the design to the dynamic and diverse conditions of Indonesian waters. Additional considerations, such as the weight of the turbine on the MFS deck, must be integrated into the design process. As part of ongoing development, the MFS concept has been redesigned and submitted as a simple patent [10].

This study aims to advance the MFS design into a more efficient, sustainable model tailored to the unique conditions of Indonesian waters. Using advanced tools like Maxsurf for hydrostatic performance, this research seeks to optimize the MFS's operational efficiency and hull design accounting for the turbine's weight and dimension. Furthermore. Energi production that can be harnessed by MFS is estimated. After producing the MFS model and determining the main dimension, the energy production is calculated using reanalysis data. The result of the study would be beneficial to choose suitable location of MFS and to develop the MFS further.

2. MFS Design

The design and analysis of the Mobile Floating Structure (MFS) for wind turbines in Indonesian waters based on turbine dimension and characteristic. This procedure ensures that the platform can accommodate the turbines, key stages of the design are as follows:

2.1. MFS platform design

This step begins with defining the MFS's main dimensions, including length (L), breadth (B), height (H), and draft (T). These dimensions are calculated based on the weight of the wind turbine, the span of its blades, and other technical considerations.

2.2. Body plan design

After the main dimensions established, the next step involves designing the lines plan, which provides a blueprint for the hull's geometry. This design serves as the foundation for creating the body plan, detailing the precise shape of the MFS hull. The process leverages Maxsurf software to optimize both the lines plan and the body plan for hydrodynamic efficiency. At the end of this stage, an initial model of the MFS is completed, ready for further analysis.

2.3. Hydrostatic analysis

The initial MFS design undergoes detailed hydrostatic analysis to assess its performance in operational conditions. Hydrostatic analysis is conducted using Maxsurf producing hydrostatic performance and parameters. These analyses ensure that the MFS design is optimized for the marine environment, providing insights into its operational efficiency and feasibility.

3. MFS Power Production

3.1. Research location and data

The research location is the same as the previous study [3], which is in the waters around the islands of Sulawesi and Maluku, within the range of 116°E – 132°E and 8°N – 10°S . To determine the amount of wind energy generated by the MFS, this study uses 11 years of ERA-Interim Reanalysis data from 1999 to 2009, whereas the previous study utilized satellite data [3]. Era Interim reanalysis data is reanalysis product provided by ECMWF (European Centre for Medium-Range Weather Forecasts) [11]. The ERA-Interim has been intensively used to assess offshore wind energy in various location in the world [12-16]. The data with a temporal resolution of 6 h, and a spatial resolution of 0.25° × 0.25° were employed. Figure 1 displays the time series of 10m u-component wind at latitude: -5, and longitude: 120 in January 2009.

3.2. Wind energy density

The magnitude of wind speed on each pixel was obtained using the following equation [17].

$$V = \sqrt{u^2 + v^2} \quad (1)$$

where, V is the magnitude of wind speed at a height of 10 m (m/s); u is the is the East-West wind component and v is the wind component u (North-South). This was done over the entire time series and all pixels of the study area.

Wind energy density is defined as the power on the unit section perpendicular to the flow. It was obtained using the following equation.

$$W = 1/2\rho V^3 \quad (2)$$

In Eq. (3), W is wind power density (W/m2), V is the magnitude of wind speed at a height of 10 m (m/s), and ρ is air density (kg/m3), taken here as 1.225 kg/m3 as the sea surface air density.

3.3. Wind power production estimation

To determine the total energy production of the platform the turbine that used in previous study is selected which is NM72/2000 manufactured by NEG Micon, the specification of the turbine is given in Table 1.

