Analysis of Tidal Energy Potential in the Merauke Papua River Waters Indonesia

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ABSTRACT

The purpose of this study is as a source of information to study the potential of tidal energy at the estuary of the Maro River in the waters of Merauke Regency. This study uses a quantitative method, while the method for determining the location of the study used is the purposive sampling method where the data collection point is right at the end of the estuary of the Maro River because it faces directly onto the Arafura Sea. Tide data for 5 months, namely September 1, 2023 to January 31, 2024 with a pool area of 1,260,000 m^2, with the consideration that from September to January there is a change of seasons that can significantly affect the tidal pattern. The tides are measured in two periods, namely the first tidal period starting at 01.00 AM to 12.00 AM and the second tidal period occurs at 01.00 PM to 12.00 PM. From the research data, it was obtained that the highest tides were in January 2024, namely the first-period tidal height difference of 5.333 meters and the energy produced was 5.292 kWh, and the second-period tidal height difference was 5.383 meters the energy produced was 5.349 kWh. The results of this study can encourage diversification of energy sources in Merauke and increase regional energy security as well as provide the data needed for further research and development of renewable energy technology, which can accelerate innovation of new technologies in the Merauke Papua region.

Keywords: *Energy, high water level, low water level, Maro river, tidal, tide period*

I. Introduction

Indonesia is an archipelago surrounded by two oceans, namely the Indian Ocean and the Pacific Ocean. Indonesia is located on the equator, causing the ebb and flow conditions, wind, waves and ocean currents that occur in these waters to be very strong [1]. In Indonesia, several areas that have tidal energy potential are Bagan Siapi-api, whose ebb and flow reaches 7 meters, Palu Bay, whose geological structure is a fault (Palu Graben), which allows for tidal phenomena, Bima Bay in Sumbawa (West Nusa Tenggara), West Kalimantan, Papua, and the south coast of Java Island, whose ebb and flow can reach more than 5 meters [2], while for the Papua region, it is found in the Digul River and the Muli Strait in southern Papua with a tidal range of around 7 to 8 m, while the Maro River in Merauke Regency has a high ebb and flow of 5 to 7 meters [3].

The potential for tidal energy can be determined from the highest and lowest levels of sea water ebb and flow [4]. Although the difference between the highest and lowest tides is an important factor in determining energy potential, there are several other factors that also play a role, namely Tidal Current Velocity: Tidal energy also depends on the speed of the water currents generated by tidal changes. The faster the water current, the greater the

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potential energy that can be generated, Volume and Area of Water Area: The greater the volume of water moving and the larger the area affected by the tide, the greater the potential energy that can be obtained, Water Depth: Water depth also affects energy potential. Areas with sufficient depth can produce more energy than shallower areas, Tidal Frequency: The frequency of tides (how often high tides and low tides occur) also affects energy potential. Areas with more frequent high tides may have greater energy potential, Geographical Conditions: The shape and structure of the seabed and the geographical conditions of a particular area can also affect the flow and movement of tidal water, which in turn affects the potential energy that can be extracted [5].

Diversification of energy sources is a priority to reduce dependence on fossil fuels and improve national energy security. Tidal energy, as a renewable energy source, supports this goal by providing a clean and sustainable alternative. The Indonesian government has set a target to increase the contribution of renewable energy to the national energy mix. Research and development of tidal energy in the Maro River is in line with this effort and can contribute to achieving the target. Globally, tidal energy technology is developing, with innovations that increase efficiency and reduce costs. Research results in the Maro River can contribute to global knowledge and practice, as well as benefit from the latest technology.

Geographically, Merauke Regency-Papua Indonesia is located between 137^o - 141^o East Longitude and 6^o 00 '- 9^o 00' South Latitude. Generally lowland, slope 0-8%, swampy coastal areas are flooded, the North and East are rather high / undulating with a few hills. The height of the tidal water is 5-7 m, the sea tide enters as far as 50-60 km and some places are intruded by salt water/seawater [6]. Merauke Regency-Papua Indonesia is crossed by the Maro River which flows from the northeast to the southwest and empties into the Arafura Sea, with a total length of 207 km and a width of between 48-900.1 m.

