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Article

Project-Based Learning at Universities: A Sustainable Approach to Renewable Energy in Latin America—A Case Study

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Abstract: New teaching methods are essential to prepare 21st-century engineers for sustainable challenges. This study used project-based learning to evaluate the energy potential of water channels in fish farms in Loreto, Peru. Chemical engineering students applied theory to practice, enhancing skills like field data collection and technical assessment. The results show a practical potential of 18.37 kW and a theoretical potential of 84.19 kW, enough to power 37–244 households. This approach not only highlights renewable energy opportunities but also demonstrates the effectiveness of connecting theory and practice in real-world contexts. Despite simplified calculations, this project significantly impacts engineering education in Latin America, serving as an example of successful learning and inspiring innovative teaching techniques. All of the students (100%) agreed that the project helped in terms of practical skill and problem-solving capability development, teaching motivation, and relevance training for professional life.

Keywords: Peruvian university; innovative teaching and learning; project-based learning; Global South; unrepresented institutions

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1. Introduction

Hydropower accounts for approximately 20% of the world's electricity generation and is generated by harnessing the kinetic and potential energy of flowing rivers, waterfalls, or tides [1]. In Central and South America, its contribution is even more significant providing around 50% of the electricity and surpassing other renewable sources such as solar, wind, and biomass (20% summed). Countries like Brazil (65%), Canada (60%), and China (13%) stand out for their high hydropower generation [2].

In developing countries, particularly in Latin America, there is an increasing interest in integrating renewable energy sources into their energy matrices and this has led to studies focused on identifying suitable areas for their implementation while minimizing ecosystem impact [3]. Moreover, access to reliable energy remains a global challenge and is a key component of the United Nations' Sustainable Development Goals [4], as it fosters socioeconomic development, reduces inequalities, and improves the quality of life [5].

In 2023, Peru's energy matrix was dominated by hydropower (61%) followed by thermoelectric power (32%), wind power (5%), and solar energy (2%) [6]. However, in the Loreto region (Northeast of Peru), electricity generation depends almost exclusively on thermal power, with an installed capacity of 412.8 MW and an annual production of 421.68 GWh [7]. Despite this capacity, only 940 out of 2346 population centers in Loreto have access to electricity, and frequent interruptions in the power supply place the region in the penultimate position nationwide in terms of electricity access [8–10]. These limitations highlight the urgent need to diversify and strengthen the region's energy infrastructure to ensure reliable and sustainable electricity access.

Fish farms are artificial and controlled aquatic systems designed to replicate the natural habitat conditions of fish to facilitate their breeding and cultivation, primarily for commercial purposes (Figure S1, in Supplementary Materials). The water supply for these systems comes from surface waters (such as rivers, lakes, and streams) and groundwater (such as wells and springs), for instance [11]. In Loreto, fish farms use both types of water sources [12] and often form reservoirs with small waterfalls that could serve as potential sites for hydroelectric energy generation if the fish farms are closed or unused.

A key component for evaluating the energy feasibility of fish farm waterfalls is conducting bathymetric studies. A bathymetric study involves measuring the depths of water bodies to identify the shape of the bed that holds the body of water [13].

The chemical engineering program in Peru aims to address contemporary challenges, such as the energy transition, through interdisciplinary approaches and project-based learning. This methodology has proven effective in stimulating active learning and improving academic outcomes by enabling students to apply theoretical concepts in real-world scenarios [14]. In our work, the propose is to demonstrate how this approach befits students and can be further applied in different engineering courses in Peru and Latin America, motivating a new generation of professionals towards sustainable approaches.

Project-based learning has been consolidated as an effective pedagogical tool, enabling students to apply theoretical concepts to complex problems in educational settings with limited teaching hours. This approach not only fosters interdisciplinary thinking but also promotes a practical understanding of innovative and sustainable solutions [15,16].

According to Kayahan Karakul (2016) [16], an educational system that aligns workforce training with high-demand strategic areas, such as renewable energy, has the potential to strengthen the connections between employment, education, and the economy. This approach not only increases job opportunities for students but also contributes to economic development by training skilled professionals in key sectors. In this context, the present study aimed at fostering the strengthening of these connections by integrating practical education with labor market needs and promoting the preparation of future engineers in a critical area such as energy sustainability.

