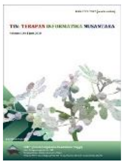

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# Technical and Economic Assessment of Tidal Barrage Power Plant at Ambon Bay, Indonesia Using Life Cycle Cost Analysis

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**Abstract−**Ambon Bay in Maluku Province possesses significant tidal energy potential due to its semi-enclosed morphology and favorable tidal characteristics, making it a promising site for tidal barrage power development in Eastern Indonesia. This study aims to evaluate the technical potential and economic feasibility of a tidal barrage power plant in Ambon Bay. Tidal energy potential was estimated using harmonic tidal data obtained from pasanglaut and the Marine Observation Research Agency (BROL), followed by energy conversion analysis based on tidal range and basin characteristics. The technical assessment was conducted using an analytical approach derived from hydrodynamic principles and benchmarked against existing tidal barrage systems. Economic feasibility was evaluated using the Life Cycle Cost (LCC) method, incorporating capital expenditure, operational costs, and Levelized Cost of Energy (LCOE), along with Net Present Value (NPV) analysis. The results indicate that Ambon Bay has a theoretical tidal energy potential of 31.05 GWh per year. A proposed 7 MW tidal barrage system could generate approximately 11.69 GWh annually with a capacity factor of 18.9%. The estimated capital cost is IDR 255,231,448 per kW, with an LCOE of IDR 15,324 per kWh. The economic analysis yields an NPV of -IDR 1,294,358,382,098.43, indicating that the project is not economically feasible under current conditions. These findings highlight that, despite its considerable technical potential, the development of tidal barrage power in Ambon Bay requires cost reduction strategies, policy support, or technological optimization to achieve economic viability.

**Keywords**: Ambon Bay; LCOE; NPV; Ocean Energy; Technical Assessment; Tidal Barrage

## 1. INTRODUCTION

The Electricity Supply Business Plan (RUPTL) of PT PLN (Persero) 2021–2030 targets the development of a 50 MW renewable energy power plant in Ambon, with a planned Commercial Operation Date (COD) in 2030. This initiative is further reinforced in the RUPTL 2025-2034, which emphasizes the exploration and development of marine energy resources in Eastern Indonesia. The urgency of this target is closely linked to the current structure of Ambon's power system, which remains highly dependent on diesel-based generation (Purwanto et al., 2020). Consequently, the national de-dieselization program requires alternative energy sources that are reliable, sustainable, and compatible with the geographical characteristics of archipelagic regions (Lapisa et al., 2023). Indonesia's total marine energy potential is estimated at 17,989 MW, indicating a substantial gap between available resources and their current utilization, particularly in meeting regional electricity demands such as those in Ambon.

Among various marine energy technologies, tidal energy especially tidal barrage systems offers significant advantages due to its predictability and relatively stable energy output compared to wave or ocean current energy (Azharul et al., 2020). Recent studies highlight that tidal barrage technology has reached a higher level of technological maturity, with competitive energy conversion efficiency and long operational lifespans, making it a viable option for large-scale power generation in coastal areas (Tanuwijaya, 2024). Furthermore, semi-enclosed bay systems provide favorable hydrodynamic conditions for tidal energy extraction, particularly when natural constrictions exist that can enhance the hydraulic head and improve overall system efficiency (Bachtiar et al., 2024).

Ambon Bay exhibits a semi-diurnal tidal pattern, characterized by two high tides and two low tides each day, which directly influences the continuity and magnitude of extractable energy. Annual tidal data indicate sufficient tidal range variability to support energy generation. In addition, the presence of a natural constriction approximately 477 meters wide between the inner and outer parts of the bay represents a critical factor in the technical feasibility of a tidal barrage system (Dangkua et al., 2022). This geographical feature enables more efficient barrage design in terms of construction scale and operational performance. These characteristics position Ambon Bay as a promising candidate for tidal energy development in Eastern Indonesia (Shahbaz et al., 2020).

This study aims to assess the annual tidal energy potential in Ambon Bay, evaluate the technical feasibility of a tidal barrage power plant based on hydrodynamic and site-specific parameters, and analyze its economic viability using key indicators such as capital cost, Levelized Cost of Energy (LCOE), and Net Present Value (NPV) (de Simón-Martín et al., 2022). The technical analysis is conducted through calculations based on tidal data and bay geometry, while the economic evaluation incorporates construction and operational cost parameters, benchmarked against comparable infrastructure projects with similar characteristics (Satriawan et al., 2021). The findings are expected to contribute to the development of tidal energy as a strategic solution for energy transition in island regions, particularly in supporting de-dieselization efforts and increasing the share of renewable energy in Ambon (Klaus, 2020).