With the large natural resources of Merauke Papua, it is very necessary to be able to make an analysis of the study of the potential for tidal energy that can be developed considering that the tidal energy that can be produced from the Maro River is quite large, because it is a clean and renewable form of energy. The study was conducted by taking data samples for 5 months with the assumption that the data to be obtained would be more accurate. Data collection was carried out by direct measurement and secondary data was obtained from the Indonesian port agency, Merauke-Indonesia branch.

Renewable energy is an alternative energy source that has very promising potential to be used as a source of future electrical energy. Indonesia's geographical position between two oceans and continents and in the equatorial region means it has abundant potential for renewable resources [7]. The potential for tidal energy in Merauke waters is actually quite large, because tidal energy is renewable and does not cause pollution (pollution-free), so it is necessary to develop and utilize tidal energy to support development. The waters of Merauke Regency are located in the southern part of Papua Island which is influenced by the Arafura Sea, so that the energy sources in the waters of Merauke Regency have untapped potential. The potential for tidal energy in the waters of Merauke Regency itself is quite large. The purpose of this study is as a source of information to examine the potential for tidal energy at the mouth of the Maro River in the waters of Merauke Regency.

II. Material and Methods

1. Research Materials

The Maro River is a river located in Merauke Regency, South Papua, Indonesia. The river flows from northeast to southwest and empties into the Arafura Sea, with a total length of 207 km (129 mi) and a width of 48-900.1 m and is located at $8^0$28’04.05” S $140^0$21’12.50” E Elev 4 m. One of the main tributaries is the Obat River, also called the Oba River. Most of the river is very fast-flowing and the lower reaches are salty due to the influence of sea water. Around the river there is a complex system of swamps and meandering lakes that are very important for the survival of several species of birds and reptiles. To the north, the river borders the Wasur National Park.

The Maro River can be used as renewable energy derived from tidal energy because the Maro River has a fairly high tidal value. The tidal value in the Maro River covers a value of 5-7 meters (tides.big.go.id). The approach uses tidal observation data analysed using the Admiralty method so that the type of tidal waters and the value of the components in them can be known as a reference for finding the tidal value in the waters to calculate its energy. The river is classified as a lowland rained river or 'lowland rained river' whose water comes from swamps and rainwater from the surrounding area which flows into the Arafura Sea [8].

The research materials used in this study consist of primary data and secondary data. Primary data in the form of tidal observation data for 5 months (September 2023 to February 2024) with 1 location point at the river mouth located at 8028’04.05” S 140021’12.50” E Elev 4 m. Determination of the location point using GPS (Global Positioning System). Secondary data in the form of tidal forecast data issued by PT. Pelindo Indonesia – Merauke Papua, as a verification processing of forecast data with observation data, a topographic map of the Maro River waters.

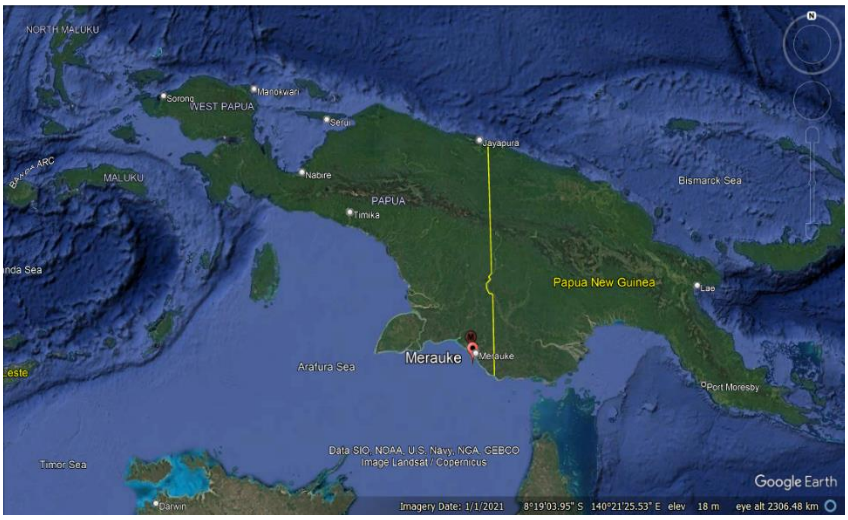


Fig. 1. Map of Papua Island-Indonesia, location of Merauke Regency-Papua Indonesia $8^0$28’04.05” S $140^0$21’12.50” E Elev 4 m

