



Economic Value Analysis of Mine Void Water Utilization from PT Timah Tbk as a Micro-Hydro Power Energy Source for Community Energy Sustainability Around the Mining Area

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Abstract: Post-mining land in the form of a former pit (void) is one of the environmental legacies of open-pit tin mining that, if properly managed, can be transformed into a productive asset. This study analyses the economic value of utilizing void water from the PT Timah Tbk tin mine, Pemali Unit, Bangka Regency, as an energy source for a Micro-Hydro Power Plant (PLTMH) to support the energy sustainability of surrounding communities. A quantitative-descriptive approach was applied, combining primary data (water-quality testing, field observation, and a purposive-sampling questionnaire of the affected community and mine employees) with secondary data (climate records, company documents, and PLN electricity tariffs). Technical calculations show that the void, covering 55.43 ha with a reliable discharge of 1.1145 m³/s and an effective head of 13.5 m, can generate 112.17 kW of power, or 982,632 kWh of energy annually, enough to supply approximately 600–800 households. Economic feasibility was assessed with the extended Net Present Value (extended NPV) method covering direct and external benefits and costs from 2009 to 2025 at a discount rate of 5.82%. The results show a direct benefit value of Rp20,550,110,104, a direct cost value of Rp15,506,962,790, an external benefit value of Rp822,466,682, and an external cost value of Rp767,635,570, producing a positive total economic value of Rp37,647,175,146, indicating that the plan is financially and environmentally feasible. Socially, 92.5% of respondents supported void utilization for PLTMH, 89.2% expected a stable electricity supply, and 56.8% expected increased income, confirming that the project can strengthen community energy independence while restoring the ecological function of the mined-out void.

Keywords: Mine void, Micro-hydro power plant (PLTMH), Economic valuation, Extended net present value, Post-mining, Sustainable community energy.

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1. INTRODUCTION

Tin (Sn) is a mineral commodity of major strategic importance for the electronics, energy, and chemical industries, being widely used in solder, batteries, and electroplating agents. Indonesia is the world's second-largest tin producer after China, with output of around 40 thousand tonnes per year, most of which is concentrated in the Bangka Belitung Islands. Decades of open-pit and hydraulic tin mining in this region have produced extensive areas of disturbed land, part of which is left as a mine void, a pit that gradually fills with rainwater and groundwater once mining operations cease.

Government Regulation of the Ministry of Energy and Mineral Resources (Permen ESDM) No. 7 of 2014 obliges mining companies to carry out reclamation and post-mining activities that restore the ecological and social functions of disturbed land. A mine void, left unmanaged, can become an environmental liability like a source of acid mine drainage, a public-safety hazard, and a habitat disruption. However, when properly treated, the large volume of water retained in a void can instead become a strategic renewable-energy and water-resource asset, supporting reservoir functions, aquaculture, irrigation, raw-water supply, or hydropower generation.

A Micro-Hydro Power Plant (Pembangkit Listrik Tenaga Mikrohidro, PLTMH) is one of the most promising void-utilization options because it converts an already-existing water body and elevation difference into renewable electricity without requiring a new reservoir to be built. For communities living around the PT Timah Tbk mining area in Pemali, Bangka Regency, this is particularly relevant: electricity outages occur at least once a week, a large share of households still rely on diesel generators, and 15% of the sampled population reports no reliable connection to the state electricity grid (PLN).

Although the technical feasibility of PLTMH has been studied extensively, most previous research stops at power-generation calculations and rarely quantifies the economic value that void utilization can create for both the company and surrounding communities. This gap motivates the present study, which integrates technical assessment of void-water potential with an extended cost-benefit (extended Net Present Value) analysis that internalizes environmental externalities, in line with Government Regulation No. 46 of 2017 on environmental economic instruments.

1.1 Problem Statement

Based on the background above, this research addresses three questions: (1) What is the potential availability and characteristics of mine void water in the PT Timah Tbk area as a resource for a micro-hydro power plant? (2) What is the

economic value of utilizing PT Timah Tbk's void water for micro-hydro power development? and (3) How does void-water utilization as a micro-hydro energy source contribute to the energy sustainability of communities around the mining area?

1.2 Research Objectives

The objectives of this study are to determine (1) the availability and hydro-environmental characteristics of void water as a PLTMH resource; (2) the economic value of utilizing PT Timah Tbk's void water for PLTMH development using the extended NPV method; and (3) the contribution of void-based PLTMH to the energy sustainability of surrounding communities.