In the case of Loreto, in the Peruvian Amazon, one of the most pressing needs is the evaluation of the energy potential of water bodies. This region faces a significant shortage of detailed studies on the use of water resources for energy generation limiting its sustainable energy development.

The identification of hydrodynamic and morphological variables, such as flow rate, slope, and channel roughness, is essential for analyzing hydroelectric potential [15–17]. Studies in similar contexts, such as in Bolivia [18] and Ecuador [19], have demonstrated that micro-hydropower projects not only provide a source of clean energy but also generate significant social and economic benefits. These precedents highlight the importance of conducting research in Loreto to propose solutions adapted to its geographical and socioeconomic context, contributing to the promotion of renewable energy and the strengthening of interdisciplinary training in chemical engineering.

The students in groups evaluated the energy potential of fish farms in Loreto, and not only addressed a critical need for energy diversification in the Peruvian Amazon but also actively involved chemical engineering students from the National University of the Peruvian Amazon through a project-based learning approach. This educational method allowed them to apply theoretical knowledge to a real-world problem in their environment, promoting the development of interdisciplinary competencies and innovative solutions. Furthermore, it strengthened other fields of study, such as civil engineering, environmental engineering, and mechanical engineering, among others.

From our understanding, this is the first time this has been reported in the literature from an engineering institution in Peru. Although the students used fundamental equations and math for calculations and considerations, our work addresses the demonstration of the teaching approach in terms of engineering training.

The relevance of this work lies in identifying a renewable energy alternative through the analysis of hydrodynamic variables of under-researched water bodies in the Peruvian Amazon, such as fish farms, thus maximizing their social and economic value. In addition, our study would be used for future applications in Latin (or South) America for project-based learning in unrepresented institutions/areas. Additionally, student participation fostered practical training and a commitment to local development, integrating education with community impact. The development of this project was crucial for highlighting a model of teaching and research that combines solving regional problems with strengthening professional skills, contributing to the advancement of renewable energy and the sustainable progress of Loreto.

2. Materials and Methods

2.1. Energy Evaluation in Fish Farms: Educational Experience with Chemical Engineering Students

The methodology was designed and implemented within the framework of the Physical Chemistry II course of the chemical engineering program at the National University of the Peruvian Amazon (Universidad Nacional de la Amazonía Peruana, in Spanish) for fifth-semester students. This project-based learning approach enabled students to integrate theoretical knowledge with practical fieldwork activities by evaluating the energy potential of water channels in fish farms located in the Iquitos region (Northeast of Peru, 371 km from the Brazil–Peru–Colombia tri-border).

The students (20–30 years old) actively participated in the identification and georeferencing of the study area, using technological tools and field techniques to analyze the physical characteristics of the fish farm channels. The activities included measuring key parameters such as flow rate, flow velocity, and water drop height, applying classical hydrodynamic analysis methods and potential energy equations, allowing students to engage and apply knowledge previously acquired in fundamental courses of the chemical engineering program and to promote the effective integration of theory and practice. This approach not only strengthened their technical skills but also emphasized the importance of applying academic concepts to solve real-world problems related to energy sustainability in the Amazon region.

In addition to enhancing their technical skills, student participation fostered essential competencies such as collaborative work, critical thinking, and ability to communicate scientific results which prepare them to face professional challenges in the field of renewable energy. Students' participation was relevant to understanding the problem, proposing solutions, and bringing in new ways to generate electricity with a few resources.

2.2. Implemented Safety Measures for the Identification and Georeferencing of the Study Area

To ensure the safety of students and staff involved in the project, a safety protocol adapted to fieldwork conditions was implemented which includes:

- Preliminary Training: Sessions were held on equipment handling, first aid, and emergency protocols, focusing on risks associated with working in water bodies and rural areas.
- Use of Personal Protective Equipment (PPE): All participants used appropriate PPE during all field activities, such as rubber boots, hats, sun-protective clothing, and sunscreen.
- Field Risk Assessment: Before starting the measurements, an inspection of the work area was conducted to identify potential risks, such as slippery areas and strong currents, and to establish safe zones for operation.
- Safe Equipment Handling: Specific training was provided for the correct use of equipment and tools, such as measuring tapes, limnimeters, and floats, minimizing the risks associated with improper handling.
- Constant Supervision: The project was supervised by faculty members throughout all activities to ensure compliance with safety regulations and the correct execution of procedures.
- Communication Plan: An emergency communication plan was established using short-range radios, along with prior coordination of meeting points and access to local medical services in case of incidents.

