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Energy Recovery from Cooling Tower Blowdown Water for Micro-Hydropower Generation: A Case Study at Asam Asam Coal-Fired Power Plant

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ABSTRACT

The global electricity sector faces increasing pressure to maintain reliable supply while reducing greenhouse gas emissions. In coal-fired power plants, cooling tower blowdown water is typically discharged as wastewater, despite containing hydraulic energy potential. This study aims to evaluate the technical, environmental, and financial feasibility of utilizing cooling tower blowdown water for low-head micro-hydropower generation at the Asam Asam Coal-Fired Power Plant in South Kalimantan, Indonesia. The research methodology combines field measurements of flow and head, hydraulic and turbine design, annual energy modeling, carbon emission reduction estimation, and financial analysis including NPV, IRR, Payback Period, and LCOE. Results indicate that the selected cooling towers, with a Q_{40} discharge of 0.15 m^3/s and gross head of 4 m, can generate 25,379–25,996 kWh/year, supplying approximately 85.42% of the mosque's annual energy demand. The system can reduce CO_2 emissions by 31.80–32.57 tons per year and demonstrates financial feasibility with an NPV of IDR 43,043,390.85 and a payback period of just over seven years. In conclusion, cooling tower blowdown water represents a viable energy recovery source, contributing to operational sustainability and emission reduction. The study recommends future exploration of hybrid energy systems and optimization for larger-scale industrial applications.

INTRODUCTION

The global electricity sector faces a dual challenge: maintaining reliable electricity supply while reducing greenhouse gas emissions (Aryai & Goldsworthy, 2022; Kabeyi & Olanrewaju, 2022). The global renewable energy report indicates that the integration of renewable energy and energy efficiency has become an important strategy in the transition of energy systems (REN21, 2024). In Indonesia, this direction is also reflected in the 2025–2034 Electricity Supply Business Plan (RUPTL), which emphasizes increasing the renewable energy mix and supporting the net zero emission target (PT PLN, 2025). In this context, improving energy efficiency in existing power generation facilities and utilizing residual energy potential are relevant to supporting emission reduction and reducing power plant auxiliary consumption.

In coal-fired power plants that use recirculating cooling systems, cooling towers play an important role in rejecting heat from the condenser to the atmosphere and maintaining the thermal efficiency of the power plant. Laković et al. (2013) explain that the performance of evaporative cooling systems in coal-fired power plants significantly affects plant operation because these systems determine the effectiveness of heat rejection. To maintain cooling water quality and prevent an increase in dissolved solids concentration, a portion of the circulating water is discharged as blowdown water. Previous studies on cooling tower blowdown water have generally focused on water treatment and recovery through reverse osmosis, electrodialysis, direct contact membrane distillation, and other membrane technologies (Ahmed et al., 2020; Soliman et al., 2022; Meng et al., 2024; Li et al., 2025). However, these studies have not specifically addressed the utilization of the hydraulic energy potential of blowdown flow as a source for micro-scale power generation.

Micro-Hydropower Plants (MHPs) are a potential technology for recovering energy from small water flows with low head. Alexander et al. (2009) showed that axial-flow turbines can be developed for low-head micro-hydropower systems within a head range of approximately 2–9 m. Kaunda et al. (2014) also emphasized that selecting the appropriate turbine type based on the combination of discharge and head is an important factor in the success of micro-hydropower systems. Most current micro-hydropower studies still focus on natural water sources, such as rivers, irrigation canals, dams, reservoirs, or rural streams (Hisyam et al., 2024; Rumbayan & Rumbayan, 2023; Syahputra & Soesanti, 2021). In contrast, the utilization of industrial wastewater flows, particularly cooling tower blowdown water in operating coal-fired power plants, remains very limited.

The global energy sector faces an urgent dual challenge: ensuring reliable electricity supply while simultaneously reducing greenhouse gas emissions. According to the Renewable Energy Global Status Report (REN21, 2024), integrating renewable energy and improving energy efficiency have become essential strategies in transitioning energy systems toward sustainability. This challenge is particularly pronounced in countries with a high dependence on coal-fired power plants, where substantial portions of thermal energy are lost through cooling processes. Efficient utilization of residual energy sources is increasingly recognized as a viable solution to enhance energy efficiency and reduce carbon footprints.

