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Optimization of Investments in Photovoltaic Microgeneration for Self-Consumption with Grid Injection

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This research focuses on the development of a technical-economic evaluation model that can optimize investments in micro solar generation, taking as a case study a poultry farm and considering technical and economic aspects of the project. The profitability is evaluated using NPV and IRR, with values that were favorable and determine the profitability of the investment in photovoltaic micro generation with the values obtained. In the optimization, a linear programming model is used with AMPL software, which allows to parameterize the information of the decision variables and optimize the costs with the modeling of the possible operating scenarios. The initial investment is reduced by 12% and the economic viability of the project is determined in spite of the existing cost and subsidy policies in the country for the different types of clients.
Keywords: Photovoltaic system, optimization, investments, viability

1. Introduction

Photovoltaic generation is currently booming, since year after year it is gaining space worldwide and therefore in Ecuador, where the source of energy from the sun is unlimited energy, which helps the cost of the kWh generated to continue to decrease continuously due to the development of new technologies.

This type of renewable generation is very attractive to invest in as it reduces the cost of monthly billing and also by lowering the costs of the different elements and equipment that make up this entire generation system (solar panels, inverters, conductors, batteries, etc.), and which, in the long run, constitute prolonged economic savings. which, according to the manufacturers, a useful life of the entire generation system of between 20 and 25 years can be achieved.

Micro generation is a solution to create clean energy, since, on the environmental conservation side, it represents a great benefit for not affecting climate change and reducing pollution by greenhouse gas emissions [1].

The poultry company that will be the case study to be evaluated, faces increasing challenges to guarantee profitability and at the same time contribute to sustainable development. The prices of electricity, the poultry industry's most important resource, increase with production levels, negatively affecting profit margins. In this context, photovoltaic micro generation is emerging as a viable alternative to reduce energy costs and carbon emissions in poultry farming. It involves the installation of small photovoltaic systems to generate electricity on site, which is sometimes located in isolated areas, to meet some or all of the farm's energy needs.

In order to have an orientation on the technology of photovoltaic micro generation that has been carried out in recent years, emphasis is placed on the study of the technical-economic feasibility, the compilation of different works and research on this subject has been made, in order to distinguish some achievements and advances that have been developed at the national and international level. with respect to self-consumption generation systems.

In the research of [2] he carried out a work in Quito-Ecuador, entitled: "Development of a technical-economic evaluation model for the optimization of investments in photovoltaic micro generation for commercial users in Ecuador", whose general objective was to develop a technical economic model for the optimization of investments in photovoltaic micro generation. Where a technical analysis is carried out that evaluates the existing technologies in the Ecuadorian market and adjusts to their nominal parameters depending on the place to be installed, here the sizing of the photovoltaic system is carried out according to the levels of solar irradiation. Then, it performs an economic tax analysis based on the model of valuation of financial assets, impact of tax benefits and the modeling of projected load flows.

The technical-economic analysis of [2] is carried out on a photovoltaic installation in residential consumers in isolated rural areas, with the aim of carrying out the technical-economic study of a photovoltaic installation in residential consumers in isolated rural areas. Where a review of the most relevant technical characteristics of the photovoltaic generator structure is carried out, for components such as solar panels and the analysis of the solar potential that must be established for the implementation of a generation structure.

The study of [3] proposes the optimization for an office with a view to the management of an isolated microgrid in the Salache sector of the city of Latacunga-Ecuador, propose a mathematical model of the generation system with the use of a control algorithm of a maximum power point tracker (MPPT) to optimize the microgrid and supply the electricity demand of a greenhouse and laboratory, where the maximum use of the solar resource is established, integrating into the photovoltaic system a converter capable of requiring the transfer of the maximum power available in the solar modules to the battery bank, based on an incremental conductance algorithm. This is evaluated using Matlab/Simulink simulation software, where the operation of the microgrid and algorithm is analyzed.   [3]

In [4] an economic evaluation of photovoltaic systems in Colombia is carried out, based on the optimization of the investment based on demand conditions and solar irradiation based on the economic model of Mr. Yogi Goswami for operation and maintenance, where the economic feasibility of photovoltaic systems in Colombia is evaluated. based on the optimization of investment based on demand conditions and solar irradiation with favorable results that show the viability of these micro-generation systems. In similar works developed by [5, 6, 7], the viability and optimization of these generation systems is also analyzed.

In the study carried out by [8] for the technical economic analysis in the modernization of a photovoltaic plant, the climatic variables of the region of Santiago de Cuba are considered, here the parameters that contribute the most to the generation of electricity are identified and a mathematical model of the system is proposed with the use of the MATLAB Simulink software. taking into account the climatic variables identified. During the simulation of generation at the plant, different solar monitoring systems are considered that require the modification of the structure of the model.

