Assessment of the Hydrokinetic Energy Potential for Electricity Generation in the Mocha River, Tungurahua Province, Ecuador

Palacios, Alex1; Contreras, Luis1*

[1]*Technical University of Ambato, Faculty of Civil and Mechanical Engineering, Civil Engineering, Ambato, Ecuador.*

Abstract: This study addresses the sustainable utilization of the Mocha River's water resource, located in Tungurahua Province, Ecuador, aiming to generate small-scale hydropower. Historical flow data from the Mocha-Quero-Ladrillos irrigation board were analyzed, revealing significant seasonal variations: maximum flows of 0.472 m³/s occur from March to June, while the minimum recorded flow is 0.273 m³/s in September. A gross head of 50 meters was determined, and through an analysis of friction losses and turbine selection, the Pelton turbine proved to be the most suitable for the local conditions. The hydraulic and electrical efficiencies were then calculated, resulting in an overall system efficiency of 72.9%. Using this efficiency, the effective power output was estimated on a monthly basis, ranging from 97.5 kW (in September) to 168.6 kW (from March to June). The findings demonstrate the technical and energetic feasibility of implementing a small hydropower station along the Mocha River. Furthermore, this project can enhance local electricity supply and promote rural sustainable development by efficiently and responsibly managing water use, as the diverted flow is returned to the irrigation canal after power generation. This integrated approach fosters diversification of the energy matrix and strengthens the region's energy resilience.

Keywords:energy, hydrokinetic, generation, electric, river.

Evaluation of hydrokinetic energy potential for power generation in the Mocha River, Tungurahua Province, Ecuador

SummaryThis study addresses the sustainable use of water resources in the Mocha River, located in the province of Tungurahua, Ecuador, for small-scale electricity generation. To this end, average monthly flows were characterized using historical data from the Mocha-Quero-Ladrillos irrigation district. Significant seasonal variations were found: maximum values of 0.472 m³/s occurred between March and June, while the minimum was 0.273 m³/s in September. A gross usable head of 50 meters was determined, and a friction loss analysis and turbine selection concluded that Pelton technology is optimally suited to local conditions. In addition, both hydraulic and electrical efficiency were calculated, establishing an overall system efficiency of 72.9%. Using this reference, the average effective power for each month was obtained, ranging from 97.5 kW (September) to 168.6 kW (March-June). The results demonstrate the technical and energy feasibility of implementing a small hydroelectric plant on the Mocha River. It also concludes that the project can contribute to the local electricity supply and sustainable rural development, as it allows for efficient and responsible water use by returning the flow to the irrigation canal after power generation. This comprehensive approach promotes the diversification of the energy matrix and strengthens the region's energy resilience.

Keywords: energy, hydrokinetic, generation, electrical, river

1. INTRODUCTION

The development of renewable energy sources is essential to address current environmental and energy challenges. [1]Given the growing demand for electricity—especially in developing countries—it is crucial to identify sustainable alternatives that minimize environmental impact and contribute to greater energy independence. Traditionally, hydropower has been the most widely used renewable source worldwide, accounting for a significant proportion of clean energy production. However, recent years have seen significant growth in emerging technologies that optimize the use of water resources, reducing costs and minimizing interference with ecosystems. [2].

This technological boom is closely linked to the need to decentralize electricity generation and bring it closer to rural or hard-to-reach areas, where the construction of large reservoirs is unfeasible or unprofitable. In this sense, technologies such as hydrokinetic energy and small hydroelectric plants based on flow diversion offer unique opportunities to exploit water resources with reduced environmental impact. [3]In addition, various international initiatives have promoted research and adoption of environmentally friendly methods, generating a framework for transnational cooperation for the implementation of small-scale solutions.

At the technological level, micro hydroelectric power plants, generally defined as facilities with a generation capacity of less than 100 kW (or up to a few hundred kW), have established themselves as an attractive alternative for rural electrification and the diversification of the energy matrix.[4]These facilities require minimal civil works, allowing them to be integrated into small channels or irrigation canals without significantly altering the natural environment. Their modularity facilitates the system's scalability based on demand or its combination with other renewable sources, such as solar or wind, to form hybrid systems that boost the efficiency of the electricity supply.

