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Techno-Economic Performance of Diesel and Solar Photovoltaic Pumping Systems for Conventional and Drip Irrigation

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Abstract*– The agricultural sector in Honduras faces significant challenges related to access to affordable and sustainable energy, especially in rural areas where diesel-powered pumping systems predominate. This dependence not only increases operating costs but also contributes significantly to greenhouse gas (GHG) emissions. In response to this problem, this study aims to evaluate the technical, economic, and environmental feasibility of implementing a solar photovoltaic pumping system for drip irrigation at the AHLE Experimental Farm, located in San Francisco de Yojoa, Cortés, Honduras. The methodology included system design and simulation using specialized software (PV*SOL), as well as financial analysis in Microsoft Excel to estimate key indicators such as the payback period to show best aspects of the study. The proposed system was compared with a conventional diesel-powered pump-based alternative, evaluating energy and water savings and CO_2 emission reductions. The results showed that the solar system, composed of 28 solar panels of 545 Wp, enabled more efficient operation, with a lower environmental impact and a faster return on investment. In contrast, the diesel system presented higher operating costs and dependence on fossil fuels, reinforcing the technical and economic advantage of the photovoltaic system.

Keywords: Drip irrigation, Energy efficiency, Solar photovoltaic pumping, Sustainability, Water savings.

I. Introduction

Solar energy is one of the most important renewable energy sources today, due to its availability and the urgent need to reduce the use of fossil fuels [1]. Honduras is a country with a great potential for renewable energy, such as solar energy [2]. Many innovations have been researched that sets solar energy at the top of renewable energies in Honduras [3].

Traditionally, diesel engine driven pumps have been widely used in agricultural irrigation systems due to their availability and ease of installation. However, factors such as the sustained increase in international oil prices, the polluting effects generated by the combustion of these fuels, the high costs of operation and maintenance, as well as their limited useful life, have motivated the search for more efficient and sustainable solutions. Considering this situation, renewable energy sources, particularly photovoltaic solar energy [4].According to recent studies, more than 80% of agricultural areas in Honduras depend on gravity irrigation or non-technological systems, which reduces the efficiency of water use and limits productive growth [5].

The use of solar photovoltaic pumping systems represents a viable alternative, since it takes advantage of a renewable resource abundantly available in the country and contributes to reducing greenhouse gas emissions associated with the use of fossil fuels [6].

In many agricultural regions of Honduras, irrigation relies on pumping systems powered by conventional electricity or diesel engines, which present high operating costs, frequent maintenance, and direct dependence on non-renewable energy sources. These conditions create a significant economic barrier, especially for small and medium-sized producers, limiting the expansion of agricultural activities and affecting crop profitability.

Despite the country's high solar irradiation potential, the average solar irradiation is 5.27 kWh/m², the implementation of photovoltaic technologies in the agricultural sector remains limited and incipient [7]. There is a technical and economic gap regarding the adoption of solar pumps, especially regarding proper design, hydraulic and electrical sizing, and the evaluation of their performance compared to traditional pumping methods. Figure 1 shows the potential of solar energy in Honduras.

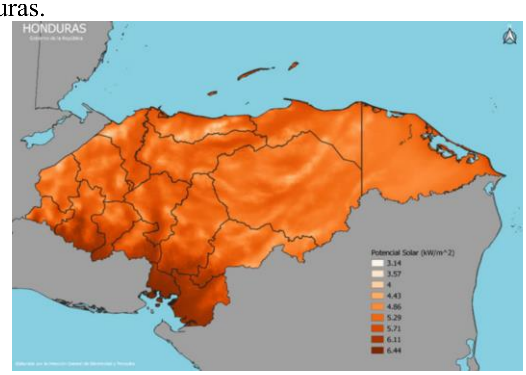

Fig. 1 Solar Potential Map of Honduras
Source: [8]

II. Methodology

This chapter presents the general methodology used to carry out the design, simulation, and analysis of a solar photovoltaic pumping system for drip irrigation of crops at the AHLE Experimental Farm, located in San Francisco de Yojoa, Cortés, with an area of 14,000 m² shown in Figure 2.

Fig. 2 Satellite image of the study area
Source: Own Elaboration

The research focuses on evaluating the hydraulic sizing of the system, determining the required power, analyzing energy and hydraulic losses, and comparing technical and economic performance with traditional pumping systems (electric or diesel).