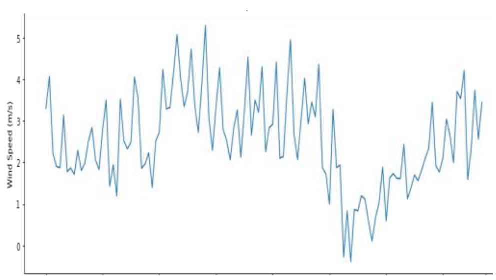

Figure 1. Time series data

Table 1. NM72/2000 turbine data [18]

Parameter	Unit
Hub height	64 m
Rated power	2 MW
Cut in speed	2 m/s
Rated speed	14 m/s
Cut out speed	25 m/s
Rotor diameter:	72.0 m
Rotor swept area:	4,072.0 m²

This study determines power generation based on the wind speed data and a selected wind turbine's characteristic. The power curve of the selected turbine is described by:

$$\begin{cases} 0, & 0 \le v \le v_{ci} \\ P_R(A + B_v + Cv^2), & v_{ci} \le v \le v_r \\ P_R\,, & v_r \le v \le v_{co} \\ 0\,, & v > v_{co} \end{cases} \quad (3)$$

where,

v_{ci}, v_r v_{co} Cut-in, rated, and cut-out speeds

A, *B*, *C*: Coefficients fitted to the turbine's power curve.

The coefficients *A*, *B*, *C* are calculated using the following equations:

$$A = \frac{1}{(v_r - v_{ci})^2}\left[v_{ci}\,(v_{ci} + v_r) - 4v_{ci}v_r\left(\frac{v_{ci} + v_r}{2v_r}\right)^3\right]$$

$$B = \frac{1}{(v_r - v_{ci})^2}\left[4\,(v_{ci} + v_r)\left(\frac{v_{ci} + v_r}{2v_r}\right)^3 - (3v_{ci} + v_r)\right] \quad (4)$$

$$C = \frac{1}{(v_r - v_{ci})^2}\left[2 - 4\left(\frac{v_{ci} + v_r}{2v_r}\right)^3\right]$$

4. Results and Discussion

4.1. MFS platform model

MFS platform is designed based on the concept in the previous study [2], the concept of catamaran with dual hull is still adopted in the present study. Furthermore, four wind turbines is installed on the platform, and two barges are used to accommodate four wind turbines. Based on the consideration, the preliminary design of MFS has been performed. The model of the platform is given in Fig. 2.

4.2. MFS Main Dimension and Body Plan

The dimension of hull is determined based on turbine dimension specifically blade expansion or rotor diameter. By referring the turbine general data that is given in Tabel 1, the main dimension of the MFS is estimated and modeled in Maxsurf. After modifying the model, the final dimensions of the MFS can be determined. The main dimension of the MFS is given in Tabel 2, and the result of body plan design of the MFS using Maxsurf is shown in Fig. 3.

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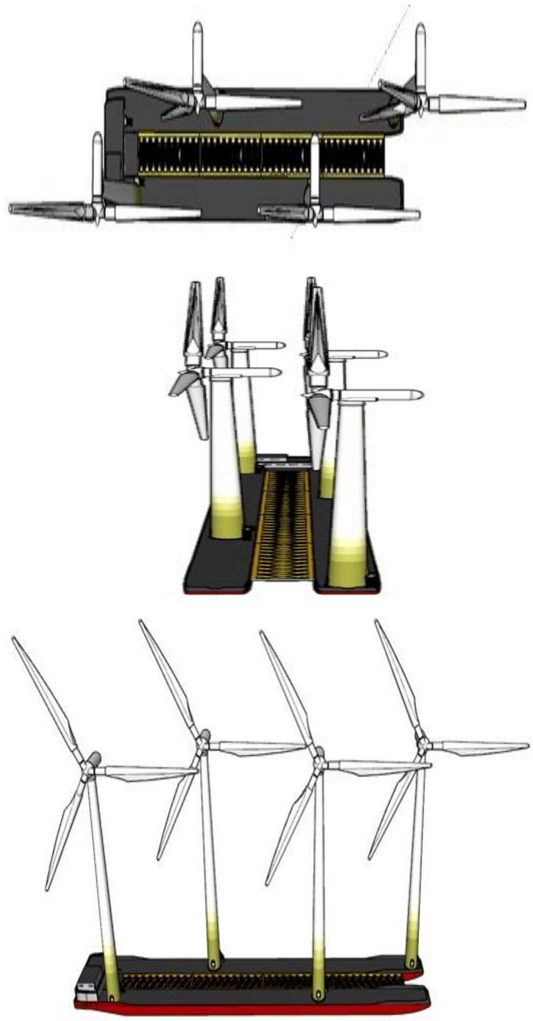