Growing interest in sustainability and climate change mitigation has driven the development of international policies and regulations that encourage the use of renewable energy. Current projections suggest that the integration of hybrid systems—combining hydrokinetic energy with conventional micropower plants—will continue to increase, demonstrating the global commitment to reducing dependence on fossil fuels and jointly harnessing available water resources. This global context is complemented by studies and reports from international organizations, which highlight the importance of diversifying energy sources to improve energy security and mitigate environmental impact.[5].

Various experiences in Latin America have highlighted the value of micro-power plants and hydrokinetic systems in decentralized electricity generation. For example, studies conducted by regional entities have shown that the combination of different water harvesting technologies can significantly improve the electricity supply in rural communities, increase resilience to natural disasters, and foster socioeconomic development. These findings are particularly relevant in the province of Tungurahua, where the geographic and climatic conditions are similar to other high-potential Andean settings.[6].

In Ecuador, micro-hydroelectric power plants have emerged as an effective solution for communities that, despite having water resources, suffer from unstable electricity supplies. In the Andean and Amazonian regions, the topography and persistent watercourses offer considerable energy potential. The province of Tungurahua, characterized by steep elevation gradients and moderate flow rates, is an ideal location for the implementation of these systems.[7]However, the interconnection of existing power plants to the National Electricity System prevents production from being used exclusively to meet local demand, generating inefficiencies and increasing the region's energy vulnerability.[8].

The Ecuadorian regulatory framework has undergone significant changes in recent years, particularly with the update of the Organic Law on Public Electric Power Services and its regulations, which has facilitated investment in small-scale renewable energy projects. These reforms have opened the door for communities and local governments to actively participate in the management and operation of micro-power plants, promoting the decentralization of energy governance and ensuring more equitable access to energy, especially for the most vulnerable sectors.[9] [10].

In scenarios where distribution infrastructure is limited, the need for on-site generation solutions becomes critical. The implementation of microturbines in waterways with moderate flows presents a clean and sustainable alternative, provided minimum maintenance and environmental conservation criteria are met.[11]From a technical point of view, international research – such as the study carried out on the Douro River (Portugal) – has demonstrated the viability and efficiency of hydrokinetic systems in rivers with moderate flows, demonstrating that even under conditions of variability, it is possible to extract significant energy potential.[12].

In the Andean context, seasonal rainfall variability and complex topography create both challenges and opportunities. The existence of exploitable waterfalls, although subject to seasonal fluctuations, allows for the installation of mini-hydroelectric plants based on controlled elevations, complementing power generation in variable-flow rivers. This strategy not only increases generating capacity but also enables the integration of water resources into irrigation systems, optimizing their use for energy and agricultural purposes simultaneously.[13].

Likewise, the integration of hydroelectric projects for irrigation purposes, such as the Mocha-Quero-Ladrillos Canal, promotes multiple uses of water resources. In these systems, water diverted for power generation is returned to the main channel, promoting crop irrigation and livestock farming, which in turn contributes to food security and comprehensive rural development. The convergence of uses in water management represents a comprehensive strategy that strengthens both environmental sustainability and the socioeconomic well-being of communities.[14].

On the other hand, the implementation of hybrid microhydro and hydrokinetic energy systems generates additional benefits in terms of social and economic development. Training in the maintenance and operation of these systems, along with job creation during the construction and commissioning phases, contributes to regional economic dynamism. Knowledge transfer and the adoption of best practices in the design and execution of renewable energy projects lay the foundation for the replicability of these initiatives in other regions with similar conditions, expanding the positive impact of technological innovation on the national energy mix.[15].

In short, the introduction of hydrokinetic solutions in the Mocha River and in the province of Tungurahua represents a strategic opportunity to transform distributed energy generation, optimize the use of water resources, and promote sustainable development that comprehensively benefits local communities. This research is part of this context and aims to establish a solid technical, economic, and environmental foundation for the implementation of small-scale power generation systems, contributing to the diversification of the energy matrix and the region's resilience in the face of contemporary energy challenges.

