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Technical, Economic, and Environmental Feasibility of Implementing A Mini Hydroelectric Plant With A Reversible System

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Abstract

Mini hydroelectric plants are a renewable energy source that harnesses the flow of water to generate electricity sustainably on a smaller scale. The objective of this research is to analyze the technical, economic, and environmental feasibility of mini hydroelectric plants. implementation of a mini hydroelectric plant with a reversible system, taken as a basis of this study, examines the "La Esperanza" dam to provide electricity to the communities supplied by the Calceta substation. The methodology employed was a literature review, resulting in a research thesis that allowed for the analysis of data collected at the study site. The results indicate that poor management and lack of maintenance have rendered the dam inoperable. Furthermore, the research suggests the possibility of converting the dam from storage to pumped storage and restoring the plant to operation. The ratio between energy generated and energy used for pumping revealed that this is technically feasible. Finally, it was concluded that, due to the results obtained, through economic investment and proper management, the mini hydroelectric plant in Manabí will be able to guarantee a continuous and sustainable energy supply to different communities that currently have poor energy quality and others that are not electrified.

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1 Introduction

Today, electricity is a basic necessity in every home, just like water. In daily life, most things function and depend on electricity. In countries with abundant water resources, such as Ecuador, hydroelectric power plants make up a large part of the country's electricity generation, serving as a key component for rural electrification.

Conventional hydroelectric power plants have large reservoirs for water storage, although these are run-of-river or "flow" plants. A drawback is the hydrological seasonality, which can affect the magnitude of the inflow to the plants, regardless of their size, causing significant service deficits and inconvenience for residents. Consequently, given the need to find alternatives to increase the reliability of hydroelectric plants, the option of implementing a small hydroelectric plant with a pumped-storage system has emerged (Laghari et al., 2013).

The basis of pumped storage hydropower is a process of transforming potential energy into usable electrical energy, providing a buffer between supply and demand, ensuring that more renewable electricity reaches consumers, which will have a lower environmental impact and lower costs.

The process involves using two dams or reservoirs at different heights. Potential energy is stored during periods of low electricity demand or when there is excess energy on the grid. This surplus energy is used to pump water from the lower dam to the upper one. When electricity demand increases, the water stored in the upper reservoir is released, flows downhill, and passes through generating turbines (Alarcón, 2022). This process transforms stored potential energy into kinetic energy and ultimately into electricity.

A hydroelectric plant typically has a very long lifespan, approximately 100 years or more. Similarly, the equipment and machinery used, such as turbopumps, generators, transformers, etc., can last around 50 years with minimal performance decline. Regular maintenance is necessary to keep it in optimal condition. Furthermore, the storage capacity does not deplete.

Currently, the country is experiencing an electricity crisis caused by drought affecting several major hydroelectric plants nationwide. The lack of rain has led to a period of drought, and the reservoirs are not at the minimum level required for proper operation, preventing a consistent supply of electricity. As a result, scheduled blackouts have caused difficulties for businesses and households; the reversible hydroelectric plant could minimize the problem in the upcoming seasons of low rainfall (Hadjipaschalis et al., 2009).

Given the country's high potential for hydroelectric power generation, a small hydroelectric plant with reversible systems could offer a sustainable and viable solution. This would benefit the province of Manabí, as it would enable the generation of electricity from local water resources, thereby stabilizing the energy supply and enhancing resilience to potential power outages.

2 Materials and Methods

A literature review was conducted (scientific journals, specialized reports, books). The research involved searching for and compiling academic documents, gathering evidence, and consulting with and receiving assistance from engineering professionals. The inductive-deductive method was employed, allowing for an analysis of how the hydroelectric plant should be implemented. This involved observing the site under study and comparing it with other existing studies, thus enabling a more complete and coherent understanding of the problem. All of this contributed to a more realistic research process, as it allowed for contrasting theory with reality and, at the same time, generating new knowledge based on evidence.