The techno-economic analysis will include calculating the return on investment (ROI) from equation 1, operation and maintenance costs, and the environmental benefits associated with the use of renewable energy.

$$ROI = \frac{Net\ Profit}{Cost\ of\ Investment} \cdot 100 \qquad (1)$$

Where:

- Net Profit is the current value – initial cost
- Cost of investment is the initial cost

In addition, the specific characteristics of the corn, plantain, sweet pepper, radish, and cilantro crops, as well as the water requirements of each, will be considered.

This research will apply a Research and Development (R&D) methodology focused on the evaluation of a solar photovoltaic pumping system for agricultural irrigation. This methodology includes the collection of technical and economic information, system design, performance simulation, and feasibility assessment.

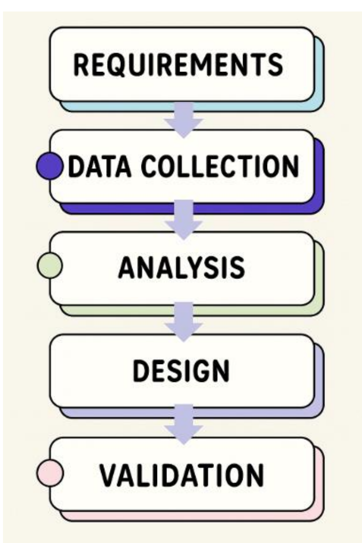

Fig. 3 Methodology Implementation
Source: Own Elaboration

A. Data Collection

Solar irradiance data was collected at San Francisco de Yojoa, Cortés, over a 15-day period to obtain an estimate of the solar energy available in the region. This information allowed for an assessment of the feasibility of implementing a solar photovoltaic pump in crop irrigation systems, considering actual radiation conditions and irrigation needs [9] .

During this period, solar irradiance values will be recorded, and the hours of peak water demand will be analyzed to determine the appropriate size of the pumping system. Figure 4 shows an example of the data collected during the testing period.

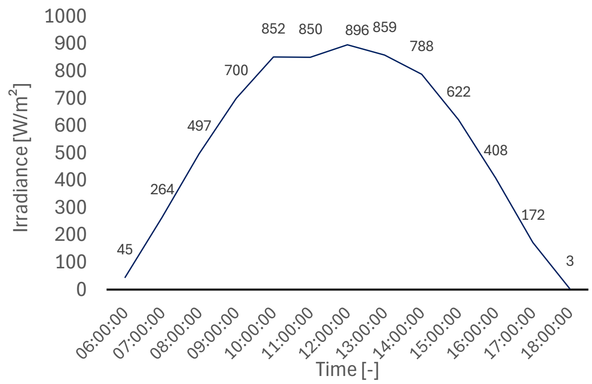

Fig. 4 Example of irradiance data
Source: Own Elaboration

Likewise, the energy demand of the solar pump was calculated, considering the flow rate, head, and operating hours required to meet the irrigation needs of crops such as corn and plantain. This analysis will be complemented by a calculation of the CO_2 emissions avoided using solar energy, using an emission factor of 0.432 kg CO_2/kWh [10]. This estimate will allow for the assessment of the positive environmental impact of implementing clean technologies in the area.

Finally, PV*SOL simulations will be conducted to validate the data obtained and project the performance of the solar pumping system over the course of a year, under average solar radiation conditions in San Francisco de Yojoa.

B. Analysis

To determine the technical and economic feasibility of a solar photovoltaic pump for agricultural irrigation systems, an analysis was conducted based on the availability of solar radiation and crop water requirements. This analysis will assess how solar energy meets irrigation needs under real-life operating conditions. Table 1 shows the approximate values of crop water needs for this research.

TABLE I
CROP WATER NEEDS

Crop	Crop water needs [mm/total growing period]
Corn	500-800
Plantain	900-1800

Source: [11]

Calculating the Return on Investment (ROI) in equation 1 was fundamental to this research, allowing for an analysis of the profitability of implementing a solar pump compared to traditional diesel or electric pumping systems [12]. This analysis was conducted using data processed in Microsoft Excel, considering investment, operation, and maintenance costs, as well as the savings generated in energy consumption over a 15-year period.

In addition, the positive environmental impact will be assessed by calculating the CO_2 emissions avoided using solar energy, applying an emission factor of 0.432 kg CO_2/kWh for the diesel use [10]. This estimate will allow for an assessment of the environmental benefits of implementing clean technologies in the study area. In addition to financial indicators, the analysis included an estimate of monthly water consumption by irrigation system type, based on reference data and field simulations. The methods compared (gravity, sprinkler, and drip) were evaluated based on their water efficiency, allowing for the projection of the savings potential of the implemented system [13].