Coal-fired power plants commonly employ recirculating cooling systems with cooling towers to maintain condenser efficiency and thermal balance. Research by Laković et al. (2013) demonstrates that the performance of evaporative cooling systems directly impacts plant operation, as effective heat rejection ensures stable electricity generation. During operation, a portion of circulating water is discharged as blowdown water to control dissolved solids, traditionally viewed as wastewater. Despite this, the blowdown flow contains hydraulic energy potential that remains largely untapped in conventional plant operations.

Previous studies on cooling tower blowdown water have primarily focused on water treatment and recovery through technologies such as reverse osmosis, electrodialysis, and membrane distillation (Ahmed et al., 2020; Soliman et al., 2022; Meng et al., 2024; Li et al., 2025). While these approaches address water conservation, they do not explore the use of the hydraulic energy inherent in blowdown flow as a source for micro-scale power generation. This gap highlights an opportunity to consider industrial wastewater streams as renewable energy resources.

Micro-hydropower plants (MHPs) provide a technological avenue for harnessing energy from small water flows with low heads. Alexander et al. (2009) demonstrated that axial-flow turbines can effectively operate within head ranges of 2–9 meters for low-head micro-hydropower applications, while Kaunda et al. (2014) emphasize the importance of matching turbine type to site-specific head and discharge characteristics. Nonetheless, most contemporary MHP studies focus on natural water sources such as rivers, irrigation canals, and dams, with limited exploration of industrial water flows as energy sources (Hisyam et al., 2024; Rumbayan & Rumbayan, 2023; Syahputra & Soesanti, 2021).

In Indonesia, coal-fired plants such as the Asam Asam Coal-Fired Power Plant in South Kalimantan generate continuous blowdown water through multiple cooling tower groups. Operational data indicate that these plants are critical to regional electricity supply (PT PLN UIP3B Kalimantan, 2025). The potential to convert the hydraulic energy of blowdown flow into electricity via low-head MHPs represents a practical approach to supplement internal electricity demands and reduce reliance on external grid supply, contributing to more sustainable plant operations.

The research gap is evident: while water recovery methods for blowdown water are widely studied, the use of its hydraulic energy for on-site power generation remains unexplored. By investigating the feasibility of deploying MHPs to recover energy from blowdown flows, this study addresses an overlooked opportunity in the nexus of industrial wastewater management and renewable energy generation. Such an approach aligns with global energy efficiency targets and offers site-specific carbon emission reductions.

The urgency of this research is reinforced by Indonesia's national electricity strategy, as outlined in the 2025–2034 Electricity Supply Business Plan (RUPTL), which emphasizes increasing renewable energy share and supporting net-zero emissions targets (PT PLN, 2025). Implementing micro-hydropower solutions using existing industrial flows can directly contribute to these objectives while mitigating the environmental impact of conventional coal-fired power plants.

The novelty of this study lies in repositioning cooling tower blowdown water from a waste stream to a renewable energy source. Unlike previous studies that focused on water treatment for conservation purposes (Ahmed et al., 2020; Meng et al., 2024), this research integrates hydraulic analysis, turbine selection, energy modeling, carbon emission reduction assessment, and financial feasibility evaluation to comprehensively explore micro-hydropower generation from industrial water flows.

The purpose of this study is to evaluate the technical, environmental, and financial feasibility of utilizing cooling tower blowdown water as a source for micro-hydropower generation. By optimizing penstock diameter, selecting appropriate turbines, and modeling energy output under operational schedules, the research aims to establish an operational framework for low-head MHP applications in coal-fired power plants.

Finally, this study contributes to both theory and practice by demonstrating the applicability of industrial wastewater flows for renewable energy generation. It provides plant operators with actionable strategies to reduce operational carbon emissions, lower electricity consumption, and enhance energy sustainability. The research objectives are to measure hydraulic potential, design an optimal MHP system, and assess energy and financial performance, while the anticipated benefits include emission reduction, cost savings, and scalable application for similar facilities.