3 Results and Discussions

Several hydroelectric power plant projects have been developed in the country, and today it is the largest source of generation, accounting for 78.58%, or 25,237.38 GWh, of the total gross energy in 2023 (CENACE, 2023). However, a reversible hydroelectric plant has not yet been built. While documents and thesis projects illustrate the concept, none have been physically implemented. The idea of a reversible hydroelectric system arose from the possibility of reusing water, which could function as a "battery" to maximize hydrogenation capacity. This type of proposal is quite interesting.

Europe has been the main focus of the research, specifically in Spain, with the Cortes-La Muela I and II pumping station being one of the largest in the European country (Guinaldo, 2025). It was taken as a reference because it has become one of the most important projects and has provided numerous benefits over time.

Pumped storage projects, such as Muela I and Muela II, have been the subject of numerous environmental impact studies in recent years due to their importance in hydroelectric power generation and their potential environmental impact. One of the most relevant studies in this area is the one carried out. This study analyzes the effects of the construction and operation of pumped-storage hydroelectric plants on aquatic and terrestrial ecosystems. It highlights the importance of assessing the environmental impacts of these projects, both during the construction and operation phases, to minimize negative effects on the environment (Wendel et al., 2015).

This study focuses on assessing the environmental impacts of pumped-storage hydroelectric plants in relation to greenhouse gas emissions and disruption of the hydrological cycle. It concludes that, although pumped-storage plants can contribute to reducing CO2 emissions, they do not necessarily have the same environmental impact. 2Compared to other energy sources, it is essential to consider the potential negative effects on the environment and adopt appropriate mitigation measures.

In the specific case of Molar I and Molar II, this study analyzes the environmental impacts associated with the construction and operation of pumped-storage hydroelectric plants in the region. It identifies the main impacts on water quality, flora and fauna, and the landscape, and proposes mitigation measures to reduce these effects. However, this study focuses on the construction phase, leaving a gap in knowledge about the long-term impacts during the plants' operation.

Based on the environmental impact study of the Muela I and Muela II pumping station project, with special attention to the long-term effects on the ecosystem and the mitigation measures necessary to guarantee the sustainability of these projects, given that 650,000 tons of CO_2 have been saved.2annually, becoming the largest pumped-storage hydroelectric plant in continental Europe, with a total capacity of 1470 MW, meeting the demand of 450,000 homes annually. This research will contribute to a better understanding of the environmental impacts of pumped-storage hydroelectric plants and will provide valuable information for the planning and management of future projects in this field.

To ensure an efficient improvement in the supply of electricity to the communities served by the Calceta substation, the implementation of a reversible mini hydroelectric plant would improve the living conditions of the surrounding population. Figure 1 shows the geographical location of the hydroelectric plant under study.

Figure 1. Daule-Peripa Reservoir and La Esperanza Transfer

As can be seen, this is the study area where the proposed reversible mini-hydroelectric plant is to be implemented in the province of Manabí. Its purpose is to supply additional or backup energy to the Calceta substation, which will then be distributed efficiently. This aims to reduce the effects of pollution. This technology is an efficient source of generation; however, its infrastructure impacts the ecosystem and is invasive in the river where it is built. During the rainy season, the river occasionally overflows and floods the surrounding areas, causing significant damage to crops and homes. The reversible system allows for more efficient regulation, taking into account all the environmental factors to which it is exposed. Furthermore, during droughts, the river flow may not be sufficient to generate the power required by demand. With a reversible system, the water that has already passed through the turbines can be reused.

The La Esperanza Dam is a major hydraulic infrastructure project located in the province of Manabí, Ecuador. It was built to provide water for irrigation, drinking water supply, and hydroelectric power generation. The reservoir covers 2,500 hectares and has a storage capacity of approximately 450,000,000 cubic meters of water (Ortiz &

Galarraga, 2015). The dam has had a significant impact on agricultural development and on the provision of water for local communities. Figure 2 shows the location of the La Esperanza dam.

