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Article

Feasibility Study of a Micro Hydro Power Plant for Rural Electrification in Lalumpe Village, North Sulawesi, Indonesia

Meita Rumbayan [1,*] and Rilya Rumbayan [2]

1 Faculty of Engineering, Sam Ratulangi University, Manado 95115, Indonesia
2 Department of Civil Engineering, Manado State Polytechnic, Manado 95252, Indonesia; rilya.rumbayan@gmail.com
* Correspondence: meitarumbayan@unsrat.ac.id; Tel.: +62-81241257171

Abstract: This feasibility study aims to assess the potential of implementing a micro hydro system in Lalumpe Village, located in North Sulawesi, Indonesia. The study focuses on evaluating the technical and economic aspects of the proposed micro hydro project. Data collection was carried out through field surveys, interviews with local stakeholders, and analysis of available hydrological and topographical data. The technical assessment involved conducting a resource assessment to determine the water availability and potential for harnessing hydroelectric power in the area. The study also examined the village's energy demand and determined the suitable capacity of the micro hydro system required to meet the community's needs. Economic analysis included estimating the initial investment costs, operation and maintenance expenses, and potential revenue generation from the sale of excess electricity to the local grid. Financial viability indicators such as payback period and net present value were calculated to assess the economic feasibility of the project.

Keywords: feasibility study; micro hydro power plant; rural electrification; village in Indonesia

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1. Introduction

The urgent need to address the challenges of energy access, climate change, and sustainable development has led to increased interest in renewable energy solutions, particularly in remote and rural areas. Micro hydro is one such solution that has gained popularity due to its ability to provide reliable and sustainable electricity from nearby water resources.

This research paper aims to conduct a feasibility study of a proposed micro hydro system in Lalumpe Village, located in North Sulawesi, Indonesia. Lalumpe Village is a remote community with limited access to electricity and relies mainly on diesel generators for power, which are expensive and environmentally damaging. The novelty of this feasibility study lies in its holistic examination of the micro hydro project, incorporating local insights, technical assessments, community needs, and rigorous financial analyses to present a well-rounded evaluation of the potential implementation in Lalumpe Village.

The feasibility study assesses the technical, economic, and environmental aspects of the proposed micro hydro system to determine its viability as a sustainable energy solution for the village. The study considers the available water resources, energy demand, project costs, and revenue generation potential to determine the overall feasibility of the project. The utilization of field surveys, interviews with local stakeholders, and analysis of hydrological and topographical data reflects a context-specific approach, ensuring that the study is grounded in the local realities and needs of Lalumpe Village.

The paper also discusses the importance of community engagement and participation in the project development process to ensure that the proposed micro hydro system meets the energy needs of the community and aligns with local values and aspirations. It also highlights the regulatory and financing challenges that need to be addressed for the successful deployment of the micro hydro project in the region.

This research paper provides valuable insights into the feasibility of implementing a micro hydro system in Lalumpe Village and the potential benefits it can bring to the community. The study serves as a foundation for further project development and decision-making processes, contributing to the development of sustainable energy solutions in remote and rural areas of Indonesia.

The literature review demonstrates that the feasibility study of micro hydro systems in Lalumpe Village aligns with existing research and experiences from various contexts. It emphasizes the importance of assessing technical viability, conducting comprehensive economic analysis, mitigating environmental impacts, and fostering community participation. Drawing on these insights, this study aims to provide a holistic understanding of the feasibility of micro hydro in Lalumpe Village and contribute to sustainable energy development in rural areas of North Sulawesi, Indonesia.

Exploring case studies of similar micro hydro projects can provide valuable insights for the feasibility study in Lalumpe Village. Examples such as the Danau Gerak micro hydro project in Indonesia [1] and the Hindiya micro hydro project in Iraq [2] showcase successful implementations and positive socio-economic impacts. These case studies offer practical lessons regarding project management, community engagement, and overcoming challenges.

In [3] the authors conducted a feasibility study of a 320 kW micro hydro power plant project in Cameroon. They proposed the approach of a feasibility study methodology which can serve as guidance for the other projects for micro hydro power plants (MHPPs) in that country. In [4], the authors performed a technical and economic analysis of a micro hydro power plant in Cameroon for sustainable development. The objective of this work was to conduct a technical and economic assessment of a MHPP in Bakassa, a remote village in the West Region of Cameroon. They found that this MHPP project can be proposed with installed power of 97 kW, with a 9-year payback period.