METHOD

This study was conducted at the Asam Asam Coal-Fired Power Plant, located in South Kalimantan Province, with geographical coordinates at latitude -3.9271088 and longitude 115.1068497 as shown in figure 1. The main object of this study is the blowdown water system of the cooling towers of Units 1 and 2, which was selected because it has a gravity-based discharge flow and has the potential to be utilized as an energy source for a Micro-Hydropower Plant (MHP).

This study uses an engineering design and feasibility analysis approach. The research stages consist of field surveys, hydraulic data acquisition, hydraulic and electromechanical design, annual energy modeling, and environmental and financial analysis. A similar approach is commonly used in micro-hydropower feasibility studies, which combine flow rate and head measurements, determination of main components, energy production estimation, and economic evaluation (Nashrulloh et al., 2021; Bawan et al., 2024; Putri et al., 2024).

Figure 1 Asam Asam Coal-Fired Power Plant

The blowdown discharge was measured directly in the drainage channel as shown in figure 2. The flow velocity was obtained using an optocoupler-based measuring device, while the channel width and water depth were measured manually. The discharge was calculated using the continuity equation, defined as:

$$Q = v \times h \times l \tag{1}$$

where Q is the flow discharge, v is the average flow velocity, h is the water depth, and l is the channel width.

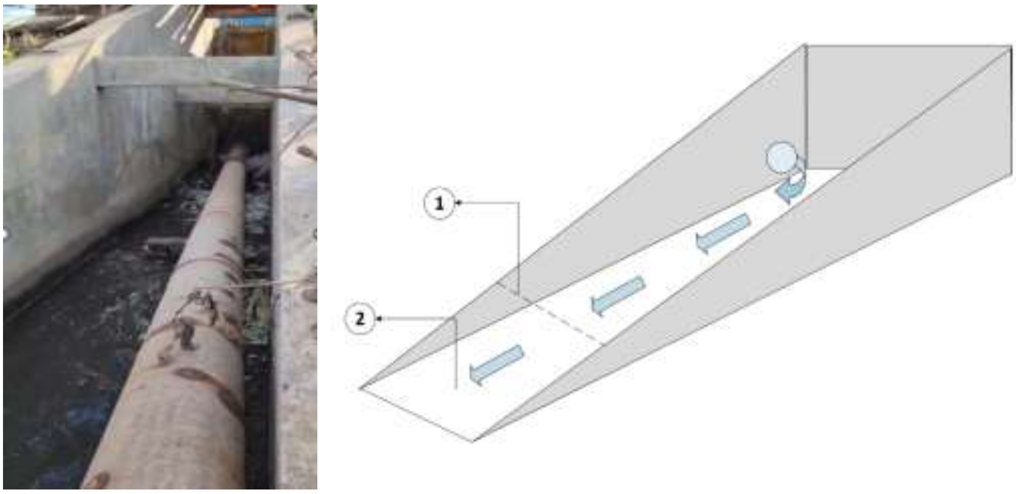

Figure 2 Measurement point location of blowdown water discharge from the cooling towers of Units 1 and 2.

Flow duration curve analysis was used to determine the reliable discharge. In this study, Q40 was selected as the design discharge because it is considered to represent a balance between generation capacity and operational continuity (Ngoma, 2020). The flow duration curve-based approach is commonly used in hydropower potential assessments because it can describe discharge availability throughout the observation period and help determine a design discharge that is not based solely on a momentary maximum value (Hisyam et al., 2024; Nashrulloh et al., 2021).

The hydraulic design of the penstock was carried out by calculating the theoretical hydraulic power, cross-sectional area, flow velocity, Reynolds number, Swamee–Jain friction factor, major losses, minor losses, total head loss, net head, and electrical output power. The Darcy–Weisbach equation and the Swamee–Jain friction factor approach were used because the flow in the penstock at the design discharge is in the turbulent regime. In low-head micro-hydropower systems, hydraulic losses must be carefully considered because even relatively small energy losses can significantly reduce the percentage of net head (Alexander et al., 2009; Kaunda et al., 2014).

The theoretical hydraulic power, defined as:

$$P_h = \rho g Q H_g \qquad (2)$$

Where ρ is the density of water (kg/m³), g is the gravitational acceleration (m/s²), Q is the flow discharge (m³/s), and H_g is the gross head (m).