These measures not only ensured a safe environment for the development of the project but also raised student awareness of the importance of scientific and professional activities standards. Such training complements classroom learning activities and promotes better understanding and fixes the knowledge to the students.

The study was conducted in the city of Iquitos, located in the Amazon region of Peru during June–July 2024. The fish farms analyzed are situated on the left side of the Zungarococha highway (at approximately kilometer 2) within the premises of a farm known as "Fundo Sarita", where four fish farms were identified and georeferenced. These fish farms have channels with slopes suitable for evaluating energy potential (Figure 1).

Figure 1. Fundo Sarita's Location (the black arrow indicates the location in Peru, and the red line shows the area analyzed).

2.3. Study of Energy and Channel Potential

The energy potential study began with the collection of hydrographic data for the bathymetric analysis of the channels using in situ measurement techniques. The students' calculation was conducted considering fundamental math and equations for the first analysis, where our approach was not an engineering project for private or government investment but teaching and learning in a real environment. The students well understood before, during, and after the project that engineering calculations must be considered in a real project, and that they will be further taught during the course (not in this particular class).

To calculate the cross-sectional area of the water flow, metric data were collected on the width, using a measuring tape, and the height from the bottom to the water surface, using a limnimeter, for each channel (Figure S2 and Equation (S1)). These data were then used to calculate the cross-sectional area of the channel using geometric analysis methods [20].

For velocity measurements, the methods described in [20–25]. The channels were divided into three equal sections (Figure S3 and Equation (S2)), and the float method was used to measure the time it took for the float to travel from an initial point to a final point in each section. Dimensions were taken for each case, and the velocity (Equation (S2)) and flow rate (Equation (S3)) were calculated as described by Pasalli and Rehiara (2014) [25]. Potential energy was calculated based on a fundamental equation (Equation (S4)) but modified to replace mass with water density and flow rate [21].

To calculate the theoretical potential, a new theoretical maximum height was determined considering the total height of the channel barriers and the minimum height at the nearest point of the pool. Additionally, the total distance traveled by the water within the channel was considered (Figure S4).

The Manning equation was used to account for the slope of the water drop and the dimensional data obtained from each channel. Manning equation (Equation (1)) is an empirical formula that relates flow velocity, hydraulic radius, and longitudinal slope, where Q is the flow rate $\left(m^3/s\right)$, n is the Manning roughness coefficient, A is the cross-sectional area $\left(m^2\right)$, R is the hydraulic radius (m, in Equation (S6)) [20], and S is the slope of each channel (Equation (S8), as indicated by Blaya et al. (2020)) [2]. Equation (2) determines flow velocity based on the Manning equation, where V is the flow velocity ($^m/_s$) .

$$Q = A\frac{1}{n}R^{\frac{2}{3}}S^{\frac{1}{2}} \tag{1}$$

$$V = \frac{1}{n}R^{\frac{2}{3}}S^{\frac{1}{2}} \tag{2}$$

The Manning roughness coefficient values were obtained from predefined tables, and the maximum value for concrete was used since the channel structure was made of this material (Table 1).

Table 1. Roughness Coefficient Values for Manning Equation [20].

Material Type	Minimum	Normal	Maximum
Rock (jagged, sinuous)	0.035	0.040	0.050
Smooth rock	0.025	0.035	0.040
Earth	0.017	0.020	0.025
Dry masonry	0.025	0.030	0.033
Concrete	0.013	0.017	0.020
Polyethylene (PVC)	0.007	0.008	0.009

The theoretical flow rates for each channel were obtained based on these calculations, and the modified potential energy equation was applied again with the new flow rate and height values resulting in theoretical potential. To calculate the average number of households that could be supplied with the practical and theoretical potential of these channels, it was assumed that a month consists of 270 operating hours (30 days/month, Equation (3)).

$$NH = \frac{PE \times t}{CM} \tag{3}$$

where

NH is the number of households;
PE is the theoretical and practical energy potential (kW);
t is the time (270 h);
CM is the average monthly consumption per household (kWh).