In [5], a researcher report the work of a small hydropower plant (SHP) at Jaracz which was examined in technical and hydraulic terms. It also analyzed the impact of changes in factors like as water head, flow rate velocity, and trash rack bar shape on predicted SHP profitability. The hydraulic performance evaluation entailed analyzing the effect of a lower flow rate and water head on power output and energy production.

Elbatran et al. examined the operation, performance, and economics of low head micro hydropower turbines for rural and remote places. They concluded that low head and micro hydropower are the most secure alternative solutions to the problem of limited electric power supply and financial problems in rural and disadvantaged communities [6].

The authors of [7] provide a comprehensive analysis of the financial and economic aspects of micro hydroelectricity plants in Central Java Province, Indonesia. They highlight the potential of utilizing water energy to generate electricity and present case studies of three different types of micro hydro plants. In [8], micro hydropower plants (MHPPs) were proven to be the best option for electricity generation in remote areas, particularly in areas with dense vegetation and limited economic activity. The chosen site has the capacity to produce 10 to 20 KW and is located fairly close to Kappadi Village, India.

According to [9], small-scale hydro is one of the most cost-effective and environmentally benign energy technologies to be considered for rural electrification in less developed countries. Additionally, it suggests that harnessing the power of falling water through small-scale hydropower plants could provide affordable energy for the development of rural areas. The research discussed in this paper specifically concerns the design and analysis of small-scale hydropower systems to generate electric power from small rivers in Ethiopia, which could be used to energize many off-grid rural areas.

Low head and micro hydropower has emerged as a highly reliable alternative to address the challenges posed by insufficient electricity access and financial constraints in underprivileged rural regions. This approach holds the key to fostering a brighter future for the local population. Establishing a strong link between renewable hydropower energy and sustainable development is of utmost importance. Additionally, it is crucial to encourage explorative investigations aimed at advancing the understanding and implementation of this specific scale of power generation.

Typically, the generation of an ample power supply demands the construction of a sizable dam, involving substantial capital costs. However, the utilization of low head micro hydropower installations presents an appealing and efficient approach for generating electricity, particularly in rural, remote, and hilly regions. This is due to the escalating levels of greenhouse gas emissions and fuel prices in such areas, rendering these micro hydropower systems increasingly favored for deployment along small rivers [10–14].

These micro hydropower setups have the potential to produce sufficient electrical power to cater to residential, agricultural, and plantation needs, or even for smaller communities. Furthermore, they find application in various mechanical processes, including agro-processing, textile fabrication, cooling, and drying [15]. The primary advantages of low head micro hydropower systems are their predictability, contingent on a consistent water supply [16], and their favorable environmental impact [17].

According to [18], Indonesia has enormous hydroelectric potential. However, those possibilities are constrained by Indonesia's geography and socioeconomic challenges. The rivers in Indonesia are often unsuitable for the construction of a large-scale hydroelectric facility. Although hydropower plants are required to provide renewable energy base loads, the usage of hydropower can be enhanced in a variety of ways. One option is to reduce the hydropower plant's capacity and build micro hydropower plants. Micro hydropower plants will be an important addition to rural communities and agricultural areas as generators of community-based energy.

The total plant cost of MHP projects in Nepal and Pakistan was more than USD 2000 per kW during 2000 [19]. The cost per kW for MHP projects for electricity supply including transmission implemented in Sri Lanka, Nepal, Peru, and Zimbabwe was found to be in the range of USD 1136–5630 [20]. The cost for the MHP projects in India for decentralized power supply for villages situated in remote and inaccessible areas is estimated to be in the range of USD 2670–5010 per kW [21]. In this study, an investment cost of USD 2000 per kW is used for planning to build a micro hydropower plant in Tulaun River, including equipment cost, construction cost, and installation. For operation and maintenance, about 2% of the investment cost is chosen as the annual cost for the financial analysis.

This article is structured as follows: the introduction is provided in Section 1, the materials and methods in Section 2, the results in Section 3, the discussion in Section 4, and the conclusion in Section 5.

2. Materials and Methods

The methodology outlined below ensures a systematic and comprehensive approach to assessing the feasibility of a micro hydro system in Lalumpe Village, North Sulawesi, Indonesia. By combining data collection, technical analysis, and economic evaluation, this study aims to provide valuable insights and recommendations for the successful implementation of a sustainable and community-driven micro hydro project in North Sulawesi, Indonesia.