## 2. RESEARCH METHODOLOGY

This research wil be conducted in Ambon Bay, Ambon City, Maluku Province, Indonesia. The study will be conducted in 2025, with secondary data collection from January 2022 to December 2022. The research design for the Engineering Assessment of Tidal barrage Power Plants in Ambon, Indonesia is as follows:

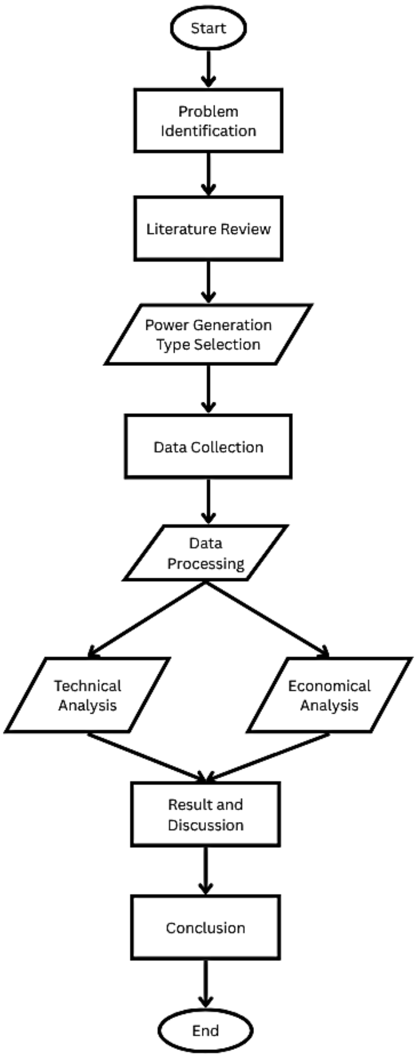
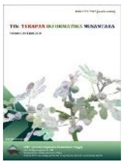


**Figure 1.** Research Design

This research was conducted in Ambon Bay, Ambon City, Maluku Province, Indonesia, using secondary data collected for the period of January 1 to December 31, 2022. The study applied a quantitative engineering assessment approach to evaluate the technical and economic feasibility of a tidal barrage power plant system. Data collection was carried out using officially published and scientifically validated sources. Tidal data were obtained from Pasanglaut and the Marine Research and Observation Agency (Badan Riset dan Observasi Laut/BROL). Bathymetric and topographic data were derived from Badan Informasi Geospasial (BIG) and BATNAS (National Bathymetry Data) to ensure accuracy in representing seabed morphology and coastal geometry. Supporting data were complemented by peer-reviewed journal articles and technical reports relevant to tidal energy development. Economic parameters, including capital and operational costs, were obtained from official publications such as the Ministry of Energy and Mineral Resources (ESDM), national construction cost standards (SNI), and benchmark data from comparable tidal and hydropower infrastructure projects. Tidal data validation was performed using the Z-test to assess data consistency and reliability. The validation criteria applied a significance level of $\alpha = 0.05$, where data are considered statistically valid if the calculated Z-value falls within the acceptable range ($-1.96 \leq Z \leq 1.96$). This ensures that the dataset used represents typical tidal conditions without significant anomalies.

$$E_{annual} = \frac{\alpha.\eta.\rho.g.H_{avg}.V_{avg}}{3.6.10^{12}} \tag{1}$$

$\alpha$ (*Usable tidal cycles)* Represents the fraction of tidal cycles that can be effectively utilized for energy generation.
$\eta$ (*Power plant efficiency)* Indicates the efficiency of the tidal power plant in converting hydraulic energy into electrical energy.



$\rho$ (*Density)* Refers to the density of seawater used in energy calculations.
g (*Gravitational acceleration)* The acceleration due to gravity acting on the water mass.
$H_{avg}$ (*Average head)* The average water level difference (head) available for power generation.
$V_{avg}$ (*Average water volume)* The average volume of water involved in the tidal exchange.
$E_{annual}$ (*Annual extractable energy)* The total amount of energy that can be extracted and converted into electricity over one year.