2.4. Project-Based Learning—Survey and Discussion

The impact of project-based learning (PBL) on renewable energy education was assessed through an anonymous, non-mandatory student survey. The survey, administered electronically via Google Forms, included multiple-choice questions to gather student feedback while ensuring anonymity. Despite a class size of 16, only six students responded, which may limit the study's statistical robustness. Future research should aim to increase participation to strengthen data analysis. We strongly believe that the low response rate is primarily due to the novelty of this activity in the chemical engineering curriculum, and participation is expected to grow in subsequent years.

The survey aimed to compare students' perceptions of PBL with traditional teaching methods and assess its qualitative impact on their learning and professional preparedness. PBL follows a structured framework that includes problem identification, research, solution development, implementation, and reflection, ensuring that students engage with real-world challenges while applying theoretical knowledge.

In this study, students applied the PBL approach to address energy challenges in the Peruvian Amazon. They identified key issues, collected hydrodynamic data from fish farm channels, analyzed energy potential using engineering principles, and reflected on the efficiency and feasibility of their proposed solutions. At the end of the project, students completed the survey, and faculty members analyzed the responses to identify patterns and trends. The survey consisted of four closed-ended questions, along with an optional section for additional comments to capture qualitative feedback. Our analysis was qualitative based on the responses. The questions assessed the following aspects:

1. The development of practical skills and problem-solving capabilities.
2. Increase in motivation when addressing practical situations.
3. Strengthening the integration of theory and practice.
4. The relevance of the acquired knowledge for their future professional careers.

3. Results and Discussion

3.1. Project Execution

The students were divided into two groups (16 students each) for collaboration and to ensure better supervision by the faculty members. Each group was responsible for evaluating two of the fish farms, ensuring an efficient distribution of tasks and a comprehensive approach to the georeferencing and physical description of the channels connecting the fish farms.

It was identified that the four fish farms operate through a reservoir system interconnected by channels, where each channel supplies the next—fish farm 1 receives water from fish farm 2, which is supplied by fish farm 3; in turn, fish farm 3 receives water from fish farm 4 (Figure 2). The water supply comes from natural streams (the "Blanca" and "King Kong" creeks).

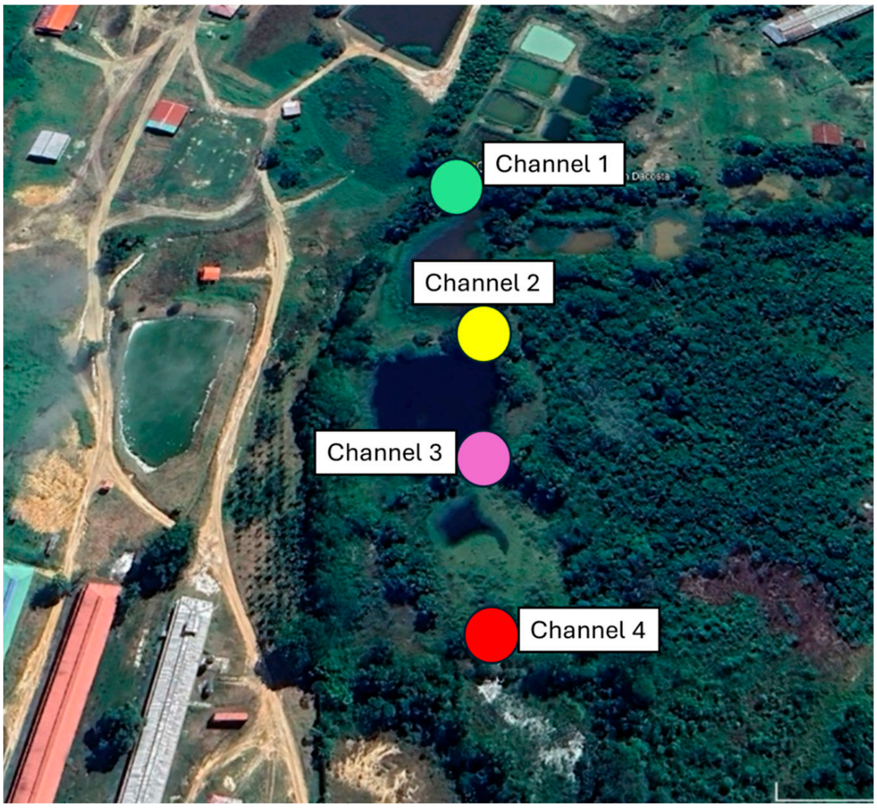

Figure 2. The locations of the channels used in the project by the students.