1. Study Area Selection: The first step in the methodology is to select Lalumpe Village as the study area. Considerations such as the village's energy needs, geographical location, water resources availability, and accessibility are taken into account. Collaboration with local authorities and community leaders is established to ensure their support and participation in the study.
2. Data Collection: The data collection involves gathering relevant information to assess the feasibility of a micro hydro system in Lalumpe Village. The following data sources and methods are utilized:
    a. Resource Assessment: Conduct a field survey to measure stream flow rates, head, and other hydrological parameters. Gather topographical data through satellite imagery and land surveys to identify potential micro hydro sites.

b. Energy Demand Assessment: Conduct surveys and interviews with community members to determine the energy needs of Lalumpe Village. Collect data on current energy sources, consumption patterns, and load requirements.
c. Financial Data: Collect data on project costs, including equipment, construction, installation, and operation and maintenance expenses. Explore funding options, grants, and financial incentives available for renewable energy projects.

3. Technical Design: Based on the resource assessment data, develop a technical design for the micro hydro system. Determine the appropriate turbine type, capacity, and distribution infrastructure required to meet the energy demand of Lalumpe Village. Consider the specific characteristics of the water resources and topography identified in the resource assessment.
4. Economic Analysis: Perform an economic analysis to evaluate the financial feasibility of the micro hydro project. Calculate the initial investment costs, including equipment, construction, and installation expenses. Estimate the operation and maintenance costs and assess the potential revenue generation from electricity sales or other income streams. Apply financial indicators such as net present value (NPV), internal rate of return (IRR), and payback period (PB) to assess the economic viability of the project.
5. Discussion and Recommendations: Compile the findings of the feasibility study into a comprehensive report with the technical and economic assessments. Provide clear recommendations on the viability of the micro hydro project in Lalumpe Village, including potential funding sources, implementation strategies, and future planned works for implementation.

3. Results

3.1. Study Area Selection

Lalumpe Village is the location of the case study which is located at 05°33′20.8″ north latitude and 127°09′6.8″ east longitude. Because the area is quite remote, this location often experiences power outages. Nonetheless, the area has many renewable local resources, such as two rivers, namely the Tulaun River and the Kawis River. Thus, a renewable energy-based micro grid system has the potential to realize an energy-independent village. This study proposes micro hydropower systems to power a small sub-village inhabited by 55 households using the micro hydro resources that are located in the village. The study site of Lalumpe Village, which is located in the Minahasa Regency of North Sulawesi, Indonesia, is shown in Figure 1.

Figure 1. The location of the study area of Lalumpe Village.

The energy demand assessment for the village was conducted based on surveys and interviews with the village community to determine the energy needs of the community. The typical load requirement of the community is described as the daily profile pattern shown in Figure 2.

Figure 2. The daily profile of community's load requirement.

3.2. Technical Assessment

3.2.1. Resource Assessment

For the resource assessment, we conducted a detailed assessment of the available water resources in Lalumpe Village to determine the potential for micro hydropower generation. This assessment includes:

a. Hydrological Data Collection: The stream flow rates, water levels, and other hydrological parameters were measured at various points within the potential micro hydro sites. The flow of water in a natural river is typically measured in cubic meters per second (cms) or cubic feet per second (cfs). Weirs and flumes are structures installed in a river to create a specific flow constriction. By measuring the water level upstream or downstream of the weir or flume, and knowing the geometry of the structure, the flow rate can be calculated. The result of the stream flow measurement is presented in Table 1.

b. Topographical Survey: A topographical survey of the selected micro hydro sites was conducted using land surveying equipment. The elevation differences (head) between the intake and turbine locations was identified to determine the available energy potential. The result of these measurement of the river head is presented in Table 1.

Table 1. The resource assessment of micro hydro site.

Parameter	Low	Medium	High
Waterflow rate (m^3/s)	0.5	0.6	0.7
Head (m)	3	4	5
Efficiency	0.85	0.85	0.85
Power (kW)	12.5	20	29.2

Images taken during the data collection and topographical survey in the micro hydro site (Tulaun River) located in Lalumpe Village are shown in Figure 3.

The micro hydro potential (P) of a site is determined using the following equation:

$$P = \rho \cdot g \cdot Q \cdot H \cdot \eta \tag{1}$$

where P is the power output in watts (W) or kilowatts (kW), ρ is the density of water (typically around 1000 kg/m^3), g is the acceleration due to gravity (approximately 9.81 m/s^2), Q is the flow rate of water in cubic meters per second (m^3/s), H is the head or vertical drop in meters (m), and η is the overall efficiency of the micro hydro system (expressed as a decimal). This formula represents the theoretical maximum power that can be extracted from a hydroelectric system under ideal conditions. It is important to note that actual performance may be lower due to factors like losses in the system (e.g., friction, inefficiencies in turbines and generators). Real-world performance is typically expressed as a percentage of the theoretical potential.