Proposed Solution

The Mocha River, which flows through the cantons of Mocha and Quero in the province of Tungurahua, exhibits favorable hydrological conditions that, if optimally utilized, can significantly contribute to the generation of clean electricity. In this context, the study proposes an innovative strategy that combines the exploitation of hydrokinetic energy with the creation of an artificial water level difference. To achieve this, the study proposes diverting part of the river's flow by constructing an alternative channel, which will generate a usable water level difference at a strategic point for the installation of a small-scale power generation system.

The key to this proposal lies in the design of a system that allows, after converting the flow's energy into electricity using a suitable turbine, to return the water to the main river channel. This flow will then be integrated into the Mocha-Quero-Ladrillos irrigation canal, ensuring that the water resource is used in a dual manner: for energy production and crop irrigation, without altering the river's natural flow. This approach avoids the need to impound large volumes of water, which significantly reduces the environmental impact and the technical and economic complexities associated with the construction of large-scale dams.[16].

The study focuses on a detailed characterization of the Mocha River's hydrological and hydrodynamic conditions, assessing the technical feasibility of generating electricity from the artificially created slope. To this end, precise calculations will be developed to estimate the available potential energy, considering critical variables such as flow rate and slope height.[17]Similarly, a comparative analysis of energy conversion technologies will be conducted, with the goal of selecting the option that offers the highest performance based on the specific environmental conditions.

This comprehensive approach simultaneously addresses two key aspects: on the one hand, the optimization of water resources for electricity generation, and on the other, the reincorporation of water into irrigation systems, which favors the continued agricultural use of the resource. In this way, a sustainable development model is promoted that not only strengthens the local energy sector but also boosts water and food security for the communities involved.[18].

Additionally, the proposal contemplates the adoption of participatory governance mechanisms involving irrigation boards and other local stakeholders. This integration strengthens the project's legitimacy and fosters its social acceptance, which is essential to ensuring the initiative's long-term viability and sustainability. Thus, the implementation of hydrokinetic solutions on the Mocha River is emerging as a transformative strategy for distributed energy generation in the region, with significant repercussions for the well-being and progress of the province of Tungurahua.

2. MATERIALS AND METHODS

To carry out this study, various technological tools and resources were used to ensure data collection, processing, and analysis, as well as the development of simulation models. The main tools and resources are described below:

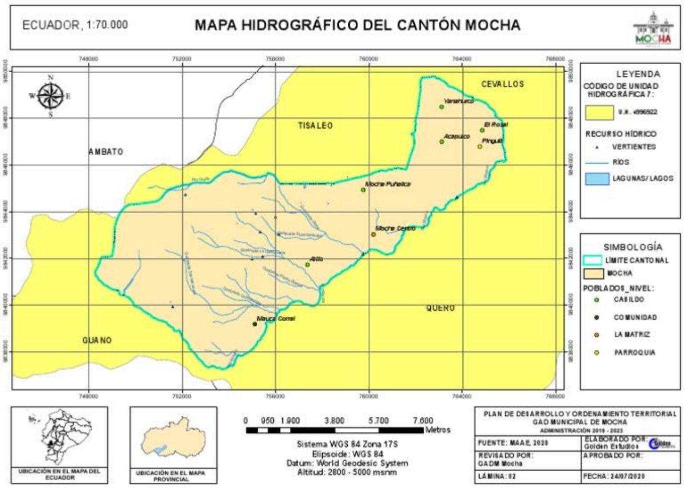
Geographic information system (QGIS 3.28), computer equipment (HP Core(TM) i7-1255U 1.70 GHz Laptop), hydraulic modeling software (WaterCAD), topography equipment (GNSS Tersus Luka), spreadsheet (Excel 2019), documentary resources (such as channel flow history) and regulations (channel organization regulations).

The simulation process involved using the topographic profile obtained, tracing the water path through the pipeline, which runs from the water intake from the Mocha-Huachi canal (temporary diversion of the additional flow through this canal) to the turbine for power generation, and proposing several possible pipe diameters (PVC) to determine which ones meet the minimum and maximum velocity and pressure parameters. The pressure drop was then calculated using the Darcy-Weisbach equation.