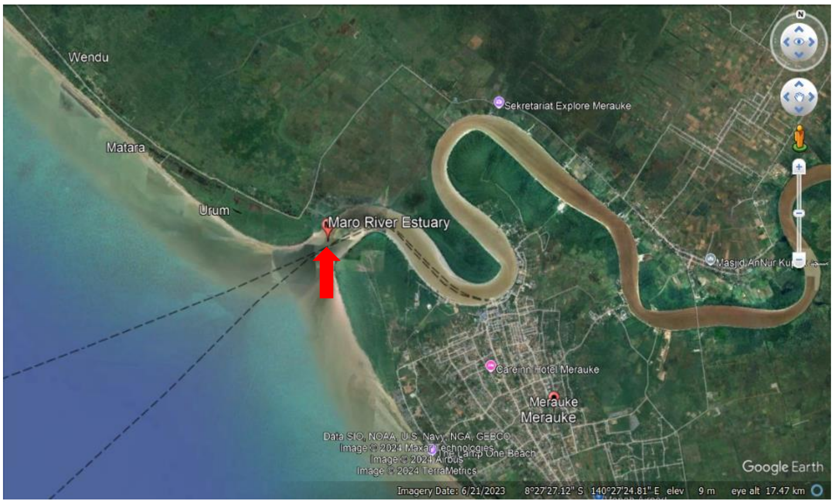


Fig. 2. Shape of the Maro River, Merauke Regency, Papua, Indonesia
$8^0$28’01.66” S $140^0$21’13.27” E Elev 4 m

The data collection period from September 1, 2023 to January 31, 2024 covers the transition between the dry and rainy seasons in many areas, including Papua. These seasonal variations can affect tidal patterns, so this period provides data that reflects the differences that may occur between the two main seasons and can identify tidal patterns related to the lunar phase. With data covering the period from September 2023 to January 2024, researchers can analyze the impact of seasonal changes on tidal patterns. This helps in understanding how seasonality affects tidal energy and planning optimal energy use throughout the year, identifying long-term trends and tidal patterns that may not be visible in shorter time periods. This helps in forecasting and managing tidal energy fluctuations more effectively.

2. Research Design

This research uses a quantitative method, namely a method that uses numbers, statistical analysis, and empirical formulas that are in accordance with scientific principles to obtain an overview of the research results. The method for determining the research location used is the purposive sampling method. The purposive sampling method is a sampling method with the required sample criteria where the sample points represent other points in the study area [9]. The method used for collecting the main data is by direct observation. The coordinates of the observation location are determined based on the purposive sampling method using GPS. Observations are made by reading the scale on the tidal palm by recording every 1-hour interval for 5 months, namely from September 2023 to February 2024, considering that in such a long period of time, there have been full moon and quarter tides (one tidal cycle) so that data collection is more accurate.

The results of the calculation of the tidal harmonic constant, obtained the high value of the tidal energy potential based on the highest high water level (HHWL) and the lowest low water level (LLWL) in meters. Electrical energy can be generated when filling the pool or when the sea water is high or emptying the pool or when the sea water is low. By using this method, the electrical energy generated depends on the length of time the pool is filled or when the sea water is high or when the pool is emptied or when the sea water is low tide [10]. The area of the pool used is 430.73 m^2 considering the area of the research location.

Fig. 3. Power plant with single pond arrangement [18]

The estimated electrical energy can be calculated from the function of the area of the pool and the difference in tidal height and the resulting discharge, namely the volume of inflow into the pool (m³), as shown in Eq. (1) [11].

$$V = A \ x \ \Delta h \ (m^3) \quad \text{(1)}$$

Where:

V_{Pool} = Pool volume (m^3)
Δh = Tidal height difference (m)
A = Pool area (m^2)

The average water discharge is determined by the Eq. (2) [12].

$$Q = \frac{V}{t} \ \left({m^3}/{det} \right) \quad \text{(2)}$$

Where:

Q = Flow rate (m^3/second)
V_{in} = Volume of water flow into the pool (m^3)
t = Tidal period (seconds)