Figure 3. The data collection and topographical survey in the micro hydro site (Tulaun River) located in Lalumpe Village.

Based on the resource assessment, the potential for water resources in the Tulaun River is outlined in Table 1.

Due to the unavailability of yearly rainfall data at the location, the rainfall information was obtained through interviews with the local community, who stated that the river does not experience a dry season.

3.2.2. System Design

Based on the resource assessment, a micro hydro system was designed to meet the energy demand of Lalumpe Village. The following aspects were considered:

a. Turbine Selection: An appropriate turbine type was selected based on the available head and flow rate. The considered factors were efficiency, maintenance requirements, and cost-effectiveness.

Large run-of-the-river plants, which employ impeller turbines, are characterized by high flow rates and low head heights. Conversely, mountain-based dam installations, driven by Pelton turbines, are characterized by a low discharge and high head. Plants with intermediate flow rates and head heights typically utilize Francis turbines.

b. System Capacity: The required capacity of the micro hydro system to meet the energy needs of Lalumpe Village was determined. The village's current and future energy demand, seasonal variations, and load requirements were considered.

3.2.3. Equipment Selection

In the selection of equipment, we selected the necessary equipment for the micro hydro system based on the design specifications and local conditions:

a. Intake Structure: An intake structure that allows for proper water diversion, as shown in Figure 4, and power house, as shown in Figure 5, were designed.

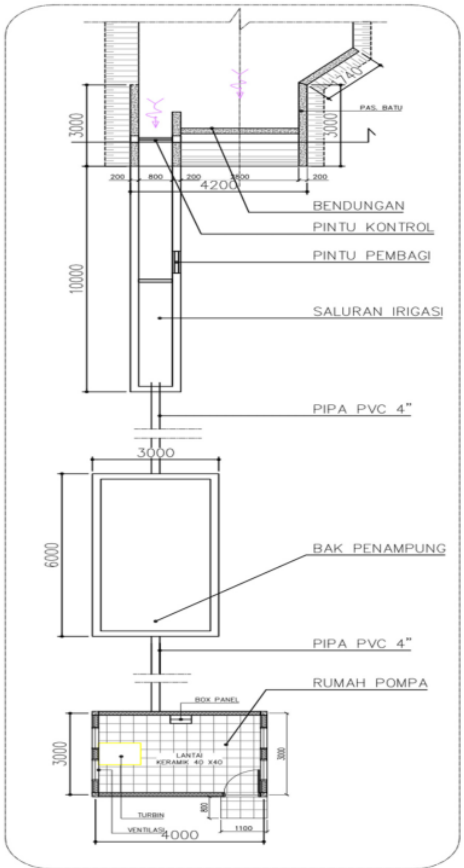

Figure 4. The layout design of civil work for micro hydro plant in Tulaun River at Lalumpe Village.

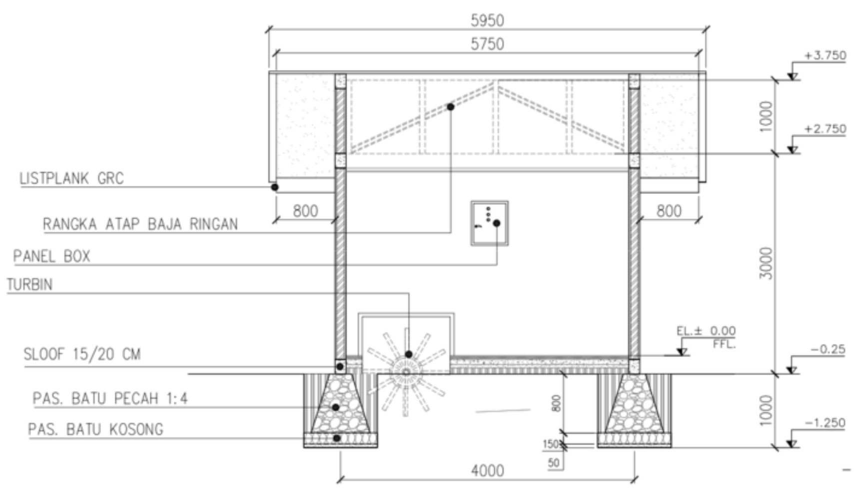

Figure 5. Layout of power house of micro hydro system in Tulaun River at Lalumpe Village.

b. Penstock: The optimal diameter and material for the penstock were determine, considering the head, flow rate, and distance between the intake and turbine, as shown in Figure 6.