Study Area

The study was conducted in a stretch of the Mocha River, located between the cantons of Mocha and Quero, in the province of Tungurahua, Ecuador.

Figure 1.
Geographic location of the study area.



Source: (GAD Mocha, 2020) [19]

The Mocha River originates on the slopes of the Carihuayrazo volcano and is part of the Pastaza River watershed. In the study area, the river's water is used for irrigation through two main canals: the Mocha-Huachi Canal and the Mocha-Quero-Ladrillos Canal.

The study proposes to capture the water from the two canals at the same point, where it is currently done for the Mocha-Huachi canal, at the coordinates 1º25'38"S, 78º39'57"W, in order to transport the liquid to the coordinates 1º24'48"S, 78º38'43"W, as indicated in figure 2, and from here conduct the water object of this study, by means of a pipeline.

Figure 2.
Mocha-Huachi Canal, start of pipeline.


Coordinates: (1º24'48"S, 78º38'43"W)

The pipeline's route is 333 meters long, according to the surveyed profile. The water arrives at the location where the turbine will be installed at coordinates 1°24'57"S, 78°38'40"W, as shown in Figure 3.

Figure 3.
Turbine installation site.


Coordinates: (1º24'57"S, 78º38'40"W)

The turbine water is released into the riverbed to be used as an irrigation source for users of the Mocha-Quero-Ladrillos canal.

Figure 4.
Mocha-Quero-Ladrillos canal intake.

Coordinates: (1º24'58"S, 78º38'38"W)

Hydrological data collection

The hydrological characterization of the Mocha River was based on historical data provided by the Mocha-Quero-Ladrillos Canal Irrigation Water Board. The collected data were tabulated, resulting in average monthly flows, reflecting the region's typical seasonal variations. The average monthly flows were:

Table 1. Average monthly flow of the Mocha-Quero-Ladrillos canal

Month	Average monthly flow (m3/s)
January	0.355
February	0.426
March	0.472
April	0.472
May	0.472
June	0.472
July	0.458
August	0.338
September	0.273
October	0.337
November	0.326
December	0.314

Source: (Mocha-Quero-Ladrillos Channel, 2024) [20]

Calculation of Energy Potential

The energy potential of the project was determined by applying fundamental equations of hydroelectric engineering, considering the available flow and the generated elevation difference. [21].

The theoretical hydroelectric power was calculated using the fundamental equation:

$$P = \eta * \rho * g * Q * H \qquad (1)$$

Where:
P is the generated power (W),
η is the overall efficiency of the system (considering losses in pipes, turbines and generators),
ρ is the density of water (1000 kg/m³),

g is the acceleration of gravity (9.81 m/s²),
Q is the flow rate (m³/s),
H is the net usable height (m).

Conversion Technology Selection

A comparative analysis of different turbine types was conducted to determine the best fit for the specific project conditions. The selection process included the following criteria: [22]:

to) Compatibility with available flow rate and height.
b) Energy efficiency.
c) Acquisition, installation and maintenance costs.
d) Experience and availability of local suppliers.

Overall system efficiency

It was calculated as the product of the efficiencies of the different components of the system [23]:

$$\eta\_global = \eta\_hidráulica * \eta\_mecánica * \eta\_eléctrica \qquad (2)$$

Where:
η_hydraulic is the hydraulic efficiency, which considers energy losses due to friction and turbulence in pipes and tubes,
η_mechanical is the mechanical efficiency of the turbine,
η_electrical is the electrical efficiency, which includes losses in the electric generator and in the transmission systems.

The Darcy-Weisbach method was used to calculate friction losses in the pipeline.

$$h_f = f * \frac{L}{D} * \frac{V^2}{2g} \qquad (3)$$

Where:
hf is the head loss due to friction (m),
f is the friction factor,
L is the length of the pipe (m),
D is the internal diameter of the pipe (m),
V is the flow velocity in the pipe (m/s).

Gross Height

Based on the topography, it was determined that the gross height that can be utilized is 50 meters.

Pipe length

Based on the pipeline layout and terrain profile, the determined pipeline length was 333 meters.