Cross-sectional area, defined as:

$$A = \frac{\pi D^2}{4} \qquad (3)$$

Where A is the cross-sectional area (m²), and D is the penstock diameter (m).

The average flow velocity, defined as:

$$V = \frac{Q}{A} \qquad (4)$$

Where A is the cross-sectional area (m²), and D is the penstock diameter (m).

Reynolds number, Swamee-Jain friction factor, define as:

$$Re = \frac{VD}{\nu} \tag{5}$$

$$f = \frac{0.25}{\left[\log_{10}\left(\frac{\varepsilon}{3.7D}+\frac{5.74}{Re^{0.9}}\right)\right]^2} \tag{6}$$

$$h_f = f\frac{L}{D}\frac{V^2}{2g} \tag{7}$$

$$h_m = \sum K\frac{V^2}{2g} \tag{8}$$

$$h_t = h_f + h_m \tag{9}$$

Where Re is Reynolds number, ν is kinematic viscosity of the fluid (m^2/s), f is the Darcy friction factor, ε is the absolute roughness of the pipe, h_f is the major head loss, h_m is the minor head loss, $\sum K$ is the total minor loss coefficient, h_t is the total head loss.

Electrical Power Output, define as:

$$P_{net} = \rho g Q H_{net} \eta_{tot} \tag{10}$$

Where ρ is the density of water (kg/m^3), g is the gravitational acceleration (m/s^2), Q is the flow discharge (m^3/s), and $H_{net}$is the gross head (m), $\eta_{tot}$is total system eficiency.

Annual energy modeling considered the maintenance schedules of Units 1 and 2. The maintenance schedules used include a Simple Inspection for 26 days, a Mean Inspection for 40 days, and a Serious Inspection for 55 days. Integrating operational aspects and unit availability into energy estimation is important because the annual performance of renewable energy generation is not only determined by installed capacity, but also by the availability of the energy source and the operating pattern of the system (Poudel et al.,2020; Lugaueret et al., 2021).

The carbon emission reduction analysis was calculated based on the electricity generated by the MHP and the emission intensity of the existing coal-fired power generation system. In 2025, the gross electricity production of Asam Asam Coal-Fired Power Plant was 1,578,050,349 kWh, while cumulative coal consumption reached 1,199,214 tons. The emission calculation used coal carbon content, oxidation factor, and the molecular weight ratio of CO_2 to carbon, as commonly applied in energy sector emission inventories. Financially, the evaluation was conducted using NPV, IRR, Payback Period, and LCOE, which are common indicators for assessing the investment feasibility of renewable energy power generation projects (IRENA, 2012; Rumbayan, 2023).

RESULTS AND DISCUSSION

The cooling towers of Units 1 and 2 have a gravity-based blowdown discharge system. Direct measurement results showed that the discharge ranged from 0.07 to 0.19 m^3/s. Based on the flow duration curve, the Q40 value was approximately 0.15 m^3/s. This value is considered feasible as the design basis because it provides a balance between power capacity and operational continuity. The selection of this reliable discharge is in line with micro-hydropower design principles, which emphasize the suitability between discharge availability and the continuity of power plant operation (Kaunda et al., 2014).