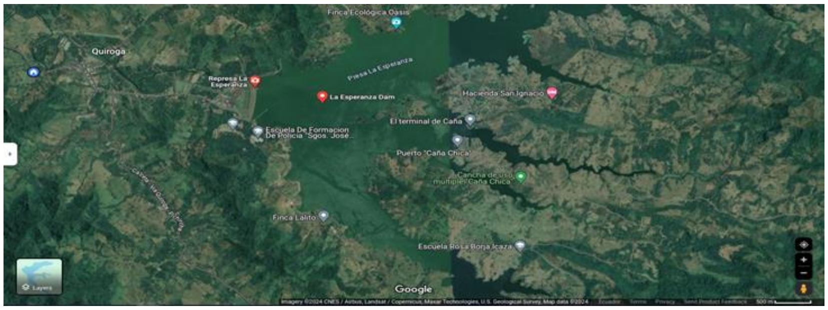

Figure 2. La Esperanza Dam
Fuente: Google Maps

It is essential to consider the importance of conserving aquatic ecosystems and protecting the biodiversity associated with these resources. Responsible water resource management is fundamental to ensuring their long-term sustainability and addressing the needs of various sectors.

Water transfer: Daule-Peripa and La Esperanza dams
The Esperanza reservoir receives its natural flow from its own basin and also from the transfer that exists between both dams, through this intake tunnel designed for 18m3/s. Hope depends on the water level in the Daule-Peripa reservoir. This water transfer is very important because it is the largest source of water that the dam receives.

Electricity demand
According to data from the Regulatory and Control Agency, the average national electricity rate is 9.20 cents USD/kWh (Energy, Ministry of Environment, 2022). Electricity demand increases during peak hours, meaning that hydroelectric production coincides with these peak demand periods, when electricity prices are highest. These peak hours typically occur between 8:00 AM and 12:00 PM and between 6:00 PM and 10:00 PM, although this varies depending on the time of year, including holidays and weekends. Furthermore, the purchase of energy for pumping would coincide with off-peak hours, periods of low electricity demand, which coincide with the hours of lowest demand and when electricity prices are lowest, typically around 5:00 AM. This would allow for a highly dynamic interaction between generation and pumping.

The La Esperanza mini-hydroelectric plant was built by Manageneración, a public-private partnership comprised of La Fabril S.A. (the majority shareholder) and the Manabí Water Management Regulatory Corporation (CRM). This plant is located in the Bolívar canton, in the province of Manabí, Ecuador.

The creation of the La Esperanza mini-hydroelectric plant was part of a broader plan to utilize Manabí's water resources, which also included the Poza Honda dam. Both dams, built by the Ecuadorian government, were adapted for use as small hydroelectric plants following a contract signed in 2003 between the CRM and La Fabril. The two plants, operated by Manageneración since 2005, harnessed the water resources of their respective reservoirs (Goraymi, 2024).

Together, the Poza Honda and La Esperanza mini-hydroelectric plants had an installed capacity of 9 MW, with Poza Honda contributing 3 MW and La Esperanza with a larger capacity of 6 MW, distributed across two 3 MW synchronous generators. Although these plants were designed to operate in a complementary manner and generate electricity for the region, both are currently out of service (ASTEC, 1986).

During its active operation, La Esperanza generated an annual average of approximately 28 gigawatt-hours (GWh), contributing to the national electricity grid, especially in the Manabí region, which has historically been vulnerable to power outages. The turbine flow rate of this mini-hydroelectric plant ranged between 8 m^3/s and 20 m^3/s, depending on both the water availability in the reservoir and the energy demand.

However, one of the most significant challenges the plant faced during its operation was sedimentation in the reservoir and the difficulty in controlling its discharge. These problems considerably affected the plant's efficiency, generating additional maintenance costs and reducing effective generation capacity. Despite these challenges, the plant managed to operate for 17 months before being taken offline.

The main purpose of the La Esperanza mini hydroelectric plant was to generate electricity sustainably, taking advantage of the water resources available in the region. This energy was mainly intended for local supply, alleviating dependence on external sources and contributing a renewable source to the national electricity system. Additionally, the La Esperanza dam was initially designed to support local agriculture, allowing irrigation of crops in nearby areas, which promoted agricultural development in the region (Widharma et al., 2017).