3. RESULTS

Hydrological Analysis and Seasonal Variability

Historical data provided by the Mocha-Quero-Ladrillos Canal Irrigation Board were processed to characterize the hydrological behavior of the Mocha River. The analysis was performed using monthly flow records obtained over several years. [20], which yielded an average annual flow rate of 0.393 m³/s. The data series shows marked seasonal variability, strongly influenced by the region's rainfall patterns.
Months of Highest Flow: The highest flow rates were recorded between March and July, with figures reaching or exceeding 0.458 m³/s. This increase is associated with the beginning and development of the rainy season, where the accumulation of water in the basin and the increase in precipitation favor a more robust flow. This behavior is essential, as it allows us to

predict that the hydroelectric plant will operate under optimal conditions during these months, maximizing energy generation. Months of lower flow:
On the other hand, a downward trend in flow rates was observed between August and December, with September recording the lowest value of 0.273 m^3/s. This decrease is related to the dry season or low rainfall, which creates a critical scenario for system sizing. The significant difference between maximum and minimum flow rates highlights the need to design the plant with safety margins that allow for stable operation even under adverse conditions.

Additionally, trend graphs were constructed and statistical analyses were performed (standard deviation and coefficient of variation).)to quantify data dispersion. The results showed considerable variability, highlighting the importance of having an adaptable system that ensures year-round energy generation. This hydrological analysis is essential for sizing infrastructure, as it allows for determining the most unfavorable operating scenarios and, consequently, planning backup strategies or integration with other energy systems.

Characterization of the Collection and Transportation System

The water intake system was used to harness water from two main canals: the Mocha-Huachi Canal and the Mocha-Quero-Ladrillos Canal. The intake is located in the Mocha River channel, at coordinates 1°25'38"S, 78°39'57"W, at an altitude of 3,218 meters above sea level. From this infrastructure, the combined flow is collected and transported along the Mocha-Huachi Canal route until reaching the intersection point located at 1°24'48"S, 78°38'43"W, at an altitude of 3,197 meters above sea level.

From this point on, the flow from the Mocha-Quero-Ladrillos canal is used exclusively for power generation, transported through a 333-meter-long pipeline. Topographic analysis, conducted through on-site surveys and the use of a Geographic Information System (GIS), determined that the usable gradient between the intake and injection points is 50 meters, which translates to an average gradient of approximately 15%.

These parameters—pipe length, elevation, and gradient—were essential for properly sizing the water pipeline, optimizing transport and minimizing frictional head losses. Accurate determination of coordinates and altitudes ensures that the system maximizes the potential energy of the water and that the infrastructure adapts to the actual ground conditions.

Conversion Technology Selection

For small-scale power generation, a comprehensive review of commercially available technologies was conducted. The selection was based on criteria such as compatibility with the available flow rate and elevation, energy efficiency, associated costs (acquisition, installation, and maintenance), and the experience and availability of local suppliers.[24] [25].

Various turbine alternatives were analyzed, among which the following stand out:

Pelton Turbine: Designed to operate at heights of 50 to 100 meters and with flow rates ranging from 0.01 to 2.00 m^3/s. Its efficiency ranges between 80% and 90% and is recognized for maintaining stable performance despite flow rate variations typical of the rainy and dry seasons. The robustness and adaptability of this turbine make it especially suitable for the Mocha River scenario.

Francis Turbine: With an operating range of heights from 10 to 600 meters and flow rates from 0.03 to 3.00 m^3/s, the Francis turbine has an efficiency of between 80% and 92%. Despite its versatility, its performance decreases when the flow rate falls below the optimal design value, which can be problematic during periods of low flow.[26].

Turgo Turbine: It operates at heights of 20 to 200 meters and can handle very low flow rates (from 0.0005 m^3/s) to 2.00 m^3/s, with an overall efficiency between 70% and 85%. However, its performance varies more abruptly depending on the flow rate, which can hinder stable power generation. [27].

Crossflow Turbine: Suitable for heads between 2 and 200 meters and flow rates between 0.005 and 2.0 m^3/s, with an efficiency ranging from 60% to 85%, reaching peaks when the flow rate remains close to the design value. Although a viable option, its performance variability makes it less predictable for this project.[28].