Figure 2. MFS platform

Table 2. MFS main dimension

Parameter	Unit
Lwl	128 m
H	4 m
B	8 m
T	3.2 m

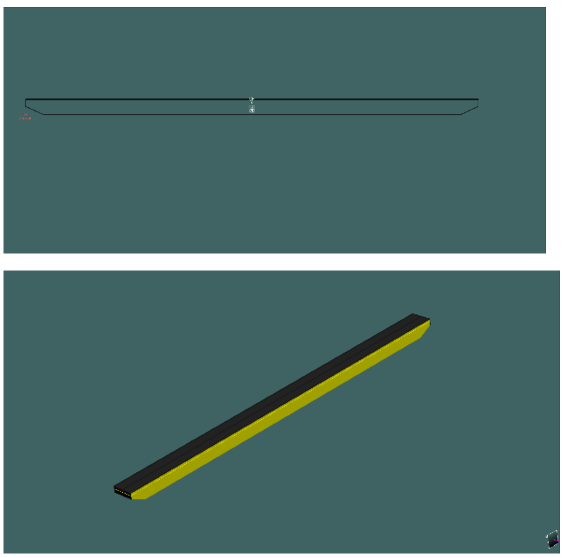
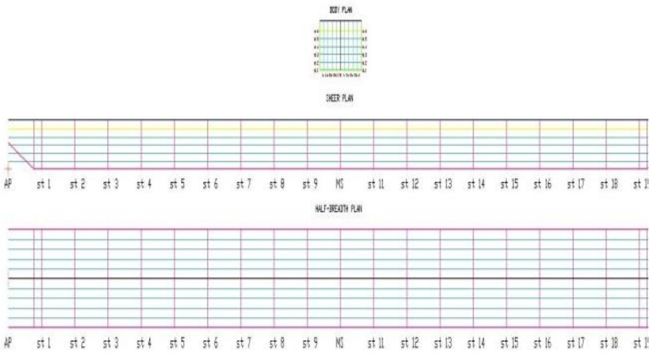


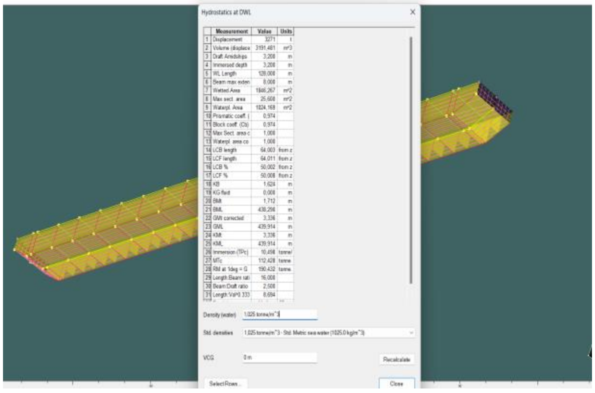
Figure 3. MFS body plan

4.3. Lines plan and hydrostatic performance

The body plan that has been produced is used to draw the lines plan of MFS hull. The lines is important because it used to analyze the hydrostatic characteristic of a floating platform. The resulted lines plane is given in Figure 4. The initial analysis of hydrostatic performance is also has been performed and the result is given in Fig. 4.



(a) lines plan;



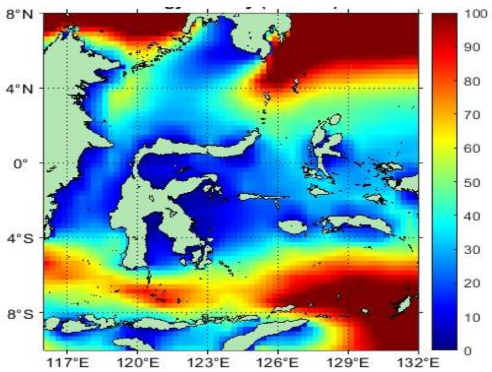
(b) hydrostatic characteristic.