The georeferencing (Figure 2 and Table 2) and physical description (Table 2) of each channel were carried out through in situ measurements. The physical parameters of the evaluated channels show significant variations that influence their conveyance capacity and hydroelectric potential.

Channel 1 presented a cross-sectional area of 0.389 m^2, a wetted perimeter of 3.760 m, and a hydraulic radius of 0.103 m. The considerable cross-sectional area and hydraulic radius suggest a superior capacity to transport mass flow than a similar channel reported in the literature [20,22,23].

Although Channels 2, 3, and 4 present smaller cross-sectional areas (0.180 m^2, 0.100 m^2, and 0.100 m^2, respectively), they also offer relevant data for potential optimizations. Channel 2 has a maximum height greater than the other channels, which could facilitate interventions to improve its efficiency. Conversely, Channels 3 and 4 show limitations in their flow capacity due to their lower water depths (0.06 m and 0.04 m) and their overall dimensions, but they may be suitable for small-scale applications or as support in interconnected systems [19].

These findings highlighted to the students the importance of conducting a detailed analysis of the physical parameters of the channels in the planning of hydropower projects such as the cross-sectional area, wetted perimeter, and hydraulic radius directly influence the energy generation potential.

The actual energy potential of the fish farm channels was determined through a bathymetric study to obtain the velocity and flow rate values for each channel (Table 3). Channel 1 presents the highest flow rate at 0.592 m^3/s compared to the other channels. Although Channel 2 shows the highest flow velocity, it has a lower flow rate than Channel

1 due to its smaller cross-sectional area [20]. Regarding Channel 3, both the velocity and the flow rate are lower than those of the first two channels, potentially limiting its energy potential. Finally, Channel 4 presents the lowest velocity and flow rate.

Table 2. Physical descriptions of the study channels.

Channel N°01	
UTM Coordinates	
Easting Northing	683043 9575956
Channel height (m)	1.73 m
Max. height (m)	2.52 m
Width (m)	3.54 m
Length (m)	3.50 m
Water depth (m)	0.11 m

Channel N°02	
UTM Coordinates	
Easting Northing	683046 9575877
Channel height (m)	1.73 m
Max. height (m)	2.58 m
Width (m)	2.57 m
Length (m)	4.10 m
Water depth (m)	0.07 m

Channel N°03	
UTM Coordinates	
Easting Northing	683039 9575811
Channel height (m)	0.90 m
Max. height (m)	1.57 m
Width (m)	1.66 m
Length (m)	4.73 m
Water depth (m)	0.06 m

Channel N°04	
UTM Coordinates	
Easting Northing	683052 9575740
Channel height (m)	0.90 m
Max. height (m)	1.93 m
Width (m)	2.51 m
Length (m)	5.14 m
Water depth (m)	0.04 m

Table 3. Water Flow Velocity and Flow Rate in Each Channel.

Parameter	Channel 1	Channel 2	Channel 3	Channel 4
Velocity (m/s)	1.522	1.691	1.408	0.995
Flow rate (m^3/s)	0.592	0.304	0.141	0.100

Precise measurements of velocity and flow rate are essential for evaluating energy potential, as these parameters determine the generation capacity of hydropower installations by directly correlating the available flow with energy output [25]. Additionally, these data pave the way for future studies on turbine selection and cost analysis for installing a micro-hydropower plant.

To calculate the energy potential of the channels, the students applied the potential energy formula adapted for this study based on the methods suggested by Pasalli and Rehiara (2014) [25]. The flow rate was determined in the bathymetric study along with the height of each channel (Table 4). Channel 1 showed the highest energy potential due to its greater drop height and higher flow rate compared to the other channels, which increases its capacity to generate energy. Given that all four channels are located in the same area, their combined energy potential totals 18.37 kW. However, it is important to note that this theoretical value could be reduced due to the efficiency losses inherent to hydroelectric equipment.

Table 4. Energy Potential of the Channels.

Parameter	Channel 1	Channel 2	Channel 3	Channel 4
Energy Potential (kW)	10.03	5.33	1.24	1.77

The operational efficiency of such systems can vary between 50% and 70% of the calculated value implying an operational potential ranging from 9.17 kW to 12.86 kW. These values highlighted, from the students' point of view, the importance of considering efficiency losses when designing and evaluating small hydropower systems to ensure their feasibility and performance. Their generation capacity falls within the range of a micro-hydropower plant with a production scale ranging from 5 to 50 kW [26].