2. LITERATURE REVIEW

2.1 Post-Mining Void and Its Utilization

A mine void is a pit remaining after open-pit mining that cannot be backfilled because of a shortage of overburden material, and which is subsequently inundated by surface runoff and groundwater. Void classification distinguishes an existing void, formed while mining is still ongoing, from a final void, which forms after the mine's operational life ends. Several companies have already demonstrated productive void utilization: PT Adaro Indonesia and PD. Baramarta in South Kalimantan use coal-mine void water for freshwater aquaculture and raw-water supply, PT Nan Riang and PT Bukit Asam use void water for fish farming, while in West Virginia and Eastern Kentucky (United States) former mine pits supply raw water to nearby towns. These precedents show that with adequate water treatment, a mine void can shift from being a reclamation liability into a source of shared economic and ecological value.

2.2 Micro-Hydro Power Plants (PLTMH)

A PLTMH is a small-scale hydroelectric installation, generally producing less than a few hundred kilowatts, that converts the potential energy of a water head into electricity. Power output is governed by the discharge (Q), the effective head (H), gravitational acceleration (g), and overall system efficiency (η), following $P = \rho \cdot g \cdot Q \cdot H \cdot \eta$. Because PLTMH systems rely on relatively small discharges and heads, they are well suited to post-mining voids, which typically combine a large stored-water volume with a manageable elevation difference between the void surface and a downstream discharge point.

2.3 Economic Valuation of Environmental Resources

Conventional financial appraisal of energy projects, based on ordinary Net Present Value (NPV), considers only direct, marketed benefits and costs. Because void utilization simultaneously produces ecological services (water-quality restoration, flood attenuation, prevention of acid-mine-drainage discharge to rivers) and social externalities (local

employment, community welfare), an extended NPV approach is applied, which augments the conventional benefit–cost stream with external (non-market) benefits and costs, consistent with the three pillars of sustainable development economic, social, and environmental, and with the mandate of Government Regulation No. 46 of 2017 on environmental economic instruments.

3. RESEARCH METHODOLOGY

3.1 Research Type and Location

This research applies a quantitative, descriptive research design intended to describe the technical and economic value of void-water utilization for PLTMH. The study was conducted at PT Timah Tbk's Land Mining Unit, located in Pemali Village, Pemali Sub-district, Bangka Regency, Bangka Belitung Islands Province.

3.2 Data Collection

Data were collected through field surveys and a structured questionnaire administered using purposive sampling to residents affected by mining activities and to PT Timah Tbk employees. Primary data comprised laboratory water-quality tests at the inlet sump and outlet of the mining area, field observation of the void's physical and vegetative conditions, and questionnaire responses on socio-economic conditions, community electricity needs, and perceptions of void utilization. Secondary data included ten years of rainfall records (BMKG Kenten Palembang), company post-mining planning documents, PLN electricity tariffs and the Cost of Electricity Supply (BPP) for the South Sumatra, Bangka Belitung region, and Bank Indonesia's benchmark interest rate.

3.3 Data Analysis

Technical analysis estimated the void's stored-water volume, reliable discharge, effective head, and generated power and energy. Economic analysis applied the extended NPV method, which sums the present value of direct benefits (B), direct costs (C), external benefits (Be), and external costs (Ce) discounted at Bank Indonesia's 2025 average benchmark rate of 5.82%. Direct benefit was computed by multiplying the annually generated electrical energy by the prevailing electricity tariff, escalated at 1.19% per year; direct cost applied the Cost of Electricity Supply (BPP), escalated at 2.15% per year. External benefits (operator salaries) and external costs (maintenance) were escalated using Bangka Belitung's regional inflation rate. The valuation period spans 2009–2025, consistent with the mine's operating life and post-mining monitoring period, and 68.4% of surface run-off and groundwater recharge was assumed to enter the void annually, following the regional infiltration ratio used in comparable studies.

4. RESULTS AND DISCUSSION

4.1 Environmental Setting

The study area experiences a tropical climate with two seasons. Ten-year rainfall records show high inter-annual variability, ranging from 818 mm (2025, partial year) to 2,078.4 mm (2020), reflecting the region's dependence on rainfall for void recharge and, in turn, for PLTMH reliability. Vegetation surrounding the void shows a clear natural-succession pattern typical of reclaimed mine land, progressing from pioneer swamp grass and *Imperata cylindrica* through young *Falcataria* and *Acacia* stands toward secondary forest is a process that both stabilizes soil and helps sustain reservoir water availability.

4.2 Void Water Quality

Laboratory testing of surface water at the inlet sump and outlet of the tin-mining area, compared with Class I quality standards under Government Regulation No. 22 of 2021, indicates that several parameters exceed the standard. The pollution-index method classifies the inlet water as lightly polluted (index 2.89) and the outlet as moderately polluted (index 6.67). Table 1 summarizes the key parameters.