## 3. RESULT AND DISCUSSION

Based on the data from BROL we found the tidal data at Ambon Bay from January 1, 2022 to December 31, 2022 as folows:

**Table 1.** *BROL Tide Data*

| Data | High Tide (m) | Low tide (m) | Range (m) |
|---|---|---|---|
| Mean | 0.564 | -0.538 | 1.102 |
| Med | 0.591 | -0.555 | 1.125 |
| Min | 0.092 | -1.287 | 0.003 |
| Max | 0.932 | 0.214 | 2.201 |

Tide Data from pasang laut is shown at the following table:

**Table 2.** Pasang Laut Tide Data

| Data | High Tide (m) | Low tide (m) | Range (m) |
|---|---|---|---|
| Mean | 1.624 | 0.611 | 1.013 |
| Med | 1.600 | 0.600 | 1.000 |
| Min | 1.100 | -0.200 | 0.000 |
| Max | 2.200 | 1.200 | 2.300 |

Data validity Z-test has been applied on the two data using the Microsoft Excel solver program with the following results:

**Table 3.** Z-test result

| Data | Result |
|---|---|
| z | 4.254 |
| P(Z<=z) one-tail | 1.048E-05 |
| z Critical one-tail | 1.645 |
| P(Z<=z) two-tail | 2.096E-05 |
| z Critical two-tail | 1.960 |

On average throughout the year, the tides in the Ambon area can be seen in the image below, with an average range of around 1.1 m.

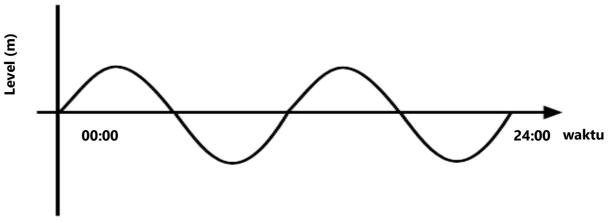
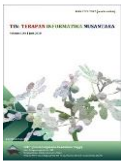


**Figure 2.** Average Tidal Wave at Ambon

The annual energy yield of the proposed tidal barrage power plant was estimated through a sequential calculation that applies real tide to the fundamental theoretical potential.

**Table 4.** Energy Calculation

| Items | Value | Unit |
|---|---|---|
| Basin Area | $10.59 \times 10^{6}$ | $m^{2}$ |
| Water Density | 1,030 | $kg/m^{3}$ |
| Gravity (g) | 9.81 | $m/s^{2}$ |
| Emax annual | 31.05 | GWh |
| $\alpha$ (% usable tides) | 0.96 | - |
| h usable (%) | 0.66 | - |



| Items | Value | Unit |
|---|---|---|
| η (Efficency PP) | 0.90 | - |
| Enet annual | 11.69 | GWh |

Basin area is 10.59 million $m^2$, seawater density of 1,030 $kg/m^3$ and gravitational acceleration of 9.81 $m/s^2$. Theoretical maximum energy, E_max annual, of 31.05 GWh, which is derived from the basin area, water density, gravity, and tide based on equation (1). The net annual energy generation, is therefore the product of the maximum theoretical energy and these three eficiency coefficients, resulting in a realistic expected output of approximately 11.69 GWh per year.

Based on the table below, the calculation for the Tidal Barrage Power Plant in Ambon reveals a system operating with a significant degree of intermittency, resulting in a relatively low capacity factor. The plant utilizes seven turbines with a combined installed capacity of 7 MW (7 x 1 MW).

**Table 5.** Capacity Calculation

| Item | Value | Unit |
|---|---|---|
| Interval Time | 6.64 | h |
| $Q_{avg}$ | 556.60 | $m^3/s$ |
| Power | 7.1 | MWp |
| Turbine Capacity | 7 x 1 | MW |
| Capacity Factor (CF) | 18.89% | |

The average interval between usable tidal energy periods is 6.64 hours and the average water flow rate (Qavg) is 556.60 $m^3/s$. The key metric, the Capacity Factor (CF), is calculated at 18.89%. This means the plant generates only about one-fifth of the maximum electrical energy it could theoretically produce if it ran at full capacity (7 MW) every hour of the year. This low CF is characteristic of tidal barrage plants, as their power generation is entirely dependent on the predictable yet periodic rise and fall of tides, leading to unavoidable downtime during slack water and periods when the tidal head is insufficient for generation (Hendinata et al., 2022).

Based on estimate construction cost on existing tidal barrage power plant, the largest plant, Shiwa (254 MW), has the lowest cost at IDR 64.8 million per kW. The medium-sized La Rance (240 MW) has a higher cost of IDR 91.3 million per kW. The smallest plant, Uldolmok (1.5 MW), has by far the highest cost at IDR 271.7 million per kW. Based on some construction data on bund construction in Indonesia shown in table below, the average on construction cost is about Rp 891.526/$m^3$.