Main equipment for a reversible power plant

Subsection should be written without a bold type. The result and analysis are presented in the present form. Please avoid too many paragraphs in this section. To identify the main technologies and equipment needed for the implementation of the reversible mini-hydroelectric plant, a visit was made to their facilities to provide information and technical data for the corresponding research. The elements required for a hydroelectric power plant to begin operation include: Penstock, Forebay, Turbines and Generators, Discharge Pipeline, Reversible Motors/Pumps, and a Control System. This section only mentions the most important main components.

Upper Reservoir: In this case, it would be the La Esperanza dam

Lower Reservoir: For a project like the one proposed, the lower reservoir is fundamental; it can be artificial or natural. In this specific case, a new one needs to be built since a reservoir relatively close by is needed to avoid pressure and flow losses.

Turbines: This generation used two Kaplan turbines, which are axial-flow, reaction turbines. They are characterized by their rotor or impeller, which resembles a ship's propeller. These are ideal for low heads and high flow rates. Their characteristics are specified in Table 1.

Table 1
Features of the KAPLAN Turbine

Turbine	Kaplan
Neto Max	41.28m
Maximum Flow Rate	9.6 m^3/s
Maximum power	3555 kW
Nominal speed	514 r.p.m

Energy efficiency of the reversible hydroelectric power plant

Hydroelectric power plants are at the forefront of the cleanest and lowest-cost energy sources, and are known for being the most efficient method of generating electricity on a large scale. But just how efficient are they? Compared to thermoelectric power plants, the difference is striking, ranging from 33% to 55%, although this depends on the type of fuel used and the technology employed in thermoelectric plants.

The efficiency percentage of a conventional hydroelectric power plant depends exclusively on the type of turbine used and the water flow in the seasons of the year; it can reach 95% for large installations. On the other hand, there are also small-scale hydro generation plants with an output power of no more than 5 MW of production, which can have an efficiency of 80% and 85% (Indar, 2012). Reversible power plants can be up and running in just a few minutes, supplying backup power in a highly efficient manner, balancing fluctuations, and thereby optimizing the reliability of the system.

Efficiency of generation components

Turbine efficiency

The turbine is one of the most important components of power plants, as it transforms the kinetic energy of water into mechanical energy, which is then converted into electrical energy by the generator. Therefore, it is essential to choose the right turbine that operates under optimal conditions to maximize the use of available water resources. The efficiency of hydraulic turbines is normally high, above 85% after accounting for hydraulic, bearing, friction, and general mechanical losses. To analyze performance or efficiency, the specific speed can be used, which is a parameter that combines the power and revolutions per minute of the turbine, along with the head, and is calculated using equation 1.

$$N_s = \frac{n\sqrt{P}}{H^{\frac{5}{4}}} \quad (1)$$

Where:
n→Turbine revolutions per minute (rpm)
P→Turbine power (kW)
H→Jump height (m)3/s)
Since the specific speed result is 292.89 and following the performance curve of the Kaplan turbines in Figure 17, it was determined that the turbine reaches an optimal efficiency range, achieving an efficiency of approximately 91%.

Pump Efficiency
In an ideal environment, pumps would operate so that the water power exiting the pump is equivalent to the shaft power entering the pump, achieving 100% efficiency. Due to friction, energy losses, and leakage, it is practically impossible for a machine or pump to operate under completely ideal conditions (Sintech Pumps, 2023). To calculate the pump efficiency and water horsepower, equations (2) and (3) can be used (LibreTexts, 2022).

$$\eta_b = \frac{HP\ water}{HP\ bomb} \quad (2)$$

To calculate the horsepower of water, equation 3 is used.

$$HP\ water = \frac{caudal\ (gpm) * Height(pies)}{3960} \quad (3)$$

Through calculations, it was determined that the pump in question has an efficiency of 98.36%. As a complement to what has been seen and the choice of the reference pump UGP-M, the necessary pump power can be calculated with equation (4). (Chemical Engineering Guide, 2023).

$$P_b = \frac{(\rho \cdot g \cdot Q \cdot H)}{\eta} \quad (4)$$

Where:
- ρ →Water density (1000 kg/m³).
- g→ Gravity (9.81 m/s²).
- Q→ Caudal (m³/s).
- H→ Pumping height (m).
- η → Overall efficiency of the pumping system.