Table 1. Selected Water-Quality Parameters at the Inlet and Outlet of the PT Timah Tbk Void

Parameter	Unit	Standard	Inlet	Outlet
pH	–	6 – 9	4.95	6.01
Biochemical Oxygen Demand (BOD)	mg/L	2	2.5	2.2
Chemical Oxygen Demand (COD)	mg/L	10	15.7	13.4
Manganese (Mn)	mg/L	0.4	1.62	3.76
Total Suspended Solids	mg/L	25	22.0	5.74
Dissolved Oxygen	mg/L	6	5.41	5.62

Source: *Competitive Research Grant Laboratory Analysis, 2025.*

The acidic inlet pH (4.95) suggests oxidation of sulfide minerals producing acid mine drainage, while the rise toward neutral at the outlet (6.01) reflects natural neutralization from contact with carbonate rock. The manganese exceedance — up to 9.4 times the standard at the outlet — indicates leaching of manganese from the parent rock; dissolved manganese may later oxidize into MnO_2 precipitate, which risks clogging PLTMH turbine and pipeline components if the water is not pre-treated. These findings confirm that active or passive water treatment (neutralization with lime, aeration and sedimentation, or

passive wetland systems) is required before void water is channeled into a PLTMH system.

4.3 Community Perceptions and Socio-Economic Impact

Questionnaire analysis of residents and PT Timah Tbk employees around the mining area shows that all respondents (100%) consider the company's presence economically beneficial, mainly through partnerships with local entrepreneurs, opportunities for small trading and transport businesses, local employment, and soft-loan assistance. On the environmental side, no respondent still relies on river water for daily needs; households instead depend on wells and piped municipal water (PDAM), spending on average Rp75,000–Rp100,000 per month, largely because river water is perceived as unhygienic and located far from residences. Reported health complaints mainly colds and headaches are commonly associated with dust exposure from mining activity.

Regarding electricity, roughly 80% of respondents currently rely on PLN, 5% on a company electricity supplier, and 15% on private generators; weekly power outages are common. Household electricity use is concentrated at the lower end of the tariff scale, with 59% of respondents subscribing to 900 VA connections, 29% to 1,300 VA, and 12% to 2,200 VA, and typical monthly bills above Rp100,000.

On the specific plan to convert the void into a PLTMH, 92.5% of respondents agreed that such utilization is needed. Among expected benefits, 89.2% anticipated a stable electricity supply and 56.8% expected increased community income. Expectations for implementation centered on community participation: 67.6% wanted local residents prioritized for construction and operational jobs, 54.1% wanted rapid realization of the project, and 45.9% hoped for new business opportunities generated by the facility (e.g., catering, transport, or eco-tourism services).

4.4 Technical Assessment of PLTMH Potential

Based on the post-mining plan, the void formed by PT Timah Tbk's tin-mining activities covers a top area (Aa) of 55.43 ha and a bottom area (Ab) of 47.43 ha at a depth (h) of 100 m. Assuming 68.4% of surface run-off and groundwater infiltrates the void, the stored water volume is approximately 35,146,113 m³, giving a reliable discharge (Q) of 1.1145 m³/s. With an upstream elevation of 34 m above sea level and a downstream elevation of 19 m, the gross head is 15 m; after deducting 10% head losses, the effective head (Heff) is 13.5 m. Applying an overall system efficiency of 76%, the calculated power output is:

$$\begin{aligned}
 P &= \rho \cdot g \cdot Q \cdot H_{eff} \cdot \eta \\
 &= 9.81 \times 1.1145 \times 13.5 \times 0.76 \\
 &= 112.17 \text{ kW}
 \end{aligned}$$

Operating continuously across the year, this corresponds to an annual generated energy of 982,632 kWh (112.17 kW × 24 h × 365 days). Assuming an average household consumption of approximately 1,200 kWh per year for a 900 VA connection, this output is sufficient to supply electricity to approximately 600–800 households, which would meaningfully reduce dependence on the PLN grid and on private diesel generators, while also reducing local air pollutant and greenhouse-gas emissions associated with fossil-fuel combustion.

4.5 Economic Valuation of Void-Based PLTMH (Extended NPV)

The direct benefit of void utilization (B_{PLTMH}) is estimated by multiplying generated electrical energy by the prevailing electricity tariff. For the study year (2025), the energy output of 982,632.60 kWh valued at a tariff of Rp1,444/kWh yields a direct benefit of Rp1,419,609,312. When the same benefit is computed for the historical period 2009–2024 and re-expressed in 2025 prices using the extended-NPV discounting approach, the cumulative direct benefit reaches Rp33,898,591,444. Direct costs were computed analogously using the Cost of Electricity Supply (BPP) escalated at 2.15% per year, while external benefits (operator salaries, cumulatively about Rp1,317,938,448 over 2009–2025) and external costs (facility maintenance) were escalated using regional inflation.