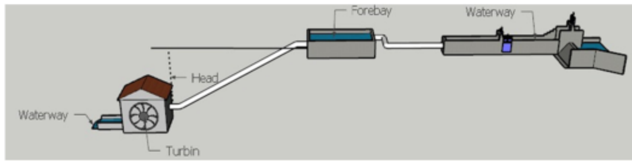

Figure 6. The components of civil work for micro hydro plant in Tulaun River.

c. Turbine and Generator: A turbine and generator combination was selected that matched the specific site conditions and system requirements.

The selection of an MHP turbine and generator specifications was based on the needs, design, budget, and market availability of MHP equipment.

The expected performance of the micro hydro system based on the design parameters using the available head and flow rate data as an independent power supply of 12.5 kW to fulfill the village's energy demand is described as the profile load (Figure 2).

3.3. Economical Assessment

3.3.1. Cost Estimation

We estimated the capital costs associated with the micro hydro system which included the following:

a. Equipment Costs: The costs of turbines, generators, penstocks, intakes, transmission lines, and other necessary equipment based on market prices and project-specific requirements.
b. Construction Costs: The costs of civil works, such as excavation, concrete structures, and installation of equipment considering the site conditions and accessibility when assessing the construction costs.
c. Miscellaneous Costs: The ongoing costs associated with operating and maintaining the micro hydro system.

The cost estimation of an MHPP depends on the site where it will be installed. The following table, Table 2, shows the cost estimation for a micro hydro plant in Lalumpe Village with a budget of about USD 2000 per kW or the total project cost, based on the literature review in [20–22].

Table 2. Power generating, investment cost, energy generation, and electricity sales in a year of micro hydro system operation.

Power Generation (kW)	Investment Cost (USD)	Energy Generation (kWh/Year)	Electricity Sales (USD)
12.5	25,000	76,650	7665
20	40,000	122,640	12,264
29	58,000	179,054	17,905.4

3.3.2. Revenue Generation

We assessed the potential revenue generation opportunities associated with the micro hydro system using the following:

a. Electricity Sales: the revenue that can be generated by selling the excess electricity generated by the micro hydro system to the local grid or nearby communities was estimated.
b. Off-Grid Applications: Potential revenue streams from off-grid applications were identified, such as providing electricity to local businesses, community facilities, or

agricultural operations. The market demand and potential income from these sources were assessed.

The economic analysis was carried out to evaluate the potential revenue of operating an micro hydro plant in Tulaun River to supply off-grid electricity to local communities outside the village. A comparison was performed between the electricity sale costs of IDR 1400 per kWh (0.1 USD per kWh) and the electricity price of the national grid. In this study, the operation time was set to 8760 h (a year) and taking into account the PF power factor of 70%, the potential electricity sales by the micro hydro system that will be obtained in one year is given in Table 2.

3.3.3. Financial Analysis

A financial analysis was conducted to determine the economic viability of the micro hydro project. Financial indicators such as NPV, IRR, and Payback Period were calculated using formulas in Excel or financial calculator

a. Net Present Value (NPV): The Net Present Value represents the difference between the present value of cash inflows and outflows over a specified time period. The NPV was calculated by discounting the projected cash flows over the project's lifespan to their present value. The appropriate discount rate that reflects the project's risks and opportunity costs was considered. The discount rate can be found using the interest rate; in this study, it was assumed that the interest rate is 10% (based on the data in 2020 at https://www.statista.com/statistics/794458/indonesia-real-interest-rates/ accessed on 27 August 2023). The Net Present Value can be calculated using the following equation:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(I+r)^t} \quad (2)$$

where NPV is the Net Present Value, CF_t is the cash flow in that period, r is the discount rate %, n is the lifetime of the project (year), and (1/1 + r)I is the discount rate which represents the NPVs for different discount rates. The calculated Net Present Values are shown in Table 3.

Table 3. Net Present Value for a capacity of 12.5 kW.

Year	Discount Factor	Cash Flow (USD)	Present Value (USD)
0	1	−25,000	−25,000
1	0.91	7165	6513.64
2	0.83	7165	5921.49
3	0.75	7165	5383.17
4	0.68	7165	4893.79
5	0.62	7165	4448.90
6	0.56	7165	4044.46
7	0.51	7165	3676.78
8	0.47	7165	3342.53
9	0.42	7165	3038.66
10	0.39	7165	2762.42
NPV			19,025.82

From the results of these calculations it is shown that the NPV value for 10th year is USD 19,025.82. This indicates that the NPV > 0 which means that the project is feasible to continue.

b. Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is the discount rate that makes the Net Present Value of a series of cash flows equal to zero. In other words, it is the rate at which the present value of inflows equals the present value of outflows.