Figure 4. (a) lines plan; (b) hydrostatic characteristic

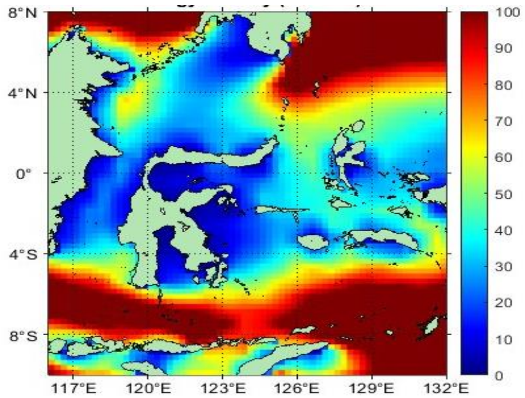
4.4. Wind energy density map

Previous study used Weibull Distribution to determine energy density. In the present study, Eq. 2 is used to estimate the energy density. After the energy density each location is calculated, the wind energy density maps are produced.

The monthly wind energy maps are shown in Fig. 5.



(a) January



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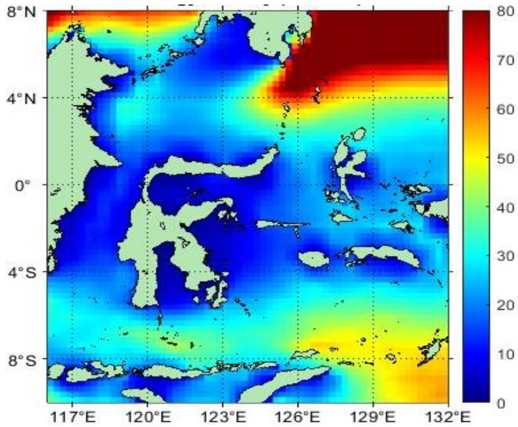
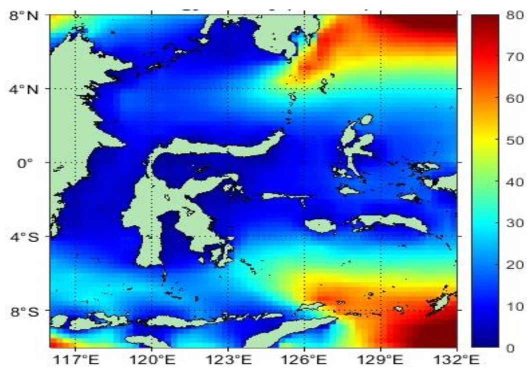


(c) March



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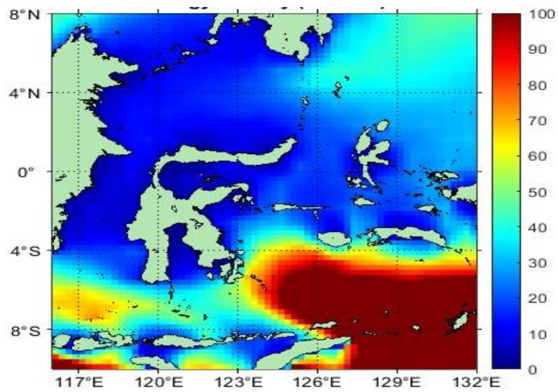