After comparing the technical and operational characteristics of each technology, it was concluded that the Pelton turbine is the most suitable option for the project, given that it is optimally adapted to the specific flow and elevation conditions of the Mocha River, offering stable and efficient performance.

Results in the Generator Analysis

In parallel with the turbine analysis, suitable power generator options for small- and micro-scale systems were evaluated. Both synchronous and asynchronous (induction) generators were considered, given their widespread use in distributed generation projects. The efficiency of these devices typically ranges between 90% and 98%, depending on factors such as machine quality, load factor, and specific operating conditions.

The analysis included compatibility tests with the selected turbine, ensuring that the generator would contribute to maintaining high overall system efficiency. Pressure drop calculations were performed for various pipe diameters (PVC material) using the Darcy-Weisbach equation, complemented by simulation in WaterCAD software to verify compliance with the minimum and maximum velocity and pressure parameters. The critical result was a value of 0.97%.

To ensure a safe minimum supply of electricity throughout the entire operating period, the following parameters were adopted:
Mechanical efficiency: 80% (worst case for selected turbine)
Electrical efficiency: 94% (average value achievable with good quality equipment)
Hydraulic efficiency: the calculated value is 0.97%

Multiplying these efficiencies produced an overall value of 0.729 (72.9%), which was used for the subsequent calculation of the energy potential of the system.

Calculation of Energy Potential and Theoretical Power

The energy potential of the system was determined by applying the fundamental equation of hydroelectric engineering:

$$P = \eta * \rho * g * Q * H \qquad (1)$$

Applying this formula for each month of the year, considering the seasonal variation of the flow, the following distribution of the theoretical power was obtained:

Table 2. Effective power per month

Month	Effective power (kW)
January	127.00
February	151.70
March	168.60
April	168.60
May	168.60
June	168.60
July	163.80
August	120.90
September	97.50
October	120.20
November	117.20
December	112.50

These values indicate that peak energy production is reached during the rainy season (March to June), with theoretical capacities of 168.60 kW, while in September, during the lowest flow rate, power drops to 97.50 kW. The difference between these values demonstrates the direct influence of flow variability on electricity generation and highlights the need to size the system to ensure stable minimum production during these critical months.

To complement the analysis, numerical simulations were performed that integrated the measured parameters (flow, elevation, and losses), and the theoretical results were compared with realistic operating scenarios. These simulations confirmed the robustness of the design and the system's ability to operate efficiently, even under low flow conditions, which is essential to ensure the project's long-term sustainability.

4. DISCUSSION

Interpretation of formulas and calculations

The basis of the energy analysis of this study is based on the hydroelectric power equation:

$$P = \eta * \rho * g * Q * H \quad (1)$$

This formula converts the potential energy of water, which depends on flow rate and elevation, into electrical energy. The overall efficiency η integrates hydraulic losses (due to friction and turbulence in the pipes), mechanical losses (related to the turbine), and electrical losses (from the generator and transmission). In our study, conservative values were adopted (80% for hydraulic efficiency, 94% for electrical efficiency, and 0.97% for mechanical efficiency), resulting in an overall efficiency of 72.9%. This approximation ensures that the design responds to the most adverse conditions and ensures a minimum safe production.

Likewise, the Darcy-Weisbach formula was used to calculate losses in the pipe:

$$h_f = f * \frac{L}{D} * \frac{V^2}{2g} \quad (3)$$

This equation is essential for sizing the pipeline, as it minimizes losses and ensures that the available gradient translates into maximum useful power.

Regulations and Regulatory Framework

Project viability depends not only on technical parameters but also on the current regulatory framework. In Ecuador, the recent update of the Organic Law on Public Electric Power Services and its regulations has facilitated investment in small-scale renewable energy projects. These regulations allow for the active participation of communities and local governments in the management and operation of micro-power plants, which favors the decentralization of electricity generation and guarantees more equitable access to energy, especially in rural areas. Furthermore, international organizations such as IRENA and IEA studies support the global trend toward diversifying the energy mix through hybrid systems and low-environmental-impact technologies.