The formula to calculate the IRR is presented in Equation (3).

$$0 = \sum_{t=0}^{n} \frac{CF_t}{(I + IRR)^t} \quad (3)$$

where CFt is the cash flow in that period and n is the total number of periods.

From the results of these calculations, it is shown that the IRR value is 26% for a micro hydropower plant with a capacity of 12.5 kW, 27% for a plant with a capacity of 20 kW, and 25% for a capacity of 30 kW.

c. The payback period is defined as the time required for the project to recover its initial costs. In this study, the calculation of the payback period is equal to the initial investment for the project divided by the cash flow per year.

The result of the payback period calculations for each planned capacity for the micro hydropower plant are shown in Table 4. Based on the calculation results, the payback period for the investment was 3.5 years, 3.4 years, or 3.6 years for the three scenarios for a micro hydropower plant at this site.

Table 4. The comparison of Net Present Value, IRR, and payback period.

Parameter	MHPP Capacity of 12.5 kW	MHPP Capacity of 20 kW	MHPP Capacity of 29 kW
Initial investment (USD)	−25,000	−40,000	−58,000
Cash flow per year (USD)	7165	11,764	16,705
NPV (USD)	$19,025.82	$32,284.69	$42,644.99
IRR	26%	27%	25%
Payback period (years)	3.5	3.4	3.6

Using the same method, the Net Present Values, Internal Rate Return (IRR), and payback period for the micro hydropower plant capacities of both 20 kW and 29 kW have been calculated and are reported in Table 4.

These formulas are widely used in finance to assess the feasibility and profitability of investments. It is imperative to note that a positive Net Present Value (NPV) and a superior Internal Rate of Return (IRR) generally signify a more favorable investment proposition.

4. Discussion

The findings of this feasibility study indicate that Lalumpe Village has favorable conditions for the implementation of a micro hydro system. The analysis suggests that the project has the potential to provide a reliable and sustainable source of electricity to meet the energy needs of the community while contributing to reduced greenhouse gas emissions and dependence on fossil fuels.

However, challenges related to financing, community engagement, and regulatory aspects were also identified during the study. These challenges should be addressed through strategic partnerships, community involvement, and adherence to local regulations to ensure the successful implementation of the micro hydro project.

Overall, the feasibility study demonstrates the potential benefits of implementing a micro hydro system in Lalumpe Village, providing insights through the technical and economic assessments. This study serves as a valuable foundation for further project development, stakeholder engagement, and decision-making processes regarding the deployment of sustainable energy solutions in the region.

In accordance with the Indonesian National Energy Policy, renewable energy will make up 31% of the country's energy mix by 2050. This will be made up of 23% biomass, 21% biodiesel, 20% geothermal, 10% hydropower, 7% nuclear, 6% coal gas methane, 4% bioethanol, and the remaining 8% consisting of biogas, solar, wind, and marine sources [22].

Overall, the feasibility of a micro hydropower plant depends on a combination of technical, economic, and environmental factors. A thorough feasibility study is necessary to determine whether a micro hydropower plant is a viable option for a particular location. By evaluating these factors, a feasibility study provides a comprehensive analysis of the costs and benefits of a micro hydropower plant project. This helps stakeholders make informed decisions regarding the viability and potential benefits of such projects. Future research should focus on integrating emerging technologies and sustainable practices to enhance the feasibility assessment process for micro hydropower projects.

When considering small hydropower facilities, the expenses associated with investments can be categorized into two segments. The initial element encompasses the expenses linked to the electromechanical equipment, which, according to the findings of scholarly research, can be reasonably approximated. Generally, for newly established small hydropower plants, the costs for electromechanical equipment constitutes approximately 30–40% of the overall investment. This aspect also takes precedence when it comes to the refurbishment of existing small hydropower plants. The second element of the investment budget allocated for small hydropower plants encompasses additional expenditures related to land acquisition, infrastructure costs, and labor expenses. Estimating these additional costs is notably challenging due to their strong reliance on local circumstances. Factors such as the location of the hydropower installations, specifically potential challenges related to accessing the intended site, and the associated local prices of construction materials, significantly influence these costs [23–28].