The power generated per cycle is determined by the Eq. (3) [13]:

$$P = \eta_o \ x \ \frac{h \ x \ Q \ x \ \rho}{75} \ (W) \quad \text{(3)}$$

Where:

P = Power generated (Watt)
h = Tidal height (m)
ηo = Power efficiency
ρ = Density of sea water (kg/m^3)
Q = Flow rate (m^3/second)

In one year consisting of 365 days, for the double daily tidal type there are 705 full tidal cycles, so the energy produced E in a year for the double daily tidal type will be obtained using Eq. (4) [14]:

$$E\ (1\ Year) = 2\ x\ \eta_o\ x\ \frac{hp\ x\ Q\ x\ \gamma}{75}\ x\ t\ x\ 705\ x\ 0.736 \quad (kWh) \quad \text{..} (4)$$

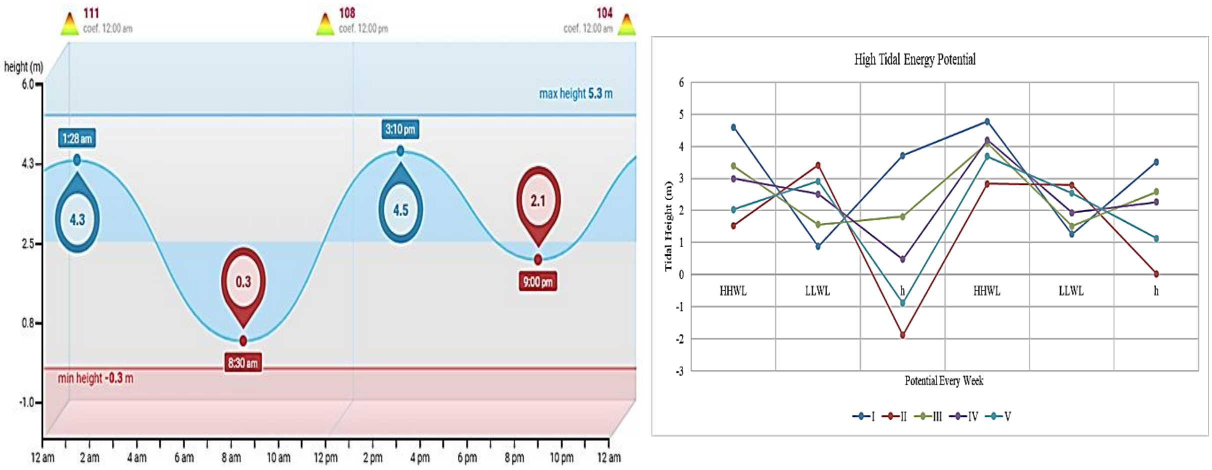
Where:

V = Volume of inflow into the pool (m^3)
A = Pool area (m^2)
Q = Flow rate (m^3/second)
hp = Difference in average high and low tide
γ = Specific gravity of sea water 1.025 kg/m^3

III. Results and Discussions

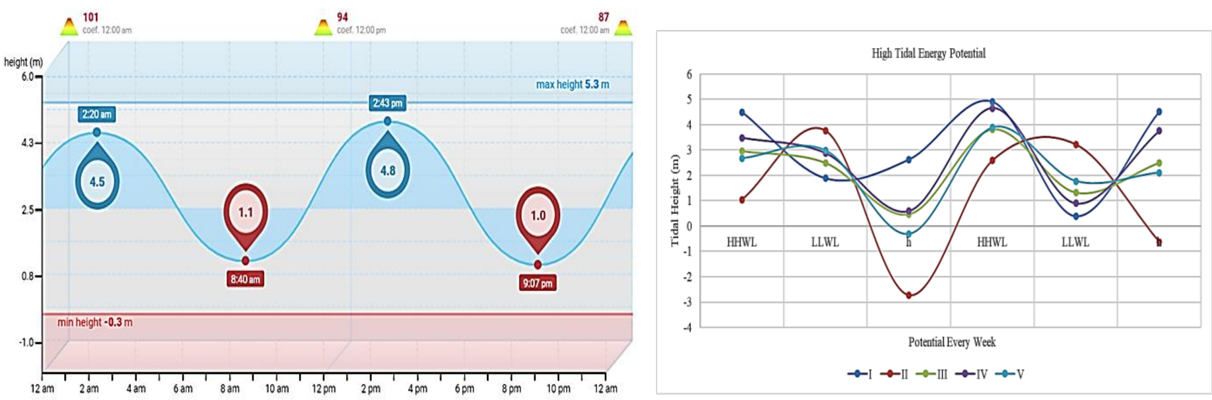
1. Results of Observation

The results of observation data for 5 months (September 1, 2023 to January 31, 2024) from tidal forecasting produced the harmonic constant values, as shown in Figure 4 to Figure 8.