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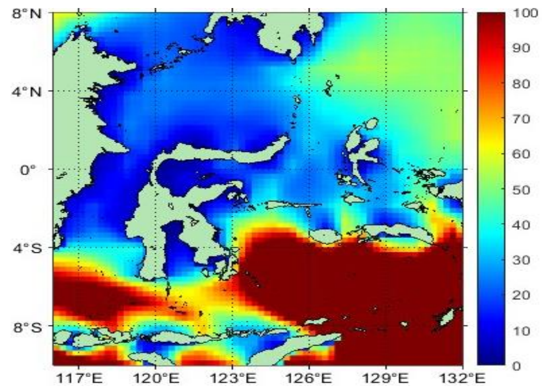
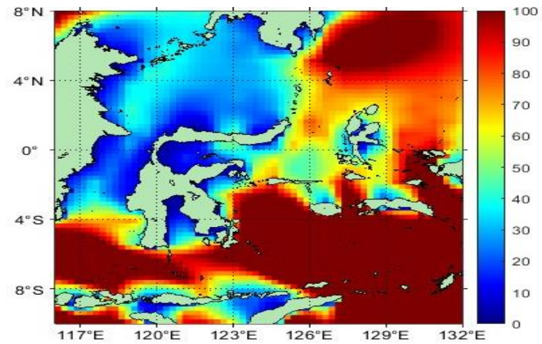
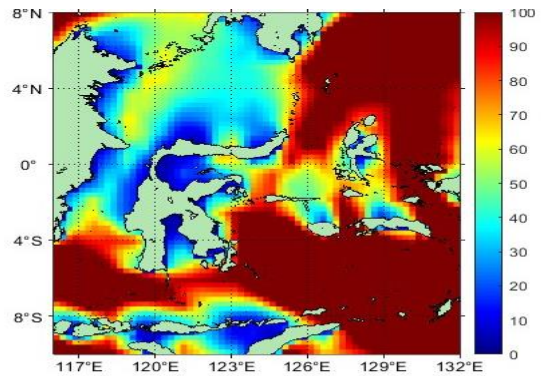


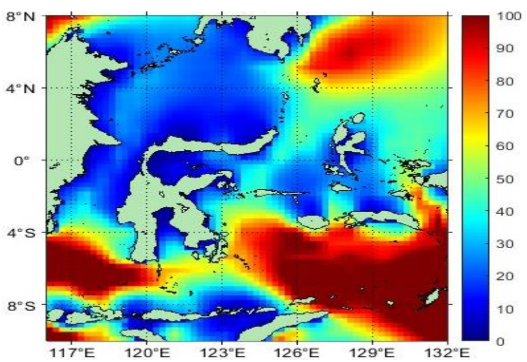
(f) June



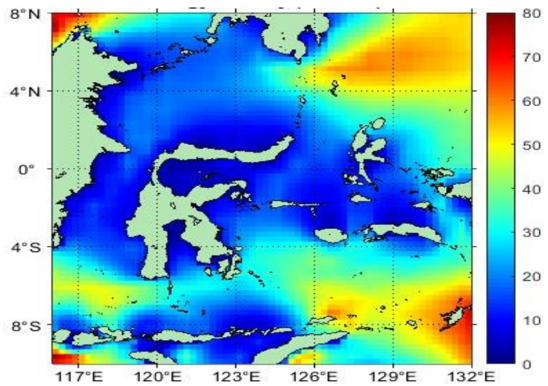
(g) July



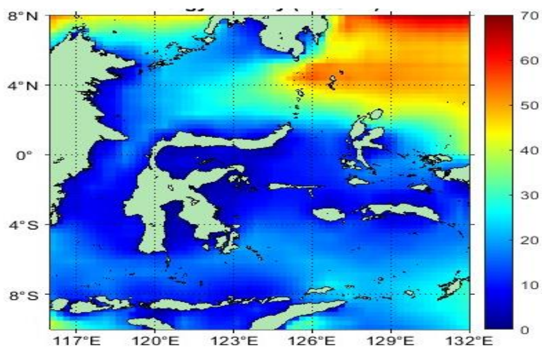
(h) August



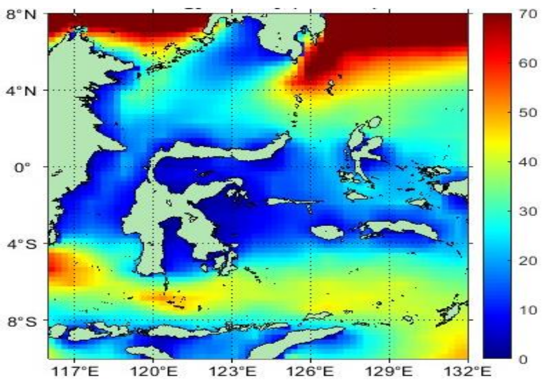
(i) September



(j) October



(k) November



(l) Dec

Figure 5. Monthly power density map

Figure 5 shows that the energy density of the research location which is in the Sulawesi and Maluku Island is around 40-100 watt/m^2. Moreover, it can be seen that Jan – Feb and Jun – August are suitable time to harness the energy.