C. Design

Various techniques and tools were used to collect and analyze the data required for this research to conduct comprehensive analysis from a technical, economic, and environmental perspective. The main tools employed are detailed below: Microsoft Excel was used to organize and analyze the data obtained, including energy consumption, pumped water volumes, and the results of photovoltaic production simulations. Thanks to its visualization functions, Excel facilitated the creation of comparative graphs and tables, allowing the system's efficiency to be observed and financial indicators such as Return on Investment (ROI). The values for the economic analysis were considered according to the prices in the Honduran market in Solar companies at the time (2025).

An economic sensitivity analysis was conducted to assess the performance of the solar pumping systems under multiples variations of energy generation. Two scenarios were tested:

- Baseline scenario: Estimated energy generation under normal operating conditions for irradiance and energy cost in the country.
- Pessimistic scenario: Assumes a reduction in the systems energy generation and reduction on the price for the kilowatt-hour in the Honduran Energy Market.

Furthermore, PV*SOL software was instrumental in simulating the solar pumping system's performance under different climatic conditions, estimating annual energy production, and analyzing energy losses due to factors such as shading and module tilt. PVSOL enabled scenario comparisons, appropriate sizing of the photovoltaic system, and the generation of detailed technical reports, thus contributing to a comprehensive assessment of the project's technical and economic viability. The water consumption for each irrigation method was found on [14] and empirical data from engineers in AHLE while data recollection for a month.

III. Results

This chapter presents the main findings obtained from the implementation of the proposed methodology, aimed at the techno-economic analysis of a photovoltaic solar pumping system for irrigation systems at the AHLE Experimental Farm, located in San Francisco de Yojoa, Cortés.

A. Design of the solar system

Figure 5 represents a three-dimensional model of the building at AHLE experimental farm with the installed solar panels. This provides a clearer visualization of the layout for a better understanding of the overall solar energy system.

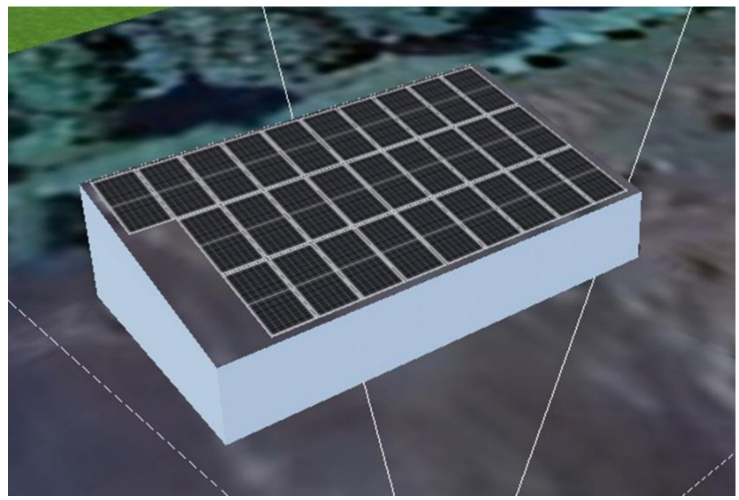

Fig. 5 Three-dimensional model of the solar system
Source: Own Elaboration

B. Inputs Parameters

Table 2 shows the input parameters considered for the solar pumping system, which will be used in the analysis of sizing, energy efficiency and economic viability of the proposed system.

TABLE II
SOLAR SYSTEM INPUT PARAMETERS

Inputs Parameters	Values
Size of the photovoltaic solar project.	15.26 kWp
Price	1.23 $/Wp
O&M	20 $/kWp

Source: Own Elaboration

C. Monthly solar power generation

Figure 6 shows the monthly solar energy generation obtained from the photovoltaic system designed for Experimental Farm. This graph visualizes the seasonal behavior of energy production, showing that the highest generation levels are concentrated in the months between March and August, with a peak of 2,360.3 kWh in July. In contrast, December and January show lower production due to decreased solar irradiance. This analysis is essential for correctly sizing storage or backup systems, ensuring continuous supply throughout the year.