The department of Loreto (where Iquitos is located) relies heavily on a petroleum-dependent energy system [27]. Research on renewable energy alternatives in this area of the Peruvian Amazon is limited, supporting the search for and training of technical professionals to develop greener solutions in specific regions such as Iquitos.

A significant capacity for small-scale renewable energy generation was noticed by the students, where Channel 1 stands out due to its higher drop height and flow rate, making it an ideal candidate for the installation of a micro-hydropower plant. The combination of the four channels provides total energy potential that, even after considering efficiency losses, could be sufficient to contribute to the local energy demand of the fish farm for its agricultural activities (Table 5).

Table 5. Theoretical Data for Velocity, Flow Rate, Slope, and Energy Potential of Channels.

Parameter	Channel 1	Channel 2	Channel 3	Channel 4
Theoretical Velocity (m/s)	8.07	6.48	4.20	3.54
Theoretical Flow Rate (m^3/s)	3.14	1.17	0.42	0.35
Slope	−0.54	−0.63	−0.33	−0.38
Theoretical Energy Potential (kW)	77.54	29.58	6.50	6.65

A critical factor influencing the energy potential data is seasonal variability that causes significant fluctuations in water availability and, consequently, in energy generation capacity throughout the year. This study was conducted during the dry season (fall), specifically in May and June 2024, where critical levels were recorded due to low river levels [28] based on the National Meteorology and Hydrology Service of Peru (SENAMHI).

Therefore, it is reasonable to anticipate an increase in energy potential during the wet season, when water flow in the channels increases significantly. According to students' conclusions (reported anonymously in the survey), the "*evaluation of water flux during different seasons would provide a more accurate estimate of the annual hydroelectric generation potential and contribute to the design of more efficient systems to meet demand during periods of low water availability*".

The Manning equation was applied to estimate the theoretical energy potential of the channels, allowing for the evaluation of energy generation capacity in small-scale hydropower systems that provided an estimate of velocity and flow. This approach makes it possible to determine how much additional energy could be generated by increasing the water body's height, considering the maximum height at the top of the channels and integrating parameters such as channel roughness and flow profile [29].

The analysis of energy potential under these optimized conditions provides a practical tool for the design of micro-hydropower plants, enabling the anticipation of the benefits of structural adjustments to water bodies to maximize energy efficiency.

Channel 1 presents the highest theoretical energy potential at 77.54 kW, making it an excellent candidate for small-scale hydroelectric systems. Channel 2, despite having lower velocity and flow rate, maintains considerable potential due to its steeper slope, while Channels 3 and 4 present lower potential due to their low velocity and flow rate, where students found out that both could be used as complements to Channels 1 and 2.

The combined theoretical energy potential of the four channels amounts to 120.27 kW. Considering an efficiency loss of 50–70% [25], the operational potential is estimated at 60.14–84.19 kW (mini-hydropower plant) and could produce 50–500 kW [23]. These results underscore the importance of theoretical calculations that combine velocity, flow rate, and slope to maximize the energy potential of the channels.

The average energy consumption per household nationwide is 93 kWh/month [30]. For the maximum practical and theoretical efficiency values of energy production estimated for the evaluated channels, the students concluded that this interconnection of channels could supply energy to between 37 and 244 households, respectively (Table 6). However, after their conclusion presentation, the faculty discussed with the students what could be done to make it possible and to construct the hydropower plants, such as a detailed engineering project, construction materials, hiring workers, and investment and payback, which are part of future engineering courses.

Table 6. Number of Households Supplied with Energy.

Energy Generated Per Month by the Channels (kWh/Month)	Households Supplied by Practical Potential	Theoretical Energy Generated Per Month (kWh/Month)	Households Supplied by Theoretical Potential
3472.2	37	22,731.3	244

A few examples of small hydropower plants have been reported on. For instance, more than 400 micro-hydropower plants were built in Nepal. The smallest (7 kW capacity) provides electricity to around 100 households while the largest (116 kW capacity) supplies energy to up to 940 homes, benefiting mostly rural and remote communities. Additionally, these micro-hydropower plants generate carbon credits that are commercialized, and the proceeds are used to fund operations and maintenance, contributing to their sustainability [31].