From the figures, it is important to note that the result of energy density in the present study seems lower than in the previous study. It could be caused that the adopted method to determine energy density and the used data are difference. It also can be concluded that the reanalysis data underestimate the wind speed in Indonesia if it is compared to the previous study using satellite data.

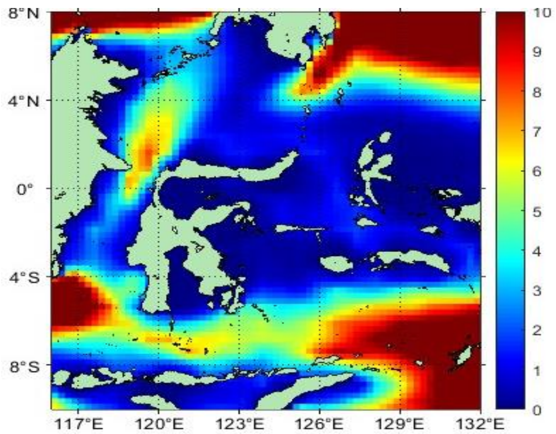
Furthermore, the density map is used to determine monthly MFS location. Tabel 3 is information on monthly MFS location.

Table 3. Monthly MFS location

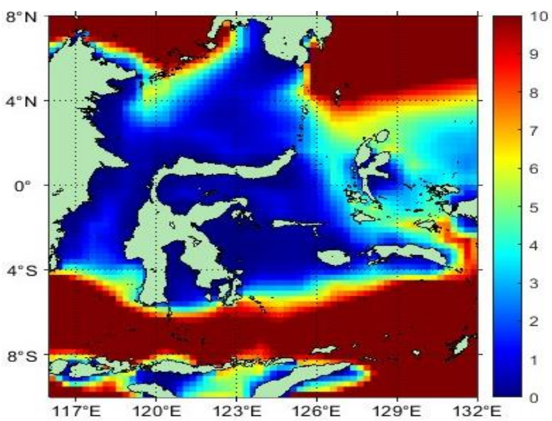
Month	Longitude	Latitude	Energy Density (Watt/m^2)
January	121.00°	-7.25°	88.81
February	118.00°	-7.25°	137.94
March	126.00°	5.00°	97.45
April	126.50°	-7.25°	65.23
May	125.00°	-6.50°	123.05
June	125.00°	-6.00°	188.22
July	126.00°	-6.00°	261.19
August	125.75°	-4.00°	186.91
September	117.25°	-6.00°	134.48
October	117.50°	-6.00°	49.22
November	126.00°	4.50°	54.85
December	126.00°	5.25°	77.56

4.5. MFS energy production

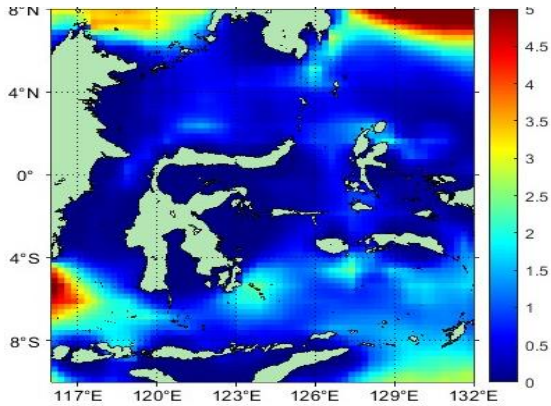
The energy production of the MFS with four turbine is estimated using wind speed data and power curve in Eqs. 3 and 4. The energy production of the MFS in the research location in the Sulawesi and Maluku Island has been determined, the monthly map is also has been drawn, the map can be used as reference to develop MFS in other location. The map of MFS energy production with four turbine is shown in Fig. 6.