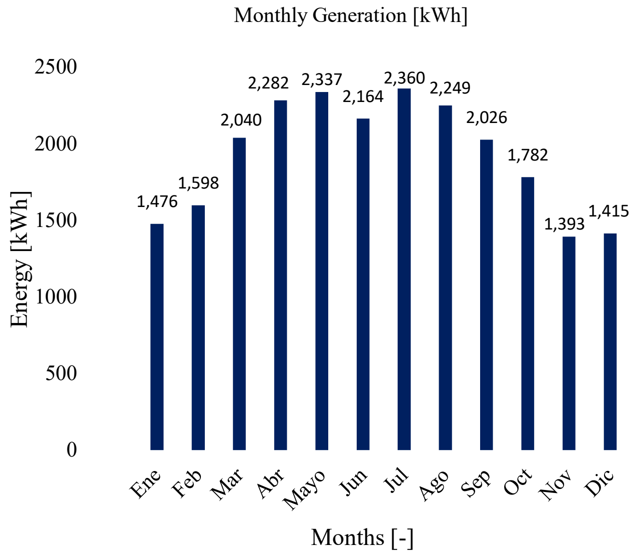

Fig. 6 Monthly solar energy generation
Source: Own Elaboration

The total amount of energy generated throughout the year reaches 23,122.7 kWh, confirming the efficiency of the photovoltaic system in the region.

D. Return on investment (ROI) analysis

Figures 7 and 8 present the results of the financial analysis of the solar photovoltaic pumping system implemented at the AHLE Experimental Farm. These graphs represent the cumulative return on investment (ROI) over 15 years, from the perspective of both the investor and the project financier respectively. This analysis clearly demonstrates the period required to recover the initial investment and how sustainable economic benefits are progressively generated over time.

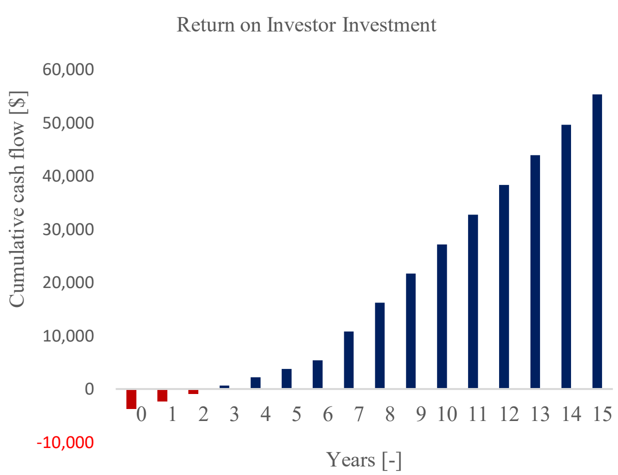

Fig. 7 ROI - Investor
Source: Own Elaboration

From Figure 7, with a ROI of approximately 2.56 years (equivalent to 2 years and 8 months), the scenario in which the investor contributes 20% of the total value of the solar pumping system allows for a rapid recovery of the invested capital. Although the recovery occurs in a relatively short period, the most significant economic returns are achieved starting in the fifth year of system operation.

After the economic break-even point, the Return on Investment (ROI) shows progressive and steady growth, reaching notable values at the end of the 15 years analyzed. This clearly suggests that the scheme with a 20% contribution from the investor presents high economic viability, being especially attractive due to the rapid initial return.

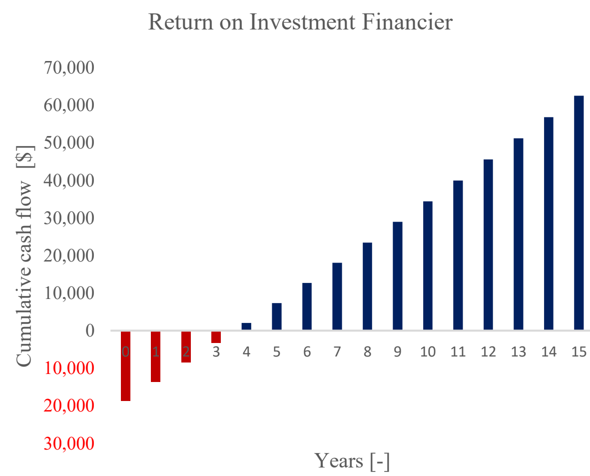

Fig. 8 ROI - Financier
Source: Own Elaboration

With a ROI of approximately 3.61 years (equivalent to 3 years and 9 months), the scenario in which the financier contributes 80% of the total solar project cost shows a slightly slower initial recovery compared to the lower investor contribution (Figure 8). However, once the financial break-even point is reached in the fourth year, the cumulative Return on Investment (ROI) shows continuous and sustained growth until the end of the 15-year analysis period.