The required power that the pump should have will be 4.04 MW or 4000KW for the pumping system.

Cycle efficiency
Pumped storage plants are net consumers of energy due to the electrical and hydraulic losses that occur when pumping water to the upper reservoir. To determine the efficiency of the cycle, it is necessary to calculate the pumping energy required and the energy generated by the plant during each operating hour of both phases, thus allowing for an evaluation of the plant's performance.

Pumping energy required
The energy required for pumping depends entirely on what a pump can consume over time, whether in specific hours or days; for example, if the pumping system operates for 6 hours, which are off-peak hours, meaning hours when energy demand is lower, and cost is minimal, it would be the right time for pumping.

To calculate the energy consumed by a pump during its operation, an adaptation is made to take into account the relationship between the energy required for pumping, the pump's power, and the operating time. This can be calculated using equation 5 (Mompeán, 2021).

$$E_b = P_b \times t \quad (5)$$

Where:
Eb→ Energy consumed
Pb→ Pump Power
t→ Operation Time

Energy produced by the power plant
The energy generated in a hydroelectric plant, after performing the corresponding calculations, yields an approximate estimate of the power produced during the hours in which the plant could generate, which would be the 5 peak hours. These generation capacity results provide a basis for analyzing its technical viability. The plant factor is within the range of 0.6 to 0.7, a range of values recommended for hydroelectric plants (Villarreal, 2017). The energy generated in a hydroelectric power plant is calculated using the following equation (6) (Ramírez, 2019)

$$E_g = P * FC * T \quad (6)$$

Where:
P →installed power
FC→load factor (60%)
T →Total hours in which the plant generates

During the 5-hour generation period, which is the peak hours for completing the cycle, the energy generated would be 18 MWh. And it would be 28 MWh during the 8-hour daily generation period.

Cycle efficiency

The efficiency of a reversible power plant's cycle is a key factor in evaluating its energy performance, considering the relationship between the energy generated and the energy consumed by the pumping system, and is a determining criterion for its viability. The cycle efficiency for the power plant is obtained from equation (7) (Carmona et al., 2022).

$$Cycle\ efficiency = \frac{Energy\ generated}{Pumping\ energy} * 100\ \% \quad (7)$$

Since the power plant has an installed capacity of 6 MW and assuming it is generating at its maximum load, with the water pumped previously, it is possible to generate 4.44 MW. This indicates that the pumping system does not allow the plant to generate its full or maximum capacity during the cycle.

Initial cost estimate
In all engineering decisions, the cost of the systems must be balanced with the reliability they must have; the reliability of the systems is established by the demands of the loads, so the equipment and its characteristics must be correlated with the reliability expected by the system.

The following items are considered for estimating the costs of a hydroelectric project:
Total cost: This is the total price of a fully constructed project. Direct costs include land, construction, and labor. Indirect costs include legal and administrative expenses, bidding documents, and auditing.
Redesign costs: These are the works and equipment that have a shorter useful life than the entire project.
Operating and maintenance costs: They depend on the size of the power plant, and can be expressed as a unit cost per year (for example, USD cents$/kW/year, these can fluctuate between $0.01 and $0.02 per kWh) or as a percentage of the total project investment.

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Considering the table above, it can be deduced that medium-sized hydroelectric plants with an installed capacity between 5 and 6 MW, taking into account the typical values of similar projects in Ecuador, would have an initial investment cost of approximately $1,500 to $2,000 US$ per kW installed. The total investment cost would be estimated between $9 and $12 million, and the annual operation and maintenance costs are between 1.5% and 3% of the initial investment cost, which would be $135,000 to $450,000 USD per year for $9 million and $180,000 to $360,000 USD per year for $12 million.