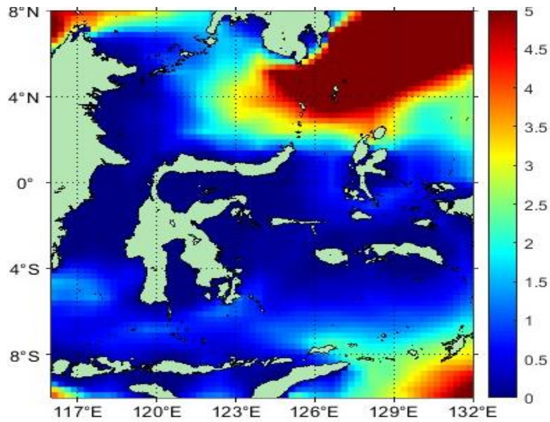
(a) January



(b) February



(c) March



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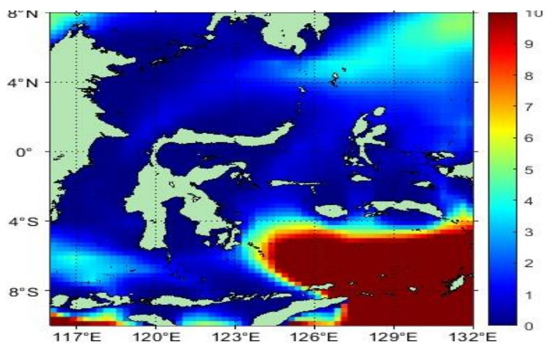

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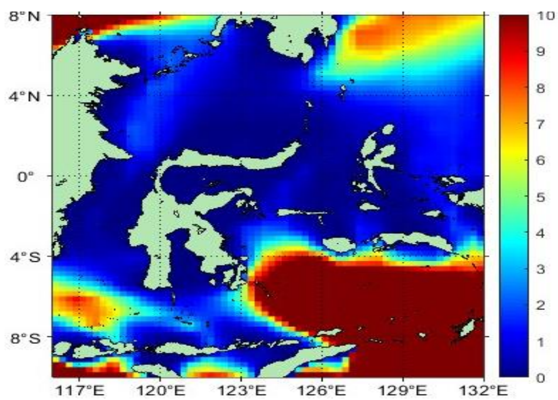
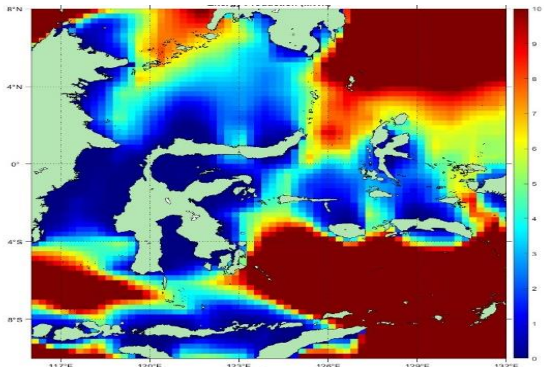
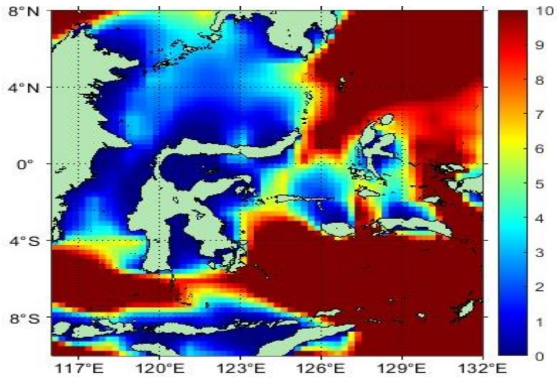


