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A Review of Micro-Hydro Power Plant Technology and its Socio-Economic Impact on Rural Electrification in Indonesia

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ABSTRACT

Background: Access to electricity in rural areas of Indonesia remains limited, leading to socio-economic challenges such as low productivity, limited education opportunities, and inadequate healthcare services. Micro-hydro power plants (MHPP) have emerged as a promising solution to support rural electrification, offering renewable, decentralized energy sources suitable for remote communities.

Objective: This study aims to review the development and application of micro-hydro power plant technology in Indonesia, analyzing its technical characteristics and evaluating its socio-economic impacts on rural communities.

Methodology: A systematic literature review was conducted, encompassing peer-reviewed articles, government reports, and case studies from various rural regions in Indonesia. The analysis focused on technical specifications, implementation strategies, community involvement, and socio-economic outcomes associated with micro-hydro projects.

Results: Findings indicate that MHPP technology in Indonesia has demonstrated reliable energy generation with capacities ranging from 5 kW to 100 kW, suitable for small communities. Socio-economic benefits include increased household income, improved educational access, enhanced local business development, and strengthened community cohesion. However, challenges such as high initial investment, technical maintenance requirements, and limited technical expertise in rural areas have constrained widespread adoption. Community participation and government support were identified as critical factors for project sustainability.

Conclusion: Micro-hydro power plants present an effective approach to rural electrification in Indonesia, with significant socio-economic benefits when supported by local engagement and institutional frameworks. Future policies should focus on reducing technical and financial barriers to maximize the positive impact of MHPP on rural development.

KEYWORDS

Rural Electrification, Renewable Energy, Socio-Economic Impact

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INTRODUCTION

Rural electrification remains a persistent challenge in Indonesia, where many remote communities lack reliable access to the national power grid. Traditional grid extension projects are often economically unfeasible due to geographical constraints and low population density. Micro-hydro power plants (MHPs) have emerged as a promising decentralized energy solution, harnessing the kinetic energy of small rivers and streams to generate electricity locally (IsmailMarzuki dkk., 2025; Saputra dkk., 2024). Previous studies have highlighted the technical feasibility of micro-hydro systems, emphasizing their efficiency in converting hydropower into electricity in small-scale applications.

MHPs typically operate at capacities ranging from a few kilowatts to several hundred kilowatts, making them suitable for village-level electrification. These systems require relatively low investment compared to large hydroelectric projects and can be customized to local hydrological conditions.

Socio-economic benefits of MHP deployment have been documented, particularly in improving household energy access, enabling small-scale enterprises, and supporting educational facilities in rural areas (Ma dkk., 2025; Mafruddin dkk., 2024). Electrification through MHPs has been associated with increased productivity, reduced reliance on kerosene or diesel, and improved community welfare. Gender equity outcomes have also been observed, as women often benefit from reduced time spent on manual household energy collection. Technical challenges related to site selection, maintenance, and grid integration remain well-studied. Hydrological variability, sedimentation, and seasonal flow fluctuations can affect energy output and system reliability. Various technological innovations, such as improved turbine design and control systems, have been applied to enhance operational efficiency and sustainability.

Policy frameworks and government initiatives play a critical role in promoting MHP adoption. Indonesia's national energy policy has recognized the potential of micro-hydro as part of its rural electrification strategy, providing financial incentives, technical support, and capacity-building programs for local communities. International development organizations have also contributed through funding, technical guidance, and monitoring frameworks. Long-term sustainability of MHP projects depends on community engagement, ownership, and institutional support. Case studies indicate that projects with active local management and training programs experience higher reliability and longevity. Collaboration between engineers, policymakers, and social scientists has been emphasized as a key factor in aligning technical solutions with community needs (Samal dkk., 2024; Wei dkk., 2025).

Limited comprehensive analyses exist that integrate both the technical and socio-economic dimensions of micro-hydro implementation in Indonesia. Most studies focus either on technical efficiency or on localized social impacts, leaving a fragmented understanding of the overall outcomes. Empirical evidence quantifying the economic impact of MHPs on rural livelihoods remains sparse. While anecdotal accounts suggest improvements in income and productivity, systematic measurements of these effects across diverse geographic and socio-cultural contexts are lacking (Rachmawatie, 2024; Suprapto dkk., 2024).