Meaning of the Effective Power Table

Table 2 in the Results chapter shows the monthly theoretical power calculated for the system, based on the seasonal variability of the flow. These values indicate the following:

Peak production (March to June): During these months, flow rates are highest (≥ 0.458 m³/s), allowing for theoretical capacities of up to 168.60 kW. This means the plant will operate under optimal conditions during the rainy season.

Minimum production (September): With a flow rate of 0.273 m³/s, power drops to 97.50 kW, highlighting the critical operating scenario. This data is crucial for sizing the plant, as backup measures or integration with other systems (e.g., solar) must be considered to ensure a continuous supply.

Intermonthly variability: The difference between maximum and minimum values shows the direct influence of rainfall patterns on electricity generation, highlighting the need for operating strategies that adapt to this variability.

Future Perspectives and Recommendations

To improve system stability and efficiency, it is recommended:

Real-time monitoring: Implement flow and operating condition monitoring systems that allow for dynamic adjustment of system parameters.

Advanced simulations: Develop predictive models that integrate meteorological and hydrological variables, thus optimizing system management and operation in different scenarios.

Integration of hybrid sources: Evaluate the incorporation of additional technologies, such as solar panels, to supplement electricity generation during low-flow months.

Regulatory Update: Stay up-to-date with local and international regulations, taking advantage of incentives and financing programs that support small-scale renewable energy projects.

The results demonstrate that the project presents a solid technical and energy feasibility, supported by a detailed analysis of hydrological conditions, technology selection, and a favorable regulatory framework. The interpretation of the effective power table, along with the use of fundamental formulas, provides a clear view of the system's potential and the operational challenges to be overcome, laying the groundwork for future research and the successful implementation of the hydroelectric plant in Tungurahua Province.

However, the substantial difference between high and low flow months poses operational challenges, especially in September. This requires developing preventive maintenance strategies and, possibly, integrating complementary systems (energy storage or hybrid sources) to mitigate the effects of low water availability.

5. CONCLUSIONS

The hydrological characterization of the Mocha River revealed marked seasonal variability in flow rates, with maximum values of 0.472 m^3/s between March and June and minimum values of 0.273 m^3/s in September. This detailed understanding of the river's behavior allowed for estimating its energy potential and sizing its pipeline and generation technology.

The comparative analysis of turbines (Pelton, Francis, Turgo, Crossflow) showed that the Pelton turbine is best suited to the project conditions, given the available height (50 m) and the variability of flow (0.273 to 0.472 m^3/s). Its efficiency, ranging from 80% to 90%, is ideal for fluctuating flow rates and a head ranging from 50 to 100 meters.

Based on hydraulic, mechanical, and electrical efficiency, an overall value of 72.9% was obtained. This data served as the basis for calculating the monthly effective power, allowing for a realistic estimate of electricity generation for each season and ensuring a safe minimum supply throughout the operating period.

The calculation of the monthly effective power output showed values between 97.5 kW (September) and 168.6 kW (March-June). These results provide sufficient information to plan water resource use, optimize plant operation, and design maintenance strategies to ensure the project's long-term sustainability and profitability.

The results obtained suggest that, despite seasonal variability, the proposed system is viable for generating electricity on the Mocha River. The selection of the Pelton turbine, based on its ability to operate stably in the face of flow fluctuations, along with the appropriate sizing of the transmission system and the compatibility of the generators, allows for efficient year-round operation.

REFERENCES

[1] International Energy Agency (IEA), Hydropower Special Market Report 2021: Analysis and forecast to 2030, Paris, 2021.

[2] International Hydropower Association (IHA), 2021 Hydropower Status Report, London, 2021.

[3] KS Balkhair and KU Rahman, “Sustainable and economical small-scale and low-head hydropower generation: A promising alternative potential solution for energy generation at local and regional scale,” Applied Energy, vol. 188, pp. 378-391, 2017.

[4] D. Singh, “Micro hydro power: resource assessment handbook,” 2009.

[5] E. Asmelash and R. Gorini, "International oil companies and the energy transition, International Renewable Energy Agency, Abu Dhabi About IRENA The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a center of excellence," 2021.