Community-based micro hydro is a promising technology for providing sustainable energy to rural communities. It has the potential to provide reliable, clean energy while promoting local economic development and improving the quality of life for rural communities. However, successful implementation requires active community participation, effective management and governance, and access to technical and financial resources. Further research and investment in this area could help to overcome these challenges and expand the use of community-based micro hydro as a sustainable energy solution. Community-based micro hydro is a sustainable energy solution that has gained popularity in rural areas where grid electricity is not available or is unreliable. This technology involves harnessing the power of flowing water in a small stream or river to generate electricity that can be used to power homes, businesses, and community facilities. Community-based micro hydro systems are typically designed, constructed, and managed by local communities, and are therefore well-suited to address the energy needs of rural communities.

Furthermore, the analysis of potential social and cultural impacts of the micro hydro project can be future work which involves the following:

a. Community Engagement: Engaging with the local community and stakeholders to understand their perspectives, concerns, and aspirations related to the project. Incorporating their input into the project design and decision-making processes.
b. Cultural Heritage: Identifying and assessing any potential impacts on cultural heritage sites or traditions in the project area. Developing mitigation measures to protect and preserve cultural assets, if applicable.
c. Social Benefits: Identifying the potential positive impacts of the micro hydro project on the local community, such as increased access to electricity, improved livelihoods, and enhanced educational opportunities.

To develop micro hydro systems, we must explore the potential financing options for a micro hydro project through three options: subsidies or financial incentives available for renewable energy projects in the region; financial institutions that provide loans or financing specifically for renewable energy projects; and the possibility of community-based financing models, such as crowd funding or community investment.

5. Conclusions

The technical and economic aspects of the proposed micro hydropower plant, including assessments of resources, energy demand, investment costs, and revenue generation have been presented in this feasibility study. By conducting a comprehensive feasibility study of a micro hydro system in Lalumpe Village, this research paper intends to provide valuable insights into the potential for sustainable energy development in rural areas of Indonesia. The findings will contribute to evidence-based decision making, encourage renewable energy adoption, and support the development of inclusive and sustainable energy systems in remote communities.

Overall, this study underscores the potential benefits of implementing a micro hydro system in Lalumpe Village, presenting a holistic evaluation that considers both the technical and economic aspects. However, it is imperative to note that ongoing monitoring and periodic reassessment will be essential to ensure the sustained success and long-term viability of the proposed project.

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References

1. Ulya, N.A.; Waluyo, E.A.; Kunarso, A. Analisis Ekonomi Pengembangan Pembangkit Listrik Tenaga Hidro: Studi Kasus di Kabupaten Muara Enim, Sumatera Selatan. *J. Anal. Kebijak. Kehutan.* **2019**, *16*, 31–45.
2. Alshami, A.H.; Hussein, H.A. Feasibility analysis of mini hydropower and thermal power plants at Hindiya barrage in Iraq. *Ain Shams Eng. J.* **2021**, *12*, 1513–1521. [CrossRef]
3. Signe, E.B.K.; Hamandjoda, O.; Nganhou, J. Methodology of Feasibility Studies of Micro-Hydro Power Plants in Cameroon: Case of the Micro-Hydro of KEMKEN. *Energy Procedia* **2017**, *119*, 17–28. [CrossRef]
4. Elie Bertrand, K.; Hamandjoda, O.; Nganhou, J.; Wegang, L. Technical and Economic Feasibility Studies of a Micro Hydropower Plant in Cameroon for a Sustainable Development. *J. Power Energy Eng.* **2017**, *5*, 64–73. [CrossRef]
5. Walczak, N. Operational Evaluation of a Small Hydropower Plant in the Context of Sustainable Development. *Water* **2018**, *10*, 1114. [CrossRef]
6. Elbatran, A.H.; Yaakob, O.B.; Ahmed, Y.M.; Shabara, H.M. Operation, performance and economic analysis of low head micro-hydropower turbines for rural and remote areas: A review. *Renew. Sustain. Energy Rev.* **2015**, *43*, 40–50. [CrossRef]
7. Purwanto. Financial and Economic Analysis of Microhydro Electricity Plants, at Some Locations, Central Java Province, Indonesia. *J. Penelit. Sos. Ekon. Kehutan.* **2011**, *8*, 251–264. (In Indonesian)
8. Palakshappa, K.; Rudresha, N.; Kumar, V. Feasibility study on proposed micro hydro power plant Kappadi (Byndoor), Karnataka, India. In Proceedings of the International Conference on Industrial Engineering and Operations Management, Bangkok, Thailand, 5–7 March 2019.
9. Dametew, A.W. Design and Analysis of Small Hydro Power for Rural Electrification. *Glob. J. Res. Eng.* **2016**, *16*, 25–45.
10. Ghosh Tushar, K.; Prelas Mark, A. *Energy Resources and Systems. Renewable Resources*; Springer: Dordrecht, The Netherlands, 2011; Chapter 3.
11. Derakhshan, S.; Nourbakhsh, A. Experimental study of characteristic curves of centrifugal pumps working asturbines in different specific speeds. *Exp. Therm. Fluid Sci.* **2008**, *32*, 800–807. [CrossRef]
12. Banos, R.; Manzano-Agugliaro, F.; Montoya, F.G.; Gil, C.; Alcayde, A.; Gómez, J. Optimization applied to renewable and sustainable energy: A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 1753–1766. [CrossRef]
13. Paish, O. Micro-hydropower: Status and prospects. *Proc. Inst. Mech. Eng. Part A J. Power Energy* **2002**, *216*, 31. [CrossRef]
14. Prodanovic, M.; Miltenović, A.; Nikodijević, M. Determination of operating parameters of turbines for micro hydroelectric power plants for optimal use of hydropower. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *659*, 012046. [CrossRef]