Based on these initial economic estimates, it is relevant to analyze the energy generation cost for this type of project, as this cost directly influences the competitiveness and economic viability of medium-sized hydroelectric plants. A detailed calculation of the cost per kWh for each year of generation is presented below, considering a 10-year amortization period and the associated operation and maintenance costs, in contrast to the regulated tariffs currently in effect for end users in Ecuador.

If the average capacity factor for hydroelectric plants is 60%, considering that the plant remains operational throughout the year, 8 hours a day, and that the plant functions as a peak generation, that is, that it covers peak demand. The annual energy production and generation cost can be obtained using equations (8) and (9) (PUCP, 2008).

$$\boldsymbol{E_{MWH}} = P \times T \times FP \tag{8}$$

Where:
E→Energy Generated
T→Working time
Fp→Power Factor
Obtaining an annual production of 10512,000 kWh.

Generation cost per kWh:

Using a 10-year amortization period, fixed and operating costs can be calculated using equation 9.

$$Cost\ per\ kWh = \frac{Annual\ fixed\ costs + O\&M}{annual\ energy\ production} \tag{9}$$

Where:
Initial cost→ 9M
Annual amortization→ $400,000 USD over 10 years
Operation and maintenance→ 360,000 USD/year
Annual production→10512,000 kWh

The estimated generation cost for a 6 MW hydroelectric plant is approximately $0.07 per kilowatt-hour per year. Regarding regulated rates for end users during peak hours, the cost may include subsidies and sector-specific rates (residential, commercial, industrial). Since 2020, the price has remained at 9.2¢USD/kW for more than 5,505,033 energy service users (Ministry of Energy and Mines, 2024).

Analyzing the costs of power generation in conventional hydroelectric systems lays the groundwork for evaluating the specific characteristics of pumped-storage hydroelectric systems, where efficiency and pumping costs play a crucial role. In this context, it is essential to consider both the technical characteristics of the equipment and the local economic and operational conditions. Subsequently, specific calculations of the operating cost and efficiency of a pumped-storage hydroelectric system are presented, taking into account off-peak energy tariffs and energy recovery during generation.

Estimated cost during off-peak hours

In the case of pumped-storage hydroelectric systems, these costs can increase due to the energy consumption required for pumping and the overall efficiency of the system. The efficiency of pumped-storage hydroelectric plants typically ranges between 70% and 85%, and some of the energy used in the pumping process is lost. The operating cost of these systems includes not only the generation cost but also the additional cost associated with the energy consumed during pumping (Saravia et al., 2022, IDB | Inter-American Development Bank, 2022).

Pumping cost
The energy consumed by the pump is 24.24 kWh and with an energy cost in off-peak hours, which are the hours in which it would be optimal to pump, of $0.05 USD/kWh, which is the approximate value of the energy cost in hydroelectric plants, the pumping cost per Kilowatt/hour can be calculated as follows (Electricity Regulation and Control Agency (ARC), 2025). The cost of pumping water is determined by equation 10 (LibreTexts, 2022).

$$Pumping\ cost = Energy\ consumed\ \times\ cost\ of\ energy\ during\ off-peak\ hours \qquad (10)$$

This result can be interpreted to mean that for every kilowatt-hour used to pump to the upper reservoir, there will be a maximum cost of $1,212 USD. The calculations were based on typical operating conditions in Ecuador, where hydroelectric power plants predominate due to the abundance of water resources. In addition, parameters such as the following were considered:

The average cost of energy during off-peak hours was assumed to be $0.05 cUSD/kWh, which is typical in scenarios with low energy rates, such as in Ecuador, where the cost of hydroelectric generation is low due to the predominance of this energy source.