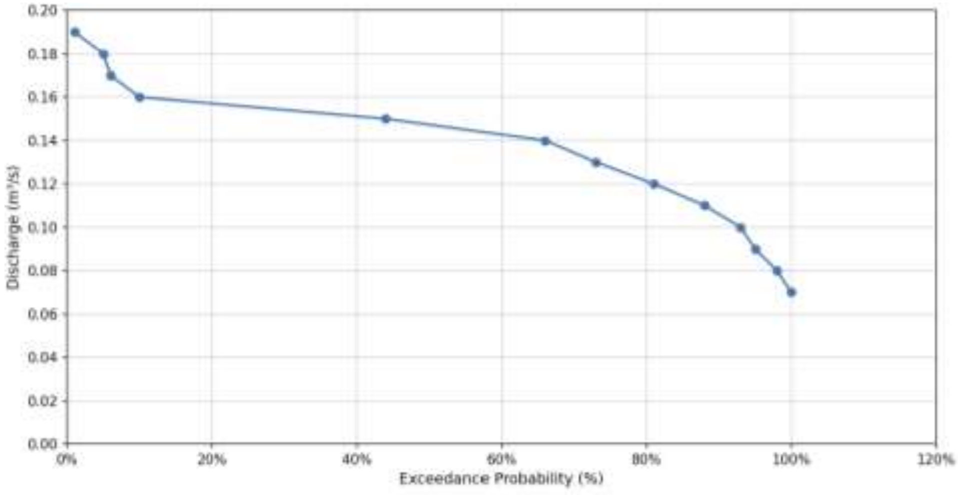

Figure 3 Flow duration curve of cooling tower blowdown water unit 1 & 2

Penstock Diameter Optimization

The penstock diameter significantly affects flow velocity, head loss, net head, and output power. Table 1 presents the hydraulic calculation results for three penstock diameter variations under full-discharge and partial-discharge conditions. In low-head micro-hydropower systems, penstock optimization is a critical aspect because friction losses and minor losses can reduce the effective head available for the turbine (Alexander et al., 2009; Marliansyah et al., 2018).

Table 1. Hydraulic performance comparison for different penstock diameter variations.

Penstock diameter (mm)	Q (m3/s)	Gross head (m)	Velocity (m/s)	Total head loss (m)	Net head (m)	Output (kW)
250	0,150	4,000	3,057	1,337	2,663	2,351
250	0,075	4,000	1,529	0,337	3,663	1,617
300	0,150	4,000	2,123	0,633	3,367	2,973
300	0,075	4,000	1,062	0,159	3,841	1,695
350	0,150	4,000	1,560	0,337	3,663	3,234
350	0,075	4,000	0,780	0,085	3,915	1,728

Sourch: Hydraulic calculations from measured blowdown flow and head.

Table 1 shows that increasing the penstock diameter reduces flow velocity and significantly decreases head loss. At a full discharge of 0.150 m^3/s, the 250 mm penstock produces a total head loss of 1.337 m, leaving only 2.663 m of net head. When the diameter is increased to 300 mm, the total head loss decreases to 0.633 m and the net head increases to 3.367 m. The 350 mm diameter provides the best performance, with a total head loss of only 0.337 m and a net head of 3.663 m.

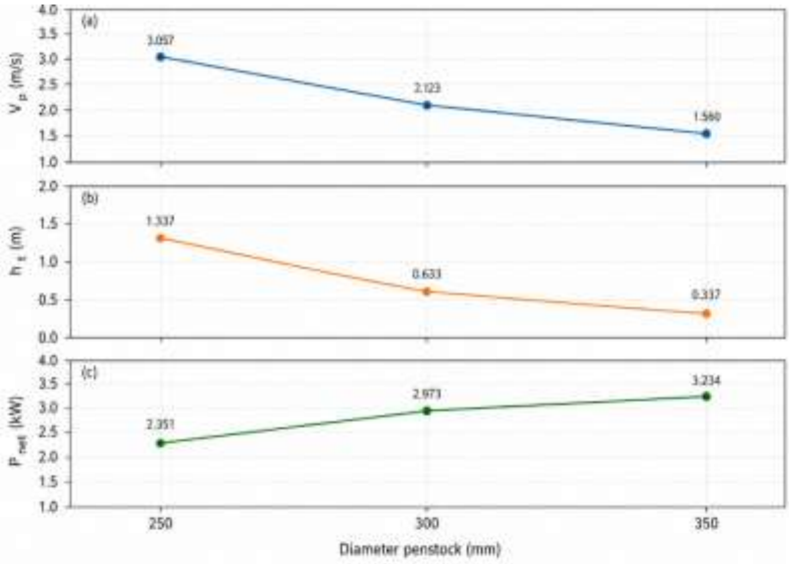

Figure 4 Effect of penstock diameter on flow velocity, total head loss, and output power under full-operation mode (Q = 0,150 m^3/s)