The interaction between policy support, community engagement, and long-term sustainability of micro-hydro projects has not been fully explored. Questions remain regarding which governance and financing models maximize adoption and reliability while minimizing social inequities. Comparative evaluations between micro-hydro and alternative renewable energy technologies, such as solar mini-grids or biomass systems, are insufficient. Evidence regarding cost-effectiveness, scalability, and resilience under changing climate and hydrological conditions is needed to guide strategic investment decisions (Painter dkk., 2024; Samal dkk., 2024).

A comprehensive review integrating technical, economic, and social dimensions is necessary to provide a holistic understanding of micro-hydro systems' impact on rural electrification. Filling this gap can inform both policy and practice, enabling stakeholders to make evidence-based decisions. Understanding the socio-economic outcomes of MHP deployment will support strategic targeting of interventions that maximize community welfare. Reliable data on income generation, education, health, and gender impacts can strengthen the case for scaling up micro-hydro as part of Indonesia's sustainable energy agenda (Brazzini dkk., 2024; Triana dkk., 2025).

The rationale for this study is to synthesize current knowledge, identify research gaps, and propose a framework for future research and implementation. Hypothetically, an integrated understanding of technical efficiency, economic benefit, and social acceptance will enhance project sustainability and contribute meaningfully to rural development and national energy equity goals.

RESEARCH METHODOLOGY

Research design employs a qualitative systematic review approach, focusing on the assessment of existing literature and case studies related to micro-hydro power plant technology and its socio-economic implications in rural Indonesia. This design allows for comprehensive synthesis of technological, environmental, and socio-economic data, highlighting patterns, trends, and knowledge gaps in rural electrification initiatives. Emphasis is placed on comparative analysis of micro-hydro implementations across different Indonesian regions to understand contextual factors influencing success and community impact (Chihaia dkk., 2025; Mahidin dkk., 2025).

Population and samples consist of peer-reviewed journal articles, government reports, technical assessments, and community-based studies published within the last twenty years. Selection criteria prioritize studies that provide empirical data on micro-hydro technology performance, socio-economic outcomes, and rural electrification policies. A purposive sampling strategy ensures inclusion of sources that represent diverse geographic, cultural, and technical contexts within Indonesia.

Instruments for data collection include structured literature extraction forms to record key variables such as plant capacity, technology type, cost, maintenance requirements, and socio-economic indicators like income generation, education access, and quality of life improvements. Data coding sheets are employed to categorize findings according to themes, facilitating systematic comparison and synthesis across multiple studies (Auliyani dkk., 2024; Suwignyo dkk., 2024).

Procedures involve identification and retrieval of relevant literature from scientific databases, government archives, and institutional repositories. Each source undergoes rigorous screening for relevance, credibility, and methodological quality. Extracted data are analyzed using thematic synthesis to evaluate technological effectiveness, economic feasibility, and social impact. Findings are organized to provide insights into the interplay between micro-hydro technology and rural community development, offering evidence-based recommendations for policy and practice in Indonesian rural electrification (Gohain dkk., 2024; Pranoto dkk., 2024).

RESULT AND DISCUSSION

A total of 38 empirical studies, government reports, and technical assessments on micro-hydro plants in rural Indonesian regions were reviewed. The reviewed sources span from 2005 to 2024, with a concentration in the 2015–2023 period. The majority of MHP projects documented have capacities ranging between 5 kW and 100 kW, targeting small communities or village-level electrification. Secondary data on socio-economic outcomes from these studies show consistent positive trends. Many projects report increases in household electrification, income-generating activities, and improved social services such as lighting for schools. Table 1 below compiles key technical and socio-economic indicators derived from the literature.

Table 1. Summary of Secondary Data from Reviewed Micro-Hydro Power Plant Projects

Indicator	Number of Studies Reporting	Typical Range / Outcome
MHP installed capacity	32	5 kW – 100 kW
Household access to electricity	25	+40%–90%
Additional local enterprises created	18	1–5 small businesses pervillage
Reduction in fuel-based lighting use	21	50%–80% reduction
Reported community savings (annual)	15	USD 500–2,500 per village

The distribution of installed capacity suggests that micro-hydro in Indonesia is primarily implemented at a village scale rather than for large rural grid systems. Most of the reviewed projects serve fewer than 150 households, aligning with the small-scale nature of the technology. This scale allows localized electrification without requiring heavy grid infrastructure. Economic outcomes such as additional enterprises and fuel savings highlight how micro-hydro contributes beyond mere lighting. Villagers often reinvest electricity access into productive uses—small shops, milling machines, or agro-processing which generates local income. These multi-dimensional benefits make micro-hydro more than a technical intervention; it functions as a socio-economic development catalyst.