[6] T. Arvanitopoulos and P. Agnolucci, “The long-term effect of renewable electricity on employment in the United Kingdom,” Renewable and Sustainable Energy Reviews, vol. 134, 2020.

[7] Q. Ping, N. Ting, S. Liu and Y. Meilin, “Trend analysis of hybrid small-hydro generation systems in rural areas.,” IOP Conference Series: Earth and Environmental Science, 2021.

[8] V. Reyes and J. Aledmer, «General evaluation of the Ecuadorian energy matrix and the contribution of non-conventional renewable energies to the decarbonization of electricity generation with emphasis on geothermal potential,» Quito, Universidad Andina Simón Bolívar, 2021.

[9] Ministry of Energy and Non-Renewable Natural Resources, "Organic Law on the Public Electricity Service," 2018.

[10] Ministry of Energy and Non-Renewable Natural Resources, "Regulations of the Organic Law of the Public Electric Power Service," 2021.

[11] L.A. Mosquera and C.A. Gallego, “Prefeasibility study for the implementation of a hydrokinetic turbine in a non-interconnected area,” 2020.

[12] M. Da Cruz, "Assessment of the potential of hydrokinetic energy production in the Douro River estuary under climate change scenarios," Portugal, Universidade do Minho, 2022.

[13] R. Iñiguez, «Feasibility of rural community micro and mini hydroelectric systems in Azuay,» Cuenca, University of Cuenca, 2013.

[14] LA Ipiales Lucero, «Socio-environmental diagnosis for the development of an environmental management plan for the Mocha-Quero-Ladrillos irrigation canal in the province of Tungurahua,» Chimborazo Polytechnic School, 2018.

[15] U. Baca and P. Aita, "Energy transition with renewable energies for energy security in Peru: a climate-resilient public policy proposal," Espacio y Desarrollo, 2018.

[16] A. Gil Olcina, «Optimization of water resources and harmonization of their uses: the Marina Baja Water Consortium.», University of Alicante, 2010.

[17] A. Castellanos Sergio and M.A. Bogotá, «Hydrological characterization of the middle and lower basin of the Magdalena River,» Bogotá, Antonio Nariño University, 2021.

[18] MC Ramos-Cárdenas, DC Hernández-Cipamocha, HY Pérez-Arenas and E. Sierra-Cárdenas, «Analysis and perspectives of the implementation of clean technologies for energy generation in Colombia,» Colombia, I3+ Journal, University of Boyacá, 2022.

[19] GAD Mocha, "Hydrographic map of the Mocha canton," Development and territorial planning plan, 2020.

[20] Mocha-Quero-Ladrillos Canal, 2024.

[21] D. Maldonado, «Analysis of the potential for hydrokinetic energy generation in the Magdalena River in Barranquilla,» 2024.

[22] K. Pérez, «Selection of the size and type of turbine to be used in a hydroelectric plant on the Villalobos River,» Universidad de San Carlos de Guatemala, 2019.

[23] C. Pinto, «Optimization of a hydroelectric peak-generation system,» Bogotá, Universidad de los Andes, 2015.

[24] B. Kirke, “Towards more cost-effective river hydrokinetic turbines,” Energy for Sustainable Development, vol. 78, 2024.

[25] MI Yuce and A. Muratoglu, “Hydrokinetic energy conversion systems: A technology status review,” Renewable and Sustainable Energy Reviews, vol. 43, pp. 72-82, 2015.

[26] L. Gil, «Design of a hydroelectric generation simulation module using Pelton and Francis turbines supplied by a recirculation system,» Peru, Catholic University Santo Toribio de Mogrovejo, 2017.

[27] T. Reyna, M. Lábaque, B. Irazusta, S. Reyna and C. Riha, «Teaching hydraulic microturbines. Turgo, Pelton and axial turbines. Challenges and adaptations,» Paysandú, VI Symposium on Experimental Methods in Hydraulics, 2019.

[28] V. Gómez, E. Higuita and A. Morán, «Computational analysis of a cross flow turbine performance. In MATEC Web of Conferences,” EDP Sciences, 2018.