Aggregating all present-value components at the 2025 valuation date, using a discount rate of 5.82%, produces the summary shown in Table 2.

Table 2. Total Present Value of Benefits and Costs of Void-Water Utilization for PLTMH (2025 Prices)

No.	Component	Total Present Value (Rp)
1	Direct benefit of void water for PLTMH (B_{PLTMH})	20,550,110,104
2	Direct cost of void utilization for PLTMH (C_{PLTMH})	15,506,962,790
3	External benefit of void utilization (B_{ePLTMH})	822,466,682
4	External cost of void utilization (C_{ePLTMH})	767,635,570
	Extended NPV	37,647,175,146

Source: Primary data, processed 2025.

The resulting extended NPV of Rp37,647,175,146 is positive, indicating that, once external environmental and social values are internalized, void-water utilization for

PLTMH is economically feasible and worth realizing. This finding is consistent with earlier extended-NPV studies of void utilization for raw-water supply at other Indonesian mines, and with related micro-hydro valuation studies for example, a micro-hydro scheme on the Enim watershed generated an estimated community benefit of Rp336,372,000, considerably smaller in scale but directionally consistent with the present findings. Notably, the present value of annual benefits declines by roughly 65.8% from 2009 to 2024 once discounting is applied, underscoring that the discount rate materially affects the economic attractiveness of long-horizon post-mining energy projects and that early realization of void-based PLTMH captures greater economic value than delayed implementation.

4.6 Contribution to Community Energy Sustainability

Beyond its aggregate monetary value, void-based PLTMH generates three mutually reinforcing forms of sustainability contribution. First, energy independence: an annual output of 982,632 kWh can supply 600–800 households, directly reducing dependence on the PLN grid and on costly diesel generators; earlier studies indicate that PLTMH-based electricity can cost communities as little as Rp12,000 per month, compared with Rp18,000–Rp30,000 for alternative sources. Second, socio-economic multiplier effects: the external benefit generated through local employment (an estimated Rp1,317,938,448 in cumulative wages) circulates through local shops, transport services, and small businesses, consistent with the 67.6% of respondents who prioritized local hiring and the 45.9% who anticipated new business opportunities. Third, environmental restoration: converting void water into an energy resource creates an incentive loop in which water quality must be improved (through treatment) before it can be used for power generation, and that improved water quality in turn protects downstream rivers from acid-mine-drainage contamination and creates habitat conditions supportive of freshwater biodiversity recovery.

Taken together, void-based PLTMH aligns the three pillars of corporate social responsibility with post-mining obligations: environmentally, it restores post-mining land function and manages water resources responsibly; socially, it provides clean and affordable energy access, employment, and community empowerment; and economically, it converts an asset previously regarded purely as a reclamation liability into a positive, quantifiable economic value for both company and community.

5. CONCLUSION

This study demonstrates that the mine void formed by PT Timah Tbk's tin-mining operations in Pemali, Bangka Regency, possesses strong potential as a source of renewable, community-scale electricity. The tropical climate

and high rainfall support sustained void-water availability, and although several water-quality parameters (pH, BOD, COD, manganese) currently exceed Class I standards, appropriate treatment can bring the water within standards suitable for PLTMH use. The technical assessment indicates the void can generate 112.17 kW of power, equivalent to 982,632 kWh annually enough to serve approximately 600–800 households while all surveyed community members supported the plan.

Economically, the extended NPV analysis produced a direct benefit value of Rp20,550,110,104, a direct cost value of Rp15,506,962,790, an external benefit value of Rp822,466,682, and an external cost value of Rp767,635,570, culminating in a positive total economic value of Rp37,647,175,146 is confirming that the void-utilization plan for PLTMH is economically feasible and worth implementing. Socially and environmentally, the project contributes to community energy independence, creates local employment and business opportunities, and supports the restoration of water quality and ecological function in the mined-out area, thereby reinforcing sustainable post-mining land management.

6. RECOMMENDATIONS

The economic valuation approach used in this study can serve the Ministry of Energy and Mineral Resources (ESDM) as a basis for shaping sustainable post-mining energy policy for PT Timah Tbk and other mining operators seeking to determine the financial, social, and environmental feasibility of void utilization once mining activities conclude. Further research is recommended to examine additional post-mining void uses not covered in this study such as recreational development or final waste-processing sites to broaden the range of economic and social benefits that post-mining land can generate.

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