These examples highlight the importance of conducting energy studies like this one in regions such as Loreto to develop robust projects that address local needs and promote socioeconomic development. These studies also enable the design of strategies to mitigate environmental impacts and strengthen the region's energy infrastructure, reducing the energy access gap and contributing to global sustainability goals in communities with limited infrastructure. Moreover, our final training session supports future classes and the students' careers.

The findings of this study are consistent with similar research conducted in other regions. For example, González et al. (2024) [1] demonstrated that in Bolivia, micro-hydropower plants in Andean communities not only produce clean energy but also provide economic and social benefits by reducing dependence on fossil fuels. These benefits are reflected in Channel 1 (our project) whose high energy potential is comparable to that of micro-hydropower plants implemented in Bolivian communities, where flow rate and slope are harnessed to meet local electricity demand.

On the other hand, the study by Cuichan-Paucar et al. (2024) in Ecuador highlights the adaptability of turbulent hydro technology in low-flow environments, which is relevant for Channels 3 and 4 in our project [6]. This low-impact environmental technology could optimize the use of water resources in these channels, where flow variability is an issue. The application of such technology provides an adaptable model for maximizing resource use in smaller waterfalls, offering an efficient and environmentally friendly design suitable for settings where flow stability fluctuates.

The students demonstrated the importance of conducting bathymetric analyses of water bodies in the Peruvian Amazon to assess the feasibility and potential value of future micro-hydropower projects in areas with renewable energy potential ensuring efficient and sustainable energy use. It could serve as a catalyst for future research on the implementation of micro- and mini-hydropower plants, contributing to reduced emissions and lower environmental impact compared to fossil fuel-based power plants. Moreover, these facilities would not alter natural ecosystems substantially but rather operate within already modified ecosystems designated for commercial use, such as fish farms, which represents a crucial advantage in highly biodiverse areas like the Amazon.

3.2. Learning Outcomes

Our work represents a significant learning advance for the students involved, as they applied theoretical concepts in a practical environment, strengthening their skills in field measurements, data analysis, and technical evaluation. Through the project-based learning methodology, the students achieved a comprehensive understanding of hydrodynamic and energy principles, as well as the importance of bathymetric studies for the utilization of water resources.

More detailed calculations, such as of the electricity production, the materials required for construction, the payback period, and so forth, will be taught further in the chemical engineering course. The main goal of the experiments and field studies was not to obtain positive or correct results but to engage students with an alternative teaching approach and introduce a new experience into the chemical engineering course.

Emerging global markets are shifting toward a green economy that demands highly trained professionals in strategic areas such as sustainable energy [16]. In this context, the experience during the study not only strengthened the students' theoretical and practical knowledge but also contributed to their holistic education, preparing them to competently engage in research and fieldwork related to renewable energy and water resource management. This preparation provides them with a competitive advantage in the labor market, aligning with the demands of a constantly expanding and evolving sector.

The experience was particularly valuable in a context such as the city of Iquitos, located in the Peruvian Amazon rainforest, where professional training faces the challenge of addressing real local issues, such as reducing greenhouse gas emissions and preserving the environment. The reality and challenges in Latin America must be considered for such studies and we were able to engage students during training. Based on their group and individual feedback, project-based learning might produce better results than if traditional teaching class was used. No comparison was made in this study and can be considered for future studies.

In this setting, project-based learning represented an innovative and effective pedagogical alternative that surpasses the traditional method centered on passive knowledge transmission (e.g., the mere repetition of formulas and theoretical calculations) by promoting active and collaborative learning in a Peruvian scenario.

During this work, the students assumed leading roles in data collection and field analysis, enhancing their ability to solve complex problems and their motivation to tackle relevant energy challenges. These results support the conclusions of de Reviere et al. (2024) [8], who demonstrated that project-based learning yields superior outcomes compared to traditional and independent laboratory exercises.

This educational model not only reinforced the link between theory and practice but also demonstrated that project-based teaching related to renewable energy can contribute to the development of interdisciplinary competencies and a commitment to sustainability. This study's proposal represents an improvement in educational quality, enhancing the preparation of future chemical engineering professionals within the context of the energy transition in the Peruvian Amazon region.