E. Water savings

The drip irrigation system implemented in this project allows for localized water distribution directly to the crop's root zone, significantly reducing losses due to evaporation, runoff, and deep percolation.

Compared to traditional methods such as sprinkler or gravity irrigation, drip irrigation demonstrates greater water efficiency. Figure 9 shows the estimated monthly water consumption for the three methods of irrigation in corn and plantain.

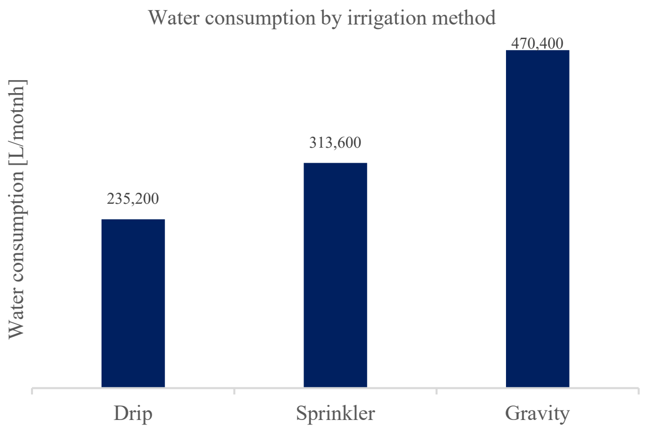

Fig. 9 Water consumption by irrigation method
Source: Own Elaboration

As seen in the graph from Figure 8, monthly water consumption with drip irrigation is 235,200 liters, while sprinkler and gravity irrigation reach 313,600 and 470,400 liters, respectively. These data were provided by agricultural engineers at the AHLE Experimental Farm. This represents a water saving of 50% compared to gravity irrigation and 25% compared to sprinkler irrigation.

F. Reduction of CO_2 emissions

The reduction in CO_2 emissions is estimated based on the annual energy generation produced by the photovoltaic system.

TABLE III
SOLAR SYSTEM CO_2 SAVINGS

1 year of emissions saved	9,989.34 kg CO_2
Life of Project emissions saved	148,840.1kg CO_2

Source: Own elaboration.

During one year of operation, the solar system avoids the emission of approximately 9,989.34 kg of CO_2, representing a significant contribution to climate change mitigation by replacing fossil fuel consumption with clean, renewable energy.

Over an estimated 15-year lifespan of the solar pumping system, a cumulative reduction of 148,840.1 kg of CO_2 is estimated. This environmental savings highlights the system's efficiency not only in energy and economic terms, but also in its positive impact on greenhouse gas reduction.

G. Solar sensitivity analysis

In the base scenario, the project shows solid financial results: an IRR of 47% for shareholders and 25% for the entire project, with net present values (NPV) of $12,577.76 and $13,732.72, respectively. The payback period is approximately 2.56 years shown in Figure 7.

In a pessimistic scenario, where generation decreases due to lower irradiance or efficiency, the shareholder's IRR is reduced to 15% and the NPV to $1,978.74, extending the payback period to 7.32 years. The project IRR drops to 14% and the NPV to $3,133.70, with a payback period of 5.31 years as shown in Figure 9.

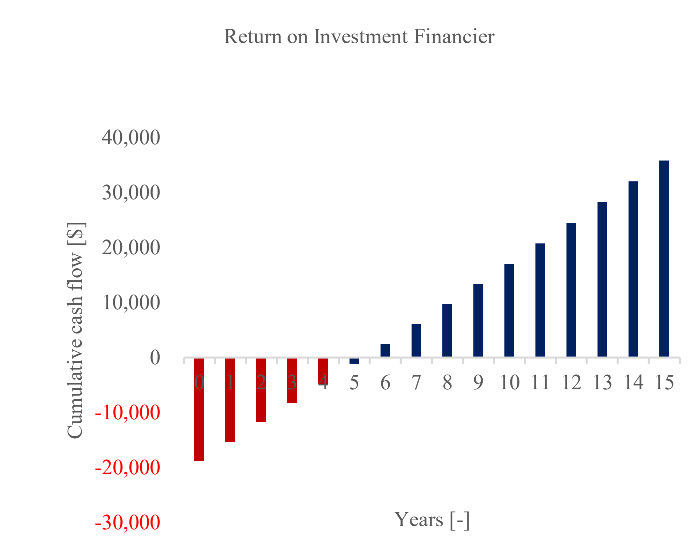

Fig. 10 ROI sensitivity analysis with solar generation
Source: Own Elaboration

These results show that the profitability of the system is sensitive to annual solar generation, so an optimized technical design and correct location are crucial to ensuring the economic success of the project.