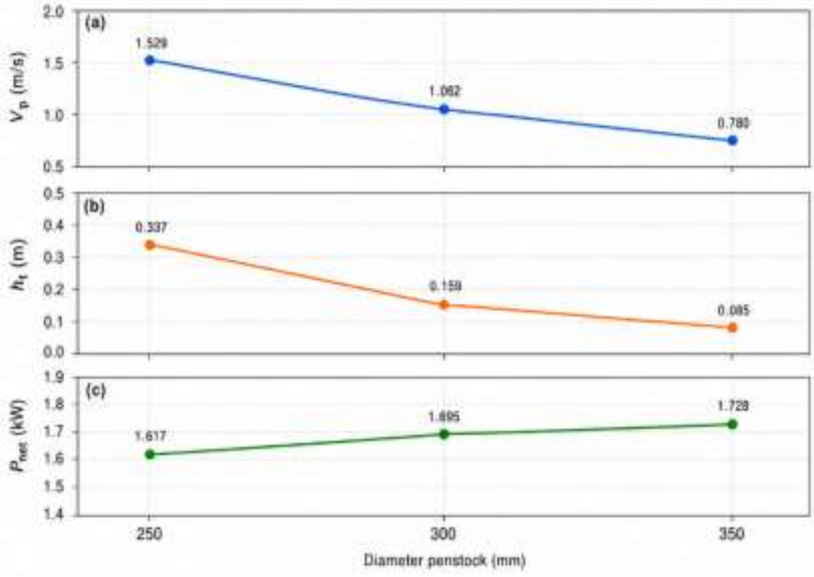

Figure 5 Effect of penstock diameter on flow velocity, total head loss, and output power under partial-operation mode (Q = 0,075 m^3/s)

Figure 4 and figure 5 show that the net output power also increases as the penstock diameter becomes larger. In full-operation mode, the power output increases from 2.351 kW with a 250 mm diameter to 2.973 kW with a 300 mm diameter, and reaches 3.234 kW with a 350 mm diameter. In partial-operation mode, the power increase is not as significant as in full-operation mode because hydraulic losses at lower discharge are already relatively small. However, the 350 mm diameter still provides the highest output power, at 1.728 kW. Therefore, the 350 mm penstock diameter was selected as the optimal diameter.

Turbine and Generator Selection

The selected location has a gross head of 4 m and a design discharge of 0.15 m^3/s. Based on the head-discharge characteristics, the most suitable turbine type is a propeller or Kaplan reaction turbine as shown in figure 6. This type of turbine is appropriate for low-head applications with relatively high discharge because it can operate under continuous low-pressure flow. This is in line with the study by (Alexander et al., 2009), which showed that axial-flow turbines are suitable for low-head micro-hydropower applications, as well as with the discussion by (Kaunda et al., 2014) regarding the importance of turbine selection based on discharge and head characteristics.

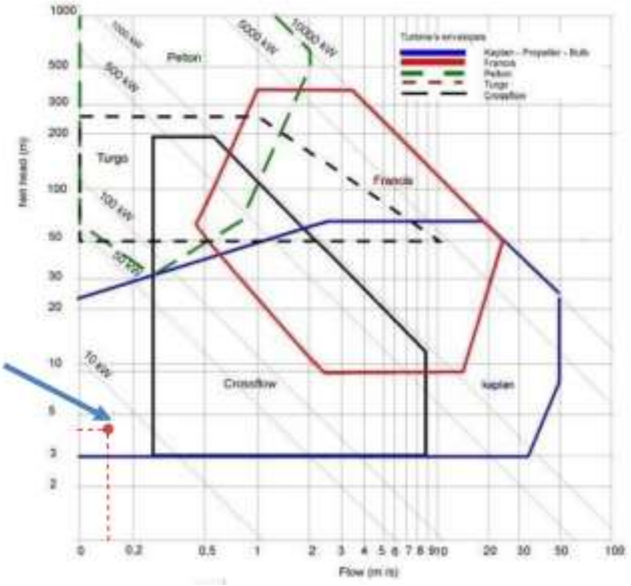

Figure 6 Turbine type selection based on Q-H characteristics of cooling tower blowdown water at Asam Asam Coal-Fired Power Plant (sangal et al,. 2013).