Our survey (Table 7) demonstrated that the students (100%) considered that the project enabled them to develop practical skills and solve problems and to increase in their motivation for learning—evidence of the fact that the project-based approach surpasses traditional methods by providing meaningful, motivating, and real-world experiences. This demonstrates that project-based learning fosters active and participatory learning by engaging with real-life situations.

Table 7. Positive response rates in the project-based learning survey.

Question	Percentage of Positive Responses (%)
Development of practical skills and problem-solving capabilities	100%
Increase in motivation when addressing practical situations	100%
Strengthening the integration of theory and practice	83%
Relevance of acquired knowledge for professional life	100%

Moreover, 83% of the students highlighted that the project improved the integration of theory and practice, enabling them to apply classroom concepts in a real context. Lastly, 100% of the students stated that the knowledge gained during the project was relevant and useful for their future professional careers, strengthening their preparation for research and work related to renewable energies and sustainability.

These results reinforce the importance of implementing active methodologies, such as project-based learning, as they promote interdisciplinary competencies and contribute to the training of future engineers capable of facing challenges in the context of energy transition. Our results are limited to a small group of one chemical engineering class, but they have been used as a positive example in the university and could also be used as a reference for Global South institutions.

While the project-based learning methodology proved effective at engaging students with real-world renewable energy challenges, several challenges were encountered throughout its implementation. One significant obstacle was the limited availability of detailed hydrological data, which required students to rely on simplified assumptions for flow rate and energy potential estimations. The faculty members consider this to be part of the engineering training preparing the students for their careers.

Additionally, seasonal variations in water availability will impact the accuracy of energy projections in different periods of the year, highlighting the need for long-term monitoring in future studies. This part was further explained and understood in group discussions. Despite these constraints, the project successfully reinforced students' ability to adapt and apply engineering principles in resource-limited settings for broader adoption in engineering education. The approach could be expanded to other renewable energy contexts.

Furthermore, our findings aligned with similar micro-hydropower initiatives in Latin America where small-scale renewable energy installations have demonstrated both technical feasibility and socio-economic benefits. Comparing our results with these efforts underscores the adaptability of project-based learning in diverse regional contexts and highlights its potential to address energy access challenges in remote areas. Additionally, analyzing performance losses in small-scale installations is crucial for optimizing energy output, as demonstrated in our assessment of efficiency losses ranging from 50% to 70%. Future work could focus on integrating detailed performance evaluations and economic feasibility studies to further strengthen the case for implementing similar educational models and renewable energy solutions in other Latin American regions. Our main goal was to use this activity for student training with engagement as part of the engineering training instead of traditional teaching approaches. Our qualitative analysis and feedback reports have demonstrated the success of the activity making it possible to improve and use in different classes of engineering courses.

4. Conclusions

This study applied project-based learning to a chemical engineering course to assess the energy potential of fish farm channels in the Peruvian Amazon. Through field measurements and hydrodynamic analysis, students estimated a maximum practical energy output of 18.37 kW, which could supply 37 households, and a theoretical maximum of 84.19 kW, sufficient for 244 households. These findings highlight the feasibility of utilizing small-scale hydropower in remote areas with limited energy access.

The project-based approach enhanced students' technical skills by integrating theoretical knowledge with hands-on experience in renewable energy assessment. Students gained proficiency in flow rate calculations, bathymetric analysis, and efficiency estimation, reinforcing their ability to tackle real-world engineering challenges. The methodology also fostered interdisciplinary collaboration, demonstrating its effectiveness in training future engineers for energy transition.

This study provides a foundation for implementing micro-hydropower plants in Loreto, emphasizing the importance of site-specific hydrodynamic analysis and seasonal flow variations in system design. Future research should focus on optimizing hydropower plant configurations, incorporating detailed efficiency loss evaluations, and assessing the economic feasibility of scaling such installations. By addressing these factors, this approach can contribute to expanding sustainable energy infrastructure in the Peruvian Amazon, ultimately improving energy security and reducing reliance on fossil fuels in isolated regions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su17125492/s1, Figure S1: Fish Farm in the Peruvian Amazon; Figure S2: Measurement of the Channel's Geometric Ratios; Figure S3: Channel Subsections; Figure S4: Measurement of Channel Height and Length Data. Equations used for energy calculation are also reported.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of No 004-2025-UI-FIQ-UNAP and No 151-2024-FIQ-UNAP on 6 May 2025.

Informed Consent Statement: Informed consent for participation was obtained from all students involved in the study.

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