In addition to the variation in energy generation, the economic sensitivity of the project was evaluated in the event of a decrease in the sale price of energy, from $0.2232/kWh to $0.15/kWh. This reduction reflects a market scenario with lower energy rates or less favorable contractual conditions.

The IRR decreased from 47% to 18% over a 10-year horizon and from 49% to 24% over 15 years. The NPV fell from $12,577.76 to $2,862.73, and the payback period increased from 2.56 to 7.05 years. These results show that the financial performance of the solar photovoltaic pumping system is highly sensitive to energy prices, and that profitability could be compromised in low-price scenarios.

H. Diesel vs solar pump comparison

The techno-economic comparison between the photovoltaic solar pump (Nastec VSP8-50) and a conventional diesel pump highlights substantial differences in cost structure, operational performance, and environmental impact. Both systems present a nominal power of 7.5 kW (10 HP); however, the solar pump operates as a submersible unit powered by photovoltaic energy, while the diesel alternative is typically a surface pump driven by fossil fuel.

Although the initial investment of the solar pumping system is considerably higher (approximately L. 240,000) compared to the diesel system (L. 65,105), its annual operation and maintenance costs are significantly lower, estimated at L. 5,029, mainly associated with panel cleaning and basic annual inspections.

In contrast, the diesel pump incurs higher recurring costs, around L. 28,000 per year, due to fuel consumption, oil changes, and more frequent maintenance requirements. Additionally, the expected service life of the solar pump ranges between 15 and 20 years, notably exceeding the 5 to 10 years typically observed for diesel pumps. From an energy perspective, the photovoltaic system does not require external fuel inputs, whereas the diesel system depends entirely on fossil fuel consumption, estimated at 350 gallons per year at a cost of L. 80 per gallon.

This dependency is directly reflected in the environmental performance, as the solar pump presents negligible carbon emissions, estimated at approximately 1.4 kg CO_2 per year, while the diesel alternative generates about 3,535 kg CO_2 annually, based on standard diesel emission factors.

IV. Conclusions

A comparative techno-economic analysis was conducted between a diesel pumping system with conventional irrigation and a solar photovoltaic pumping system with drip irrigation, evaluating their performance at the AHLE Experimental Farm in San Francisco de Yojoa. Based on the design, simulation, and analysis of financial and technical indicators, the following conclusions were reached:

- Technical Performance of Excelotovoltaic System: The solar photovoltaic pumping system with drip irrigation, designed using PV*SOL and Microsoft Excel, proved to be technically feasible. The simulation allowed the system to be adapted to the soil conditions and water demands of crops such as corn, plantain, sweet pepper, radish, and cilantro, ensuring an efficient water supply with clean energy.
- Comparative Economic Analysis: The financial evaluation showed that the solar photovoltaic system requires a higher initial investment than the diesel system; however, it has lower operation and maintenance costs. The ROI of the photovoltaic system was 2.56 years (investor scenario), indicating a rapid return on investment and attractive profitability.
- Energy Efficiency and Resource Consumption: The photovoltaic system demonstrated improved energy efficiency, generating more than 23,000 kWh annually without dependence on fossil fuels, while the diesel system incurs high diesel consumption (350 gal/year) and high emissions.
- Water Savings: The drip irrigation system allowed for a 50% reduction in water consumption compared to gravity irrigation, and a 25% reduction compared to sprinkler irrigation. This efficiency positions the photovoltaic system as an ideal solution for water-stressed areas.
- Project Economic Sensitivity: The sensitivity analysis showed that the system's viability depends primarily on solar radiation and investment costs. In the pessimistic scenario, ROI extended to more than five years, but remained within acceptable profitability margins, especially under financing models.

Despite the limitations encountered during this research in terms of the availability of supplier data, this study will assist future researchers as a basis for conducting further research into water optimization, energy efficiency, and greenhouse gas reduction to achieve a much more sustainable energy and agriculture sector for Honduras.

Acknowledgements

This research is dedicated to my parents and grandparents, especially my beloved grandfather Daniel Mancia who, although no longer physically with me, continues to guide me with his presence and wisdom. This academic achievement is dedicated to you; in memory of all the moments we shared and lessons we learned. You will always be present in my heart and in every step of my life. JZ

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