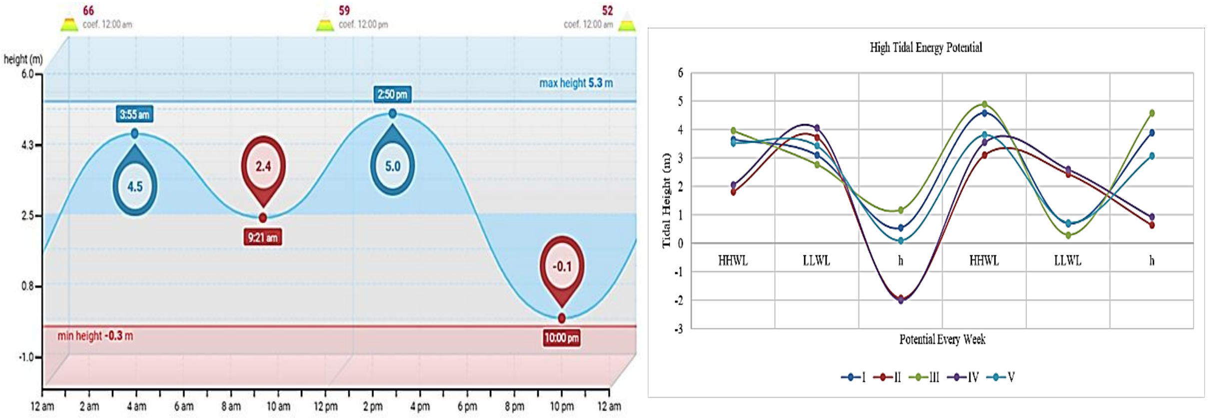
(a) Tides for Merauke (b) Potential high and low tides every week

Fig. 4. Potential tides in September 2023



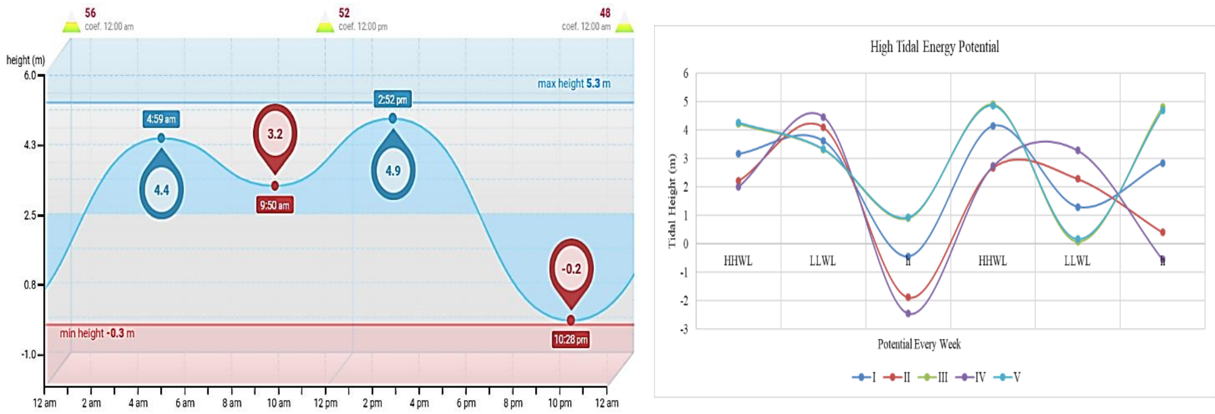
(a) Tides for Merauke (b) Potential high and low tides every week