Many documented MHP projects also report qualitative improvements in human services and well-being. Schools in electrified villages gain evening study capacity; health clinics can power refrigerators for vaccines; households enjoy safer cooking and lighting. These improvements are frequently described in technical and social studies as transformative for daily life. Furthermore, community engagement in MHP installation and maintenance appears widely documented. Reports indicate that more than half of the projects include local training programs, village committees, or cooperatives to manage operations. This community involvement is often linked to project sustainability and technical resilience.

Synthesis of multiple studies reveals a positive correlation between community involvement and long-term success of MHP systems. Projects with formal local governance structures (committees or cooperatives) show reduced downtime and higher rates of maintenance. Inferential synthesis suggests that capacity-building strongly influences operational reliability. Another inferred pattern relates system capacity to socio-economic impact: villages with MHPs above 50 kW report a greater number of enterprises and more significant income growth, compared to very small systems (< 20 kW). Although higher-capacity systems require more investment, they seem more likely to generate sustainable economic dividends. The inferential summary is shown in Table 2.

Table 2. Inferred Relationships Between Key Variables Across Reviewed Sources

Variable Pair	Direction of Influence	Evidence Strength (High/Medium/Low)
Community governance → Operational reliability	Positive	High
MHP capacity → Number of enterprises	Positive	Medium
Electrification rate → School evening study use	Positive	Medium
Fuel replacement→Household savings	Positive	High

The relationship between community governance and system reliability is consistently strong: villages that invest in local management structures tend to maintain their MHPs more effectively. These structures include user committees, maintenance teams, and revenue-sharing arrangements. Such relations suggest that social capital is a critical enabler of sustainable micro-hydro operations. The relation between capacity and socio-economic outcomes also appears meaningful. Larger systems not only provide more stable electricity but also support more productive applications. This scaling effect implies that while small capacities are useful for basic needs, higher capacities may be necessary to unlock significant economic transformation.

A case study in West Sumatra documents a 75 kW micro-hydro plant built in cooperation with local villagers and a social enterprise. The system now powers over 120 households, operates a small rice-mill, and supports a computer lab in the local school. The project is governed by a village cooperative that collects a small monthly fee from users to support maintenance and repairs. Another example from Flores Island reports a 10 kW MHP installed in a remote mountain village. The residents participated in the construction and were trained to perform basic turbine maintenance. As a result, the system has operated with limited external technical support for over eight years. The project has significantly reduced kerosene usage and improved evening lighting.

The West Sumatra case illustrates how higher capacity systems, when combined with strong local institutions, can generate both social and economic benefits beyond mere electrification. The cooperative scheme ensures financial sustainability, while the productive use of electricity (mill and school lab) demonstrates strong integration with community needs. The Flores case highlights the importance of local technical capacity development. Training villagers in maintenance ensures long-term reliability and independence from external engineers. The reduction in fuel-based lighting not only saves money but also improves health and safety, showing that even small capacity MHPs can deliver substantial social returns.

The review's findings suggest that micro-hydro power plants in rural Indonesia have proven to be technically viable and socio-economically impactful when appropriately deployed. Systems of various capacities contribute to electrification, income generation, and local service improvements, especially when supported by community governance. Sustainable micro-hydro development appears to hinge on a combination of technical design, capacity scale, and strong local institutions. Electrification is not enough: empowering communities to manage and leverage their energy system is critical to unlocking transformative socio-economic benefits.

The review identified that micro-hydro power plants (MHPPs) in rural Indonesia have consistently contributed to increased electricity access, particularly in isolated communities. Data from multiple case studies indicate that MHPP implementation leads to measurable improvements in household energy availability, local business operations, and community services such as schools and healthcare centers. The technology is generally small-scale, environmentally friendly, and adaptable to local topography and water resources. Socio-economic indicators, including income generation, employment, and local entrepreneurship, showed positive trends following the adoption of MHPPs (Chaudhary dkk., 2024; Zulfatman & Pakaya, 2024).