**Table 6.** Dam Construction Cost

| No | Name | Construction Cost (IDR) |
|---|---|---|
| 1 | Meninting Dam (2025) | 1,400,000,000,000 |
| 2 | LausimeDam (2024) | 1,760,000,000,000 |
| 3 | Bagiong Dam (2025) | 1,670,000,000,000 |
| 4 | Bendo Dam (2021) | 1,100,000,000,000 |
| 5 | Randugunting Dam (2022) | 880,000,000,000 |
| 6 | Rukoh Dam (2024) | 1,800,000,000,000 |
| 7 | Sei Gong Dam (2024) | 238,440,000,000 |

The cost and economic feasibility calculations for a 7 MW tidal barrage Power Plant in Ambon Bay are shown in the table below. This project is the result of a study combining local technical data with reference data from similar plants such as Uldolmok and Sihwa Lake. The calculation show the LCOE of the project is aproximately Rp 15,324/ kWh.

**Table 7.** LCOE Calculation

| Item | Unit | Value |
|---|---|---|
| Capacity | MW | 7 |
| Civil Work (2025) | IDR | 156,310,956,501 |
| ME (2025) | IDR | 1,630,309,176,849 |
| Capital Cost | IDR | 1,786,620,133,350 |
| Capital Cost | IDR/ kW | 255,231,448 |
| Interest rate | % | 9.1% |
| Life Cycle | year | 30 |
| Capacity Factor | % | 18.89% |
| Internal Power Consumption | % | 2% |
| CRF | % | 9.82% |
| AC | - | 175,447,262,969 |
| Unit Generated | kWh/year | 11,685,977 |

| Item | Unit | Value |
|---|---|---|
| Fixed Capital Cost (FCC) | IDR/ kWh | 15,013 |
| O&M Cost | IDR / kWh | 311 |
| Unit Fuel Cost (UFC) | IDR / kWh | - |
| LCOE | IDR / kWh | 15.324 |

NPV calculation is show in tabel below. After all cash flows are discounted to the present value at an interest rate of 9.1%, the NPV result is negative Rp. 1,294.36 billion.

**Table 8.** NPV Calculation

| Items | Unit | Value |
|---|---|---|
| Electricity Rates | IDR/ kWh | 1,444.70 |
| Sales/ year | IDR | 16,882,730,952.12 |
| Sales | IDR | 171,920,761,342.24 |
| Investment cost | IDR | - 1,786,620,133,350.39 |
| Salvage value | IDR | 357,324,026,670.08 |
| Fuel cost/ year | IDR/year | - |
| Fuel cost | IDR | - |
| Repair & Maintenance Cost/year | IDR/year | 3,631,758,343.45 |
| Repair & Maintenance Cost | IDR | - 36,983,036,760.35 |
| NPV | IDR | -1,294,358,382,098.43 |

The analysis of the LCOE calculation for the Ambon Tidal Barrage Power Plant shows that although tidal power plants have the advantage of being renewable energy without fuel costs, their LCOE is still very high (Rp 15,324/kWh) compared to the average electricity tariff in Indonesia or other renewable energy plants such as solar power plants. This high cost is mainly driven by the very large initial investment for M&E equipment and a low Capacity Factor, so that the energy produced per year is relatively limited. The feasibility of such projects is highly dependent on government policies in the form of incentives or special financing schemes for new renewable energy technologies that are not yet commercially competitive (Rizal & Ningsih, 2020). The discussion highlights that Ambon Bay possesses considerable tidal energy potential, yet faces substantial economic constraints that limit its practical implementation. From a technical standpoint, the semi-diurnal tidal pattern, characterized by two high and two low tides daily, provides a predictable and reliable energy source. The average tidal range of approximately 1.1 meters, combined with the semi-enclosed geomorphology and natural constriction within the bay, creates favorable hydrodynamic conditions for the deployment of a tidal barrage system. These physical characteristics enhance the hydraulic head and improve the efficiency of energy extraction (Rufinaldo & Brent, 2025).