From an economic perspective, investment in small hydroelectric projects is very interesting since they have a useful life of around 40 years. Although they have a high initial cost, the investment is recoverable in approximately 10 years because their operating and maintenance costs are gradually low (FOCER Strengthening of Renewable Energy Capacity for Central America, 2002).

Environmental impacts of hydroelectric power plants
Ecuador has environmental policies that promote the protection and safe exploitation of natural resources. The construction of the pumped-storage hydroelectric plant requires an assessment of its environmental impact. The project needs to be as environmentally friendly as possible, both during construction and throughout its long-term operation.

Approximately 90% of Ecuador's energy is supplied by hydroelectric plants, located primarily in the Sierra and Amazon regions, which are characterized by their magnificent landscapes and rich ecosystems. Therefore, special care must be taken to protect ecosystems near hydroelectric plants and ensure that these plants do not encroach upon, invade, or weaken the aquatic and terrestrial ecosystems.

In Ecuador, the Coca Codo Sinclair hydroelectric plant, the largest in the country with an installed capacity of 1500 MW, has had a significant environmental impact. "It has a major impact on the sediment; there is extremely high erosion in this basin," says Encalada. (Davalos, 2022).

While they are considered green projects and also the most sustainable and safe way to generate clean energy without compromising the stability of the electrical system, the truth is that they actually have many environmental problems, such as:

- Deforestation or tree felling during civil works.
- Land displacement and risk of soil erosion.
- Sedimentation in the dam and consequently a decrease in storage capacity.
- Low water flow.
- Poor management of solid waste, which pollutes the water and the land.
- Of course, environmental changes also cause social impacts such as:
- Invasion of indigenous, historical and cultural territory due to civil works.
- Noise pollution from the turbine and generator.
- Visual impact on the landscape since hydroelectric projects are usually located in mountainous and forested areas.

Mitigation proposals
These problems must be treated carefully and in the least invasive way possible; mitigation measures can be implemented as a response:
- It is essential to care for and respect cultural, historical, and water heritage because it is our foundation; for this reason, the best option is to build civil works in uninhabited areas.
- To avoid noise pollution, a machine house can be built with noise-insulating materials.

- If it is necessary to cut down trees, it is inevitable to delimit the layout of the land and design for the civil works, since it does not require significant tree cutting.
- Create a reforestation plan to replace the cut trees and thus not disturb the available flow.
- Civil infrastructure must have a safe place to avoid landslides and prevent soil excavation.
- It is mandatory to maintain the ecological flow in rivers of at least 10% of the average flow.
- During the construction phase, it is necessary to implement a water quality management program and an integrated solid waste management program for materials such as stones and soil.
- Advanced filtration and sand removal technologies can be implemented for sediment control.

The long-term social impacts in terms of sustainable development involve communities gaining the privilege of having a quality electricity service, in addition to avoiding floods that could affect citizens, such as the loss of their crops or water entering their homes; these would be mitigation measures to minimize adverse effects and contribute to a more equitable and sustainable relationship between the reversible hydroelectric plant and its social environment.

This project aims to verify the feasibility of implementing and operating a mini hydroelectric power plant, considering its reversible conversion through a pumping system, to contribute to the Ecuadorian energy sector.

With the compiled information plus the data collected from the study center, with the consultation and assistance of engineering professionals, insulation tests were carried out and the condition of the main components of the center, both electrical, electromechanical and hydraulic, was evaluated, concluding that certain parts of the infrastructure and components could be reused if the center were restarted, including the turbines and the transformer that has the characteristics specified above.

The Daule-Peripa and La Esperanza water transfer system was designed to improve water resource management in the province of Manabí, guaranteeing a constant flow and maintaining an adequate level in the La Esperanza dam. This would benefit the hydroelectric plant's energy generation; thanks to the transfer between the dams, generation could be scheduled according to demand.

Regarding the reversible aspect of this specific case, it is necessary to construct a new reservoir at a lower elevation and with a smaller capacity than the La Esperanza dam. Due to its specific characteristics, it has been determined that it will be a pure pumped-storage hydroelectric plant, since both its lower and upper reservoirs would be located at ground level. The lower reservoir does not receive any external water input, serving exclusively for storage; all the energy generated is a result of this closed-loop system between the two reservoirs.