Fig. 5. Potential tides in October 2023



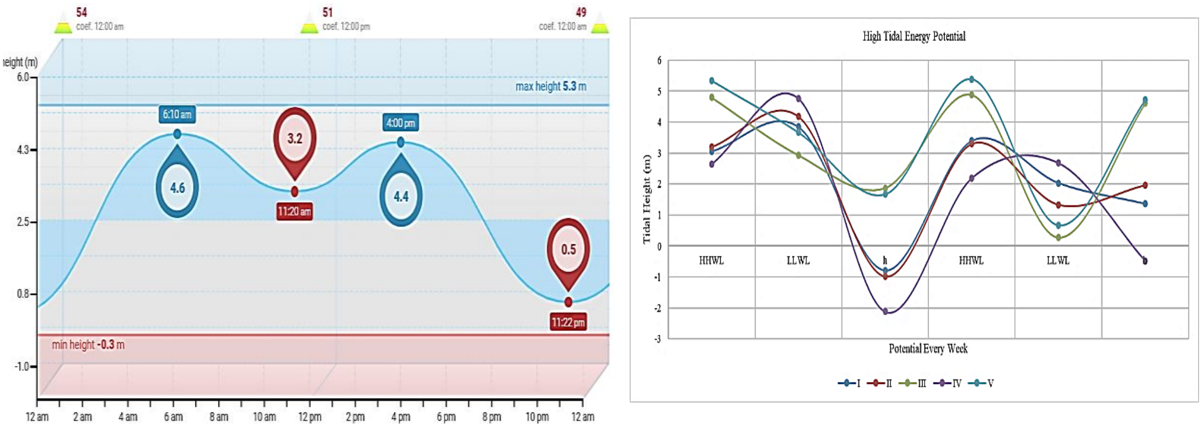
(a) Tides for Merauke (b) Potential high and low tides every week

Fig. 6. Potential tides in November 2023



(a) Tides for Merauke. (b) Potential High and low tides every week

Fig. 7. Potential tides in December 2023



(a) Tides for Merake (b) Potential high and low tides every week

Fig. 8. Potential tides in January 2024

2. Analysis of Tidal Potential Energy

The potential energy generated during 5 months (September 1, 2023 to January 31, 2024) is presented in Table 1 to Table 5, and visualized at Figure 9.

Table 1. Potential tidal energy during September 2023

River Area (m^2)	h (m)	V (m^3)	Q (m^3/min.)	E (kWh)
		Tide Period I		
1,260,000	4.600	5,796,000	134.167	7.169
1,260,000	1.533	1,932,000	44.722	0.796
1,260,000	3.383	4,263,000	98.681	3.878
1,260,000	3.000	3,780,000	87.500	3.049
1,260,000	2.033	2,562,000	59.305	1.401
			The energy generated during tide period I	**3.259**
		Tide Period II		
1,260,000	4.783	5,796,000	134.166	7.455
1,260,000	2.833	1,932,000	44.722	1.472
1,260,000	4.100	4,263,000	98.681	4.699
1,260,000	4.200	3,780,000	87.500	4.269
1,260,000	3.683	2,562,000	59.306	2.537
			The energy generated during tide period II	**4.087**

Table 2. Potential tidal energy during October 2023

River Area (m^2)	h (m)	V (m^3)	Q (m^3/min.)	E (kWh)
		Tide Period I		
1,260,000	4,500	5,670,000	131.250	6.861
1,260,000	1.033	1,302,000	30.139	0.362
1,260,000	2.956	3,724,000	86.203	2.959
1,260,000	3.483	4,389,000	101.597	4.111
1,260,000	2.675	3,370,500	78.021	2.424
			The energy generated during tide period I	**3.343**
		Tide Period II		
1,260,000	4.900	5,670,000	131.250	7.471
1,260,000	2.583	1,302,000	30.138	0.904
1,260,000	3.814	3,724,000	86.203	3.819
1,260,000	4.650	4,389,000	101.597	5.488
1,260,000	3.887	3,370,500	78.021	3.523
			The energy generated during tide period II	**4.241**