The estimated theoretical energy potential reaches 31.05 GWh annually; however, after incorporating real operational factors such as usable tidal cycles, system efficiency, and hydraulic losses, the net energy output decreases to 11.69 GWh per year. This reduction reflects the inherent limitations of tidal energy systems, where environmental variability and conversion inefficiencies significantly influence actual performance. Furthermore, the installed capacity of 7 MW with a capacity factor of 18.89% indicates that the system operates intermittently. Although tidal energy is highly predictable, it is not continuously available, as electricity generation only occurs during specific tidal phases. From an operational perspective, the relatively low capacity factor implies suboptimal utilization of installed infrastructure (Suryani et al., 2025). The plant cannot operate at full capacity throughout the year, resulting in limited annual electricity production compared to its maximum potential. This characteristic distinguishes tidal power from more stable energy sources such as geothermal or fossil-based generation, which typically achieve higher utilization rates (Rahmanta et al., 2025).

Economically, the project demonstrates significant challenges. The capital cost is notably high, exceeding IDR 255 million per kW, primarily driven by the complexity of marine infrastructure and mechanical-electrical components. Consequently, the Levelized Cost of Energy (LCOE) is estimated at IDR 15,324 per kWh, which is substantially higher than the average electricity tariff in Indonesia. The elevated LCOE is largely attributed to the combination of high initial investment and relatively low annual energy production (Latuconsina et al., 2022).

The financial feasibility analysis further reinforces this limitation, as indicated by a significantly negative Net Present Value (NPV). This outcome suggests that the projected revenue generated over the plant’s lifecycle is insufficient to offset the total investment and operational costs (Satriawan & Rosmiati, 2022). The negative NPV is mainly influenced by high upfront expenditures, limited revenue streams due to low capacity factors, and the absence of supportive economic mechanisms such as incentives or preferential tariffs (Boretti, 2020).

Despite these economic constraints, the development of tidal energy in Ambon Bay remains strategically important within the broader context of energy transition and diesel dependency reduction in archipelagic region (Rumerung & Siaila, 2023). The reliance on diesel-based power generation in remote areas underscores the need for alternative renewable sources (Bima Sakti et al., 2020). Therefore, policy interventions such as feed-in tariffs, capital subsidies, and green financing schemes are essential to enhance project viability (Amoussou et al., 2024). In addition, technological advancements aimed at reducing construction costs and improving turbine efficiency could significantly improve the competitiveness of tidal energy (Marwan et al., 2018).

The results of the economic analysis show that the Net Present Value (NPV) of the tidal barrage power plant development project is negative, indicating that the total present value of economic benefits generated over the project's lifetime is smaller than the total present value of investment, operation, and maintenance costs (Suparta, 2020). This condition indicates that, based on the technical and economic assumptions used in the study, the project is not yet financially feasible to be implemented at the scale and configuration analyzed. The negative NPV value is generally influenced by the high initial investment costs required for the construction of the (Lowan-Trudeau & Fowler, 2022)dam and supporting infrastructure, while the revenue generated from the sale of electrical energy is relatively limited due to suboptimal installed capacity, low capacity factors, or electricity tariffs that are not yet able to cover the total project costs (Petley et al., 2019).

From an economic perspective, negative NPV can be caused by high initial investment costs and long payback periods (Mia, 2021). Therefore, further studies are needed on financing schemes and policy support, such as renewable energy incentives, feed-in tariffs, or green financing mechanisms. Research can also be directed at analyzing indirect benefits (co-benefits), such as coastal protection, flood control, or coastal infrastructure development, which have the potential to increase the overall feasibility of the project.

## 4. CONCLUSION

This study demonstrates that Ambon Bay possesses a considerable tidal energy potential of 31.05 GWh per year, indicating strong prospects for marine renewable energy utilization in Eastern Indonesia. Based on technical evaluation, a tidal barrage power plant with an installed capacity of approximately 7.06 MW is capable of generating 11.69 GWh of net electrical energy annually, with a capacity factor of 18.9%. These results confirm that the semi-diurnal tidal characteristics and the natural bay constriction provide favorable conditions for energy extraction. From an economic perspective, the estimated capital cost of the project reaches IDR 255,231,448 per kW, reflecting the high investment required for marine-based infrastructure. The calculated Levelized Cost of Energy (LCOE) is IDR 15,324 per kWh, which is significantly higher than conventional electricity generation costs in Indonesia. Furthermore, the Net Present Value (NPV) is estimated at -IDR 1,294,358,382,098.43, indicating that the project is not financially viable under current economic conditions. Despite its technical feasibility, the development of a tidal barrage power plant in Ambon Bay remains economically challenging due to high capital expenditure and relatively low energy output. Therefore, achieving feasibility would require strategic interventions such as cost reduction through technological innovation, financial incentives, or policy support to enhance the competitiveness of tidal energy within the national energy mix.

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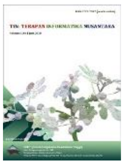

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