15. Singh, D. *Micro hydro Power Resource Assessment Handbook*; Prepared for APCTT Asian and Pacific Centre for Transfer of Technology of the United Nations; Economic and Social Commission for Asia and the Pacific (ESCAP): Bangkok, Thailand, 2009.
16. Teuteberg, B.H. *Design of a Pump-As-Turbine for an Abalone Farm*; Final Report for Mechanical Project 878; Department of Mechanical and Mechatronic Engineering, Stellenbosch University: Stellenbosch, South Africa, 2010.
17. Yaakob, O.B.; Ahmed, Y.M.; Elbatran, A.H.; Shabara, H.M. Are view on micro hydro gravitation alvortex power and turbine systems. *J. Teknol. (Sci. Eng.)* **2014**, *69*, 1–7.
18. Ardiansyah, H. *Hydropower Technology: Potential, Challenges, and the Future*; BRIN Publishing: Jakarta, Indonesia, 2022. Available online: https://penerbit.brin.go.id/press/catalog/download/562/475/11489?inline=1 (accessed on 27 August 2023).
19. Hussain, A.; Sarangi, G.K.; Pandit, A.; Ishaq, S.; Mamnun, N.; Ahmad, B.; Jamil, M.K. Hydropower development in the Hindu Kush Himalayan region: Issues, policies and opportunities. *Renew. Sustain. Energy Rev.* **2019**, *107*, 446–461. [CrossRef]
20. Khennas, S.; Barnett, A. *Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries*; The Department for International Development: London, UK; The World Bank: Washington, DC, USA, 2000.
21. Nouni, M.R.; Mullick, S.C.; Kandpal, T.C. Techno-economics of micro-hydro projects for decentralized power supply in India. *Energy Policy* **2006**, *34*, 1161–1174. [CrossRef]
22. Barelli, L.; Liucci, L.; Ottaviano, A.; Valigi, D. Mini hydro: A design approach in case of torrential rivers. *Energy* **2013**, *58*, 695–706. [CrossRef]
23. Singal, S.K.; Saini, R.P. Analytical approach for development of correlations for cost of canal-based SHP schemes. *Renew. Energy* **2008**, *33*, 2549–2558. [CrossRef]
24. Ogayar, B.; Vidal, P.G. Cost determination of the electro-mechanical equipment of a small hydro-power plant. *Renew. Energy* **2009**, *34*, 6–13. [CrossRef]
25. Aggidis, G.A.; Luchinskaya, E.; Rothschild, R.; Howard, D.C. The costs of small-scale hydro power production: Impact on the development of existing potential. *Renew. Energy* **2010**, *35*, 2632–2638. [CrossRef]
26. Mishra, S.; Singal, S.K.; Khatod, D.K. Optimal installation of small hydropower plant—A review. *Renew. Sustain. Energy Rev.* **2011**, *15*, 3862–3869. [CrossRef]
27. Santolin, A.; Cavazzini, G.; Pavesi, G.; Ardizzon, G.; Rossetti, A. Techno-economical method for the capacity sizing of a small hydropower plant. *Energy Convers. Manag.* **2011**, *52*, 2533–2541. [CrossRef]
28. Cavazzini, G.; Santolin, A.; Pavesi, G.; Ardizzon, G. Accurate estimation model for small and micro hydropower plants costs in hybrid energy systems modelling. *Energy* **2016**, *103*, 746–757. [CrossRef]

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