The selected generator is a TECO asynchronous generator with a voltage of 220/380 V, a frequency of 50 Hz, a capacity of approximately 5.5 hp or 4 kW, and a rotational speed of 1500 rpm. This capacity is compatible with the full-load output power of 3.23 kW and still provides a margin for variations in discharge, head, and system losses. The asynchronous generator was selected because of its simple and robust construction, relatively low maintenance requirements, and ease of integration with internal low-voltage loads. These characteristics make asynchronous generators commonly used in small-scale micro-hydropower applications that require simple and reliable systems (Kaunda et al., 2014; Riaz et al., 2018).

Annual Energy Production and Contribution to the Mosque Load

Annual energy production was calculated by considering full-operation and partial-operation modes resulting from the overhaul schedule. In full-operation mode, two cooling towers supply the blowdown flow, allowing the system to generate 3.23 kW. In partial-operation mode, only one cooling tower supplies the blowdown flow, reducing the output power to 1.73 kW. This operation-mode-based modeling is important because the annual energy production of a micro-hydropower system is strongly influenced by discharge availability and effective operating hours.

Table 2. Annual energy production based on the overhaul schedule.

Year	Partial operation mode (days)	Full operation mode (days)	Energy from partial operation mode (kWh)	Energy from full operation mode (kWh)	Total energy (kWh/year)
2026	81	284	3.363,12	22.015,68	25.378,80
2027	66	299	2.740,32	23.178,48	25.918,80
2028	66	300	2.740,32	23.256,00	25.996,32
2029	81	284	3.363,12	22.015,68	25.378,80
2030	81	284	3.363,12	22.015,68	25.378,80
2031	66	299	2.740,32	23.178,48	25.918,80
2032	66	300	2.740,32	23.256,00	25.996,32
2033	81	284	3.363,12	22.015,68	25.378,80
2034	81	284	3.363,12	22.015,68	25.378,80

Sourch: Modeled annual MHP energy based on operation schedule.

Table 2 shows that annual energy production ranges from 25,378.80 to 25,996.32 kWh/year. The highest energy production occurs in years with a greater number of full-operation days, while lower energy production occurs in years with longer partial-operation durations. However, the variation in energy production between years is relatively small, indicating that the system can be considered to have stable energy production despite being affected by the maintenance schedule.

Table 3. Summary of the Mosque Load Profile

Indicator	Value	Unit
Measured peak power	9,336	kW
Measured minimum power	1,958	kW
Representative daily average power	3,392	kW
Representative daily energy	81,402	kWh/day
Equivalent annual energy (365 days)	29711,666	kWh/year

Sourch: Measured mosque electricity demand.

Compared with the mosque's annual energy demand of 29,711.67 kWh/year as shown in table 3, the MHP is able to supply approximately 85.42% of the energy demand in 2026. The remaining demand of approximately 4,332.87 kWh/year still needs to be supplied by the existing electrical system. This indicates that the MHP is suitable as a base-load supply source, but it cannot fully replace the main electricity supply, especially during peak-load periods.

Carbon Emission Reduction

Based on coal consumption in 2025, the annual CO_2 emissions of Asam Asam Coal-Fired Power Plant were estimated at 1,977,049.78 tons of CO_2/year. When compared with the annual gross electricity production, the emission intensity was approximately 1.25 $kgCO_2/kWh$. Using this emission intensity, the potential emission reduction from MHP generation is shown in Table 4.

Table 4 Estimated CO_2 emission reduction from MHP generation

Year	MHP energy (kWh)	Emission reduction (ton CO2/tahun)	Cumulative emission reduction (ton CO2)
2026	25.378,80	31,80	31,80
2027	25.918,80	32,47	64,27
2028	25.996,32	32,57	96,84
2029	25.378,80	31,80	128,63
2030	25.378,80	31,80	160,43
2031	25.918,80	32,47	192,90
2032	25.996,32	32,57	225,47
2033	25.378,80	31,80	257,27
2034	25.378,80	31,80	289,06

Sourch: CO_2 reduction calculated from MHP output and coal emission factor.