Table 3. Potential tidal energy during November 2023

River Area (m^2)	h (m)	V (m^3)	Q (m^3/min.)	E (kWh)
Tide Period I				
1,260,000	3.650	4,599,000	106.458	4.514
1,260,000	1.816	2,289,000	52.986	1.118
1,260,000	3.967	4,998,000	115.694	5.331
1,260,000	2.067	2,604,000	60.278	1.447
1,260,000	3.533	4,452,000	103.056	4.230
The energy generated during tide period I				3.328
Tide Period II				
1,260,000	4.583	4,599,000	106.458	5.668
1,260,000	3.100	2,289,000	52.986	1.908
1,260,000	4.883	4,998,000	115.694	6.563
1,260,000	3.550	2,604,000	60.278	2.485
1,260,000	3.8167	4,452,000	103.056	4.569
The energy generated during tide period II				4.239

Table 4. Potential tidal energy during December 2023

River Area (m^2)	h (m)	V (m^3)	Q (m^3/min.)	E (kWh)
Tide Period I				
1,260,000	3.167	3,990,000	92.361	3.397
1,260,000	2.217	2,793,000	64.653	1.665
1,260,000	4.217	5,313,000	122.986	6.024
1,260,000	2.017	2,541,000	58.819	1.378
1,260,000	4.267	5,376,000	124.444	6.168
The energy generated during tide period I				3.727
Tide Period II				
1,260,000	4.150	3,990,000	92.361	4.452
1,260,000	2.683	2,793,000	64.652	2.015
1,260,000	4.900	5,313,000	122.986	7.001
1,260,000	2.733	2,541,000	58.819	1.867
1,260,000	4.867	5,376,000	124.444	7.0354
The energy generated during tide period II				4.474

Table 5. Potential tidal energy during Januari 2024

River Area (m^2)	h (m)	V (m^3)	Q (m^3/min.)	E (kWh)
Tide Period I				
1,260,000	3.058	3,853,500	89.201	3.169
1,260,000	3.200	4,032,000	93.333	3.469
1,260,000	4.800	6,048,000	140.000	7.806
1,260,000	2.650	3,339,000	77.292	2.379
1,260,000	5.333	6,720,000	155.556	9.637
The energy generated during tide period I				5.292
Tide Period II				
1,260,000	3.400	3,853,500	89.201	3.523
1,260,000	3.300	4,032000	93.333	3.578
1,260,000	4.883	6,048,000	140.000	7.942
1,260,000	2.200	3,339,000	77.292	1.975
1,260,000	5.383	6,720,000	155.556	9.728
The energy generated during tide period II				5.349