This type of power plant has a simple operation and combines the functions of a conventional power plant with a separate pumping system to move water to the upper reservoir, using an electric pump when demand is low and electricity is cheaper. The stored water is then continuously released to generate electricity during peak demand periods.

The size of the selected pump, which would pump 2500l/s or 2.5 m3/s with an efficiency of 98%, was determined based on the criterion of protecting the ecological flow and taking into account that the La Esperanza dam is multifunctional and many people depend on it for their own benefit.

In pumped-storage hydroelectric plants, the cycle efficiency or overall efficiency ranges from 70% to 80% due to mechanical and hydraulic losses. In this case study, an efficiency of 74.25% is achieved, which is within the acceptable range for a pumped-storage plant to be technically viable. It generates 28 MW daily during peak hours and consumes 24.24 MW for the pumping system during off-peak hours.

The gap between socio-economic progress and energy demand is very narrow, since increased demand coincides with socio-economic growth. If a country has not increased its energy demand over several years, its economic progress has stagnated. The development of a hydroelectric project enables the country's energy advancement and is linked to progress in economic, productive, and, above all, social sectors, resulting in significant benefits for Ecuadorian citizens.

From an economic perspective, small-scale hydroelectric projects are very attractive compared to large-scale projects, as they can have a similar lifespan of 40 years. The initial investment is generally quite high; in this case study, the estimated initial financing is between 9 million and 12 million, recoverable in approximately 10 years.

To optimize resources and boost the efficiency of pumped-storage hydroelectric plants, an existing conventional hydroelectric plant with an upper or lower reservoir (depending on the site's topography) can be combined with a pumping system. Utilizing an existing upper reservoir, facilities, and equipment can significantly reduce project costs. In this case, savings could range from 30% to 35% compared to a new installation, depending on the specific project requirements.

To justify whether a pumping station is profitable, a comparison is made between the energy generated and the energy used for pumping using equation 11 (Diego & Días, 2012).

$$IN_t * C_t > IN_b * C_b \tag{11}$$

Where:
Wt→ The energy generated
Wb→ Energy consumed
Ct→ The cost of high-demand energy
Cb→ The specific cost of low-demand energy

The results show that the ratio between energy consumption and pumping costs is lower than the energy generated, meaning the plant meets demand. This demonstrates that, in general terms, it is technically and economically viable.
In environmental terms, pumped-storage and conventional hydroelectric plants have the same environmental impact. The La Esperanza dam, for example, has existing infrastructure, eliminating the need for a completely new plant. This avoids altering the terrain and surrounding environment, thus minimizing disruption to the ecosystem. Additionally, CO_2 emissions are reduced. 2It is entirely negligible since, during the pumping phase, renewable energy is used for powering the system, without any additional use of fossil fuels. The aim is not to significantly alter the volume of water flowing downhill, as the ecological flow is already taken into account.

4 Conclusion

The key elements necessary for the successful implementation or conversion of a mini-hydroelectric plant with an integrated pumping system were identified to ensure optimal performance and reliable power generation. To supply power to the Calceta substation to benefit the communities it serves, the potential environmental impacts of hydroelectric generation were assessed. The assessment concluded that the plant is environmentally sustainable and poses no ecological or biodiversity risks, as there are no endemic flora or fauna species in the surrounding area that are threatened with extinction.

The implementation of the mini-hydroelectric plant with a reversible system is technically feasible and profitable, as the necessary resources are available and the costs can be covered by the benefits generated. Furthermore, it is concluded that it is environmentally sustainable if the potential negative impacts on the aquatic ecosystem and biodiversity are considered and mitigated. Conservation and mitigation measures are proposed to guarantee environmental protection throughout the project process.

Conflict of interest statement
The authors declared that they have no competing interests.

Statement of authorship
The authors are responsible for the conception and design of the study. The authors have approved the final article.

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