The MHP system is capable of reducing emissions by 31.80–32.57 tons of CO_2/year. Although this value is relatively small compared with the total emissions of the coal-fired power plant, its benefit remains important as a form of operational decarbonization at the facility scale. In the context of energy transition, emission reductions through energy efficiency and the utilization of local renewable energy sources are relevant supporting strategies, particularly for reducing energy consumption from fossil-based systems (REN21, 2024; PT PLN, 2025). During the 2026–2034 period, the cumulative emission reduction reaches 289.06 tons of CO_2.

Financial Feasibility

The annual financial benefit was calculated by multiplying the electricity generated by the MHP by the electricity tariff of IDR 1,699.53/kWh as shown in table 5. The annual gross savings range from approximately IDR 43.13 million to IDR 44.18 million. After deducting the annual O&M cost of IDR 9.52 million, the annual net cash flow ranges from approximately IDR 33.61 million to IDR 34.66 million.

Table 5. Financial assumptions

Parameter	Value
Initial investment cost	IDR 238.053.375
Annual O&M cost	IDR 9.522.135
Electricity tariff	IDR 1.699,53/kWh
Project lifetime	15 years
Discount rate	8,63%

Sourch: Financial data from investment, O&M, and tariff assumptions.

Table 6. Financial feasibility results

Indicator	Result	Feasibility criteria	Interpretation
Net Present Value	IDR 43.043.390,85	> 0	Feasible
Internal Rate of Return	11,55%	> 8,63%	Feasible
Payback Period	7 years 1 Month	< 15 years	Feasible
Levelized Cost of Electricity	IDR 1.496,08/kWh	Competitive against the tariff	Feasible

Sourch: Financial data from investment, O&M, and tariff assumptions.

Table 6 shows that a positive NPV indicates that the project is capable of generating added value over its operating lifetime. The IRR of 11.55% is higher than the WACC of 8.63%, indicating that the project's rate of return exceeds the cost of capital. The Payback Period of 7 years and 1 month is also considerably shorter than the 15-year project lifetime. In addition, the LCOE of IDR 1,496.08/kWh is lower than the electricity tariff used in the savings calculation, indicating that the generated energy is economically competitive. The use of NPV, IRR, Payback Period, and LCOE indicators is consistent with common practices in assessing the feasibility of renewable energy and micro-hydropower projects (IRENA, 2012; Rumbayan, 2023; Nashrulloh et al., 2021).

Technically, the results of this study show that cooling tower blowdown water can serve as an energy source for MHP if the flow is gravity-based, has sufficient reliable discharge, and provides usable head. This finding expands the scope of micro-hydropower research, which has so far been more commonly applied to rivers, dams, reservoirs, or rural water systems (Syahputra and Soesanti, 2021; Hisyam et al., 2024; Bawan et al., 2024). Thus, the main novelty of this study lies in the utilization of industrial wastewater flow as a micro-scale hydraulic energy source without interfering with the main cooling process of the coal-fired power plant.

CONCLUSION

This study concludes that cooling tower blowdown water at the Asam Asam Coal-Fired Power Plant can be effectively utilized as a source for low-head micro-hydropower generation. The selected cooling towers, with a gravity-based flow, reliable Q40 discharge of 0.15 m^3/s, and a gross head of 4 m, proved technically feasible for micro-hydropower implementation. Optimizing the penstock diameter to 350 mm maximized net head and output power, achieving an annual energy production of approximately 25,379–25,996 kWh, which can supply 85.42% of the internal electricity demand of the on-site mosque. The system also contributes to carbon emission reduction of 31.8–32.57 tons CO_2 per year and demonstrates financial viability with a positive NPV, IRR above the cost of capital, and a payback period of just over seven years. Overall, the research validates industrial wastewater flows as a practical and replicable renewable energy source, offering operational sustainability and emission mitigation for coal-fired power plants.

For future research, it is recommended to explore scaling the system to supply larger facility loads or integrating multiple industrial water streams to enhance energy recovery potential. Further studies could investigate hybrid configurations combining micro-hydropower with solar photovoltaic or energy storage systems to increase reliability and flexibility in industrial power supply. Additionally, research into the long-term operational performance, maintenance optimization, and potential environmental impacts of micro-hydropower in coal-fired plants will provide a more comprehensive framework for adopting this approach across similar facilities and other industrial contexts.

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