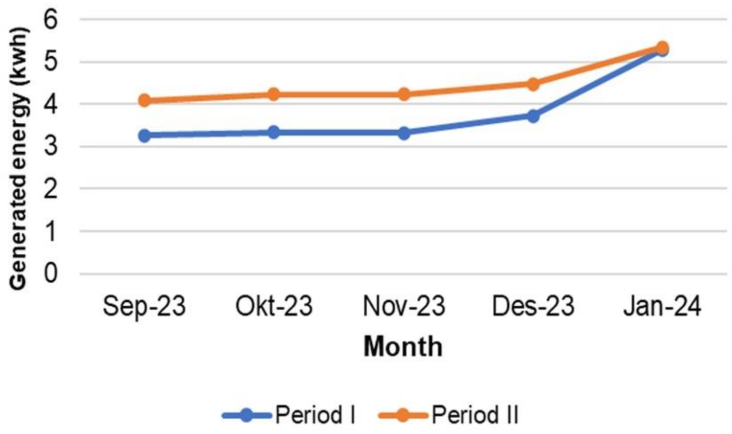


Fig. 9. Tidal Energy Potential

3. Discussion

The high potential of tidal energy in the waters of the Maro Merauke-Papua River obtained is quite high based on the maximum tide and the lowest ebb, because the energy obtained from the tidal generator is when the sea water is high and when the sea water is low. The high tide in the Maro Merauke River is caused because the end of the estuary directly faces the Arafura Sea so the volume of water at high tide is very high because the water in and out is greater. The high potential of tidal energy based on the results obtained is due to the full moon or new moon which occurs alternately every two weeks, when the position of the moon and sun are in a straight line with the earth so that the highest tide occurs, namely at the new moon and full moon. The potential of tidal energy obtained in the waters of the Maro Merauke River based on 5 months with a pool area of 1,260,000 m^2 obtained varying energy conversions. The tides are measured in two periods, namely the first period of the ebb and flow starting at 01.00 AM to 12.00 AM and the second ebb and flow occurs at 01.00 PM to 12.00 PM. In September 2023, the energy generated is 3.259 kWh for the first period and 4.087 kWh for the second period (Table 1) and will then increase from October 2023 to January 2024 where the amount of energy generated is 5.292 kWh for the first period and 5.349 kWh for the second period (Table 5). The results of the tidal energy values come from the instantaneous energy that occurs when the tide is at maximum. The maximum tide is obtained when a difference between the HHWL value and the LLWL value. The maximum tide occurs not for too long a period so it only lasts a few moments. This is due to the different dynamics between the Arafura Sea water level and the river water level which have different periods. With the large area of the Maro Merauke River, the potential energy produced will be even greater, so the use of known energy can be used as a reference in the future in the development of electricity generation planning by utilizing the potential of tidal energy to obtain maximum tidal energy.

Factors that cause the energy generated from the tides to vary between periods include: gravitational influence: Tidal energy is generated by the gravitational influence between the Earth, the moon, and the sun. The moon has a greater influence because it is closer to the Earth. When the moon is in a certain position (for example, a full moon or new moon), the moon's gravitational pull causes seawater to rise (high tide) and fall (low tide), Period: Tidal energy is periodic, following the daily and monthly cycle of high and low tides. This period affects the amount of energy generated, height difference, and the height of the tides varies between periods. On a full moon, the difference in height between high and low tide is greater than on a new moon. This is due to the relative positions of the moon, sun, and Earth. In addition, it is also influenced by coastal topography: The shape of the coast and the depth of the water affect the amplitude of the tides. In areas with sloping coasts, the difference in height will be smaller than in areas with steep coasts [19].

The potential for tidal energy varies between periods due to variations in tidal periods including seasonal changes that affect tidal patterns [20]. For example, during the rainy season or dry season, rainfall patterns and river flows can affect water levels and tides, changes in temperature and atmospheric conditions throughout the year also affect tidal levels. In addition, there are also factors that Influence Variations in Tidal Energy Potential, including the gravitational pull of the moon and sun affecting tides. Variations in the distance of the moon and sun from Earth (for example, due to elliptical orbits) affect the strength of tides, the shape and depth of the coast, and the shape of the seabed affect how tidal energy is channeled and expressed. Bays, estuaries, and other coastal structures can strengthen or weaken tides, and ocean currents and waves can affect tidal patterns by changing the distribution and energy of seawater along the coast [21].

The uniqueness of this research is its location at the end of the Maro River estuary which directly faces the Arafura Sea, which is a route for ship traffic entering and leaving the port of Merauke. So it is necessary to create a single pool where the column is directly connected to the sea through a water gate. When the water reaches its highest point (high tide), the gate is closed [22]. When the water recedes, the gate is opened, and the water that comes in and out through this gate drives a turbine connected to an electric generator to produce energy.

IV. Conclusions

The tides in the waters of the Maro River, Merauke-Papua, based on the results of 5 months of research, have a mixed type of tide which tends to be daily. This type means that in one day there are two high tides and two low tides, but have different heights and periods. The study of the tidal energy potential in the Maro River waters of Merauke-Papua proves that the Merauke waters have a fairly high tidal value. With a river area of 1,260,000 m^2, the highest energy potential obtained within a period of 5 months was in January 2024 at 5.349 kWh. The tidal energy value results from the instantaneous energy that occurs at the maximum riding state. This is due to the difference in dynamics between sea level and the water level of the simulation pool at different periods. The higher the tidal height, the greater the potential tidal energy that will be generated. The highest tidal height difference value is 5.383 meters and the tidal energy value is 5.349 kWh, indicating the potential energy that can be generated from the movement of seawater during one tidal cycle. The potential of tidal energy can be used as information and study material for further research in order to optimize available natural resources to improve community welfare. The results of this study can encourage diversification of energy sources in Merauke, reduce dependence on fossil fuels, increase regional energy security, and provide data needed for further research and development of renewable energy technology, which can accelerate innovation and application of new technologies in the Merauke Papua region.

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