(f) June



(g) July



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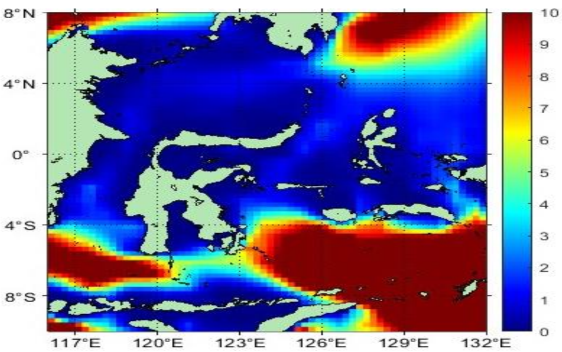
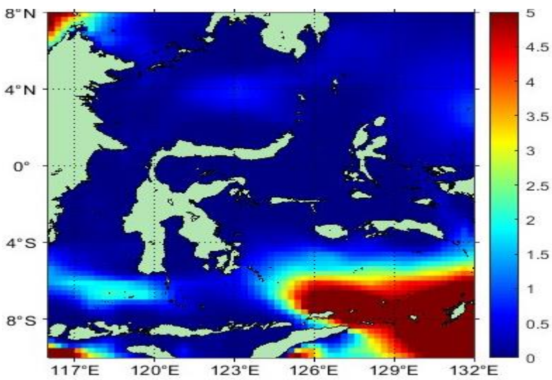


(i) September



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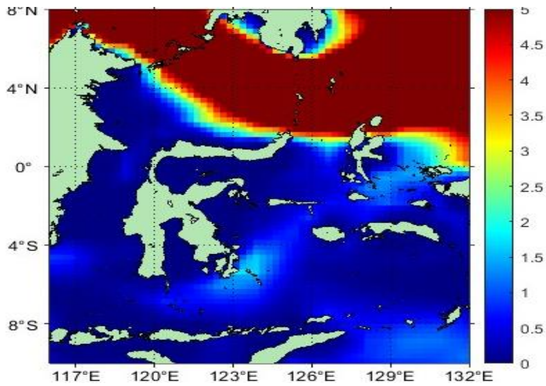

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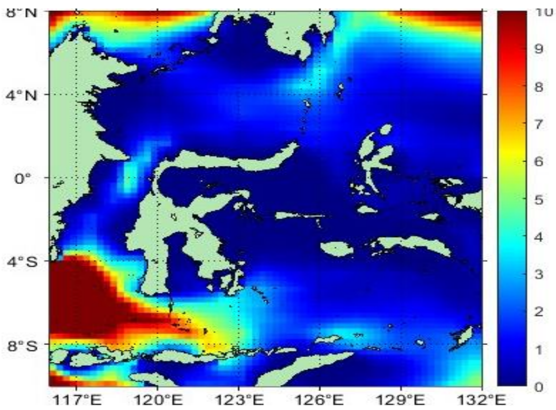

(l) December

Figure 6. Energy production map

Form Fig. 6, the energy production from the monthly location of MFS is also can be calculated. The monthly energy production of MFS in the chosen location has been estimated and it is given in Table 5. Based on Table 5, the maximum energy production is in July.

Table 5. The expected power production.

Month	Total power production KWh	Expected Power (KW)	Power Percentage (%)
January	9260.94	385.87	19.29
February	10768.50	448.69	22.43
March	10245.65	426.90	21.35
April	6187.34	257.81	12.89
May	13571.74	565.49	28.27
June	20495.91	854.00	42.70
July	29808.80	1242.03	62.10
August	21127.29	880.30	44.02
September	14142.05	589.25	29.46
October	4211.88	175.50	8.77
November	4649.01	193.71	9.69
December	7705.81	321.08	16.05

5. Conclusion

This study presents the preliminary design and energy production analysis of a Mobile Floating Structure (MFS) tailored for offshore wind energy harvesting in Indonesian waters. By employing a catamaran-based platform equipped with four NM72/2000 wind turbines, and utilizing Maxsurf software for hydrostatic and hydrodynamic analysis, the design ensures both structural efficiency and operational feasibility. The innovative mobility feature of the MFS allows it to be relocated seasonally to optimize energy capture, with energy density and power production assessed using 11 years of ERA-Interim reanalysis data. The results demonstrate significant variation in monthly energy potential, with peak production occurring in July. Although the reanalysis data slightly underestimates wind energy compared to satellite-based methods, the findings validate the MFS as a promising solution for dynamic and sustainable offshore wind energy exploitation. The energy production and location maps produced in this study can serve as strategic tools for future deployment planning and further development of mobile offshore renewable energy systems in Indonesia.

Acknowledgements

This research was funded by Institute for Research and Community Service (LPPM) ITK through Internal Grant 2024 with contract number 4340/IT10.II/PPM.04/2024.

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