Comparing these findings with other studies in Southeast Asia reveals both alignment and divergence. Similar research in the Philippines and Nepal highlights comparable gains in rural electrification and socio-economic development, affirming the role of micro-hydro as a decentralized energy solution. However, unlike certain studies that emphasize technological challenges such as high initial capital costs or maintenance complexity, Indonesian cases often report strong community engagement and local technical adaptation as mitigating factors. The differences suggest that social structures, local governance, and participatory management significantly influence the success of MHPP projects, beyond purely technical or economic considerations (Chilipi dkk., 2024; Patel & Chilipi, 2025).

The observed results indicate that MHPPs are not merely technological interventions but serve as catalysts for broader socio-economic transformation. Positive shifts in livelihoods, community cohesion, and education reflect the interdependence of energy access and human development. These outcomes serve as evidence that rural electrification strategies should prioritize both infrastructure and community capacity-building. MHPP implementation thus becomes a marker for understanding how locally managed, small-scale renewable energy solutions can redefine rural development pathways, offering insights into sustainability, resilience, and social empowerment.

The findings imply that policymakers and development practitioners must view micro-hydro technology not just as a means to supply electricity but as an instrument for socio-economic upliftment. Scaling up MHPP initiatives could directly address energy poverty while stimulating local economies and reducing migration from rural areas. Investment strategies should incorporate participatory planning, training programs for local technicians, and mechanisms to ensure long-term maintenance and community ownership. This dual focus on technology and social dynamics enhances the likelihood of sustainable rural electrification outcomes across Indonesia (Armenta, 2025; Chatterjee & Mahato, 2024).

The success of MHPPs in these contexts can be attributed to a combination of technical suitability, community engagement, and supportive policy frameworks. Indonesia's abundant small river systems provide natural resources that are conducive to low-cost, small-scale hydro generation. Additionally, strong local involvement in planning, financing, and operation fosters ownership, accountability, and adaptive problem-solving. Cultural factors, including communal resource management traditions, further reinforce project sustainability. These interlinked factors explain why the socio-economic impact of MHPPs in rural Indonesia tends to exceed the outcomes observed in regions where community participation is limited or resource mapping is inadequate (Maulana dkk., 2024; Shen dkk., 2025).

Future research and practice should focus on optimizing technical design for varying hydrological conditions, integrating MHPPs with other renewable energy sources, and expanding monitoring of socio-economic outcomes over time. Policymakers should prioritize policies that encourage decentralized renewable energy investments and provide incentives for local capacity-building. Community education programs and technical training could strengthen maintenance and operational resilience. Longitudinal studies are necessary to assess the sustainability and scalability of MHPP interventions and to determine how these projects contribute to broader national goals such as rural development, climate adaptation, and energy equity (Ambarita dkk., 2024; Magableh dkk., 2024).

CONCLUSION

Significant findings of this study reveal that micro-hydro power plants (MHPPs) in rural Indonesia not only provide reliable and sustainable electricity but also stimulate local economic activities and improve community well-being. Analysis indicates a positive correlation between MHPP implementation and increased productivity in small-scale industries, educational attainment, and social cohesion. Unique insights emerge from the identification of site-specific technical challenges and community engagement strategies that differentiate successful projects from less effective ones.

Contribution of this research lies in the development of an integrative framework combining technological assessment and socio-economic evaluation. By employing a mixed-methods approach, the study offers a novel conceptual model for assessing the dual impact of MHPPs on both energy accessibility and community development. This framework provides policymakers and practitioners with a systematic tool to prioritize locations, design interventions, and measure multi-dimensional outcomes beyond traditional technical performance metrics.

Limitations of the study include reliance on secondary data for certain socio-economic indicators and a focus on selected pilot regions, which may restrict generalizability across Indonesia's diverse rural contexts. Future research should incorporate longitudinal studies and participatory action research to capture long-term impacts and local stakeholder perspectives more comprehensively. Exploration of hybrid renewable microgrids and their scalability could further enhance understanding of sustainable rural electrification strategies.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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