In works such as, [9] and [10] it is proposed to improve the operational efficiency of the network with a comprehensive optimization from a Multiobjective Optimization (MOMVO) algorithm and machine learning for the optimal integration of distributed generation (DG) and Capacitor Banks (CBs) in electricity distribution networks. This research seeks to minimize energy losses and voltage deviations, leading to an improvement in operational efficiency and grid reliability with up to 47% reduction in energy losses and up to 55% improvement in voltage stability

It is also necessary to mention that the energy regulatory framework of Ecuador has proposed to increase the participation of renewable energy sources in order to reduce dependence on conventional generation sources, however this effort has been insufficient to achieve a balanced development in the participation of renewable sources applied in the DG mode [11]. This is of greater importance today due to the generation deficit that the country presents in the dry seasons, where electricity service has had to be cut.

In this context, the present research aims to provide the tools for the modeling of micro generation systems with a view to making informed decisions about the implementation of this technology, considering both technical and economic aspects, where a photovoltaic generator for a poultry farm will be used as a case study. With this feasibility study to incorporate this energy source and DG, an important contribution could be made to the current energy situation of the country

2. Materials and methods

This research has a quantitative and exploratory nature, where the data obtained with field measurements is collected that allow considering the different levels of radiation existing in the place and the energy demand of the company, to establish generation and cost trends with the application of the inductive method that considers the average levels of radiation and the modeling of the system. This is how the acquisition of the necessary data for the development of the project begins; starting with the monthly solar irradiance levels at the installation site, using the local meteorological databases and the PVSyst Software, then proceeding to the collection of information on the payment rates for energy consumption, for which the relevant electricity distribution company is consulted. In addition, the user's current load demand is analyzed and the location and dimension of the installation site is evaluated, considering the available space, shadows and the orientation of the solar panels for solar capture.

Then, in the study, the sizing of the photovoltaic system is defined according to the data of peak solar hours and radiation levels obtained, calculating the number of solar panels needed, battery bank, inverter and electrical protections. The annual energy production is modelled based on solar irradiation data, peak solar hours and the sizing carried out that considers the losses and efficiency of the system in an energy balance, where the energy produced is compared with the user's energy demand and the possibility of storing and using the surplus energy is analysed.

Subsequently, it focuses on the financial analysis of the project, where the initial investment costs are estimated, including the cost of the equipment, required structure, its installation and maintenance. The annual billing for electricity consumption is calculated, projecting the long-term economic savings, taking into account the useful life of the system for 20 years. To determine the profitability of the project, the calculation of the Net Present Value NPV is used, which must be positive, and the Internal Rate of Return (IRR) is determined, which allows us to understand the expected economic return on the investment.

Finally, in the optimization of investments, strategies are identified to maximize the economic and energy benefits of the system, implementing energy management and storage techniques to improve the overall efficiency of the system. Data analysis is performed to improve PV system predictions and performance over time. This procedure described is detailed in Fig. 1 with a flowchart that shows the methodology to be used.

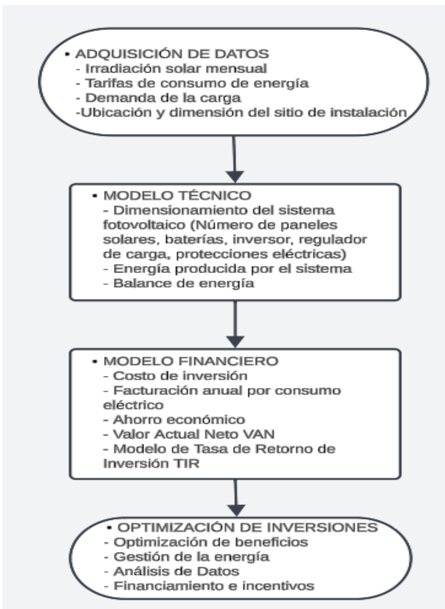

Fig. 1 Proposed methodology for the study. In original language: Spanish

For the development and elaboration of this model, the poultry plant located in the Pelileo Canton, in the south-central area of the country with coordinates 1° 22′20.8″W and 78°

31´31.6´´S, a purely rural area, without the presence of tall buildings, will be used as a case study.

To calculate demand, the measurements of the company's daily consumption shown in Figure 2 are taken as a reference, where the consumption of all the months of 2023 is observed.

TABLE I MONTHLY CONSUMPTION KWH DURING THE YEAR 2023

Months (2023)	Total [kWh]
January	620
February	434
March	411
April	458
May	574
June	404
July	510
August	230
September	340
October	378
November	423
December	502

Fig. 2 shows the demand of the poultry farm, where at 1:00 p.m. the highest energy demand is manifested for a value of 12.25 kWh, while at 11:00 p.m. the minimum demand of the poultry farm is presented with a value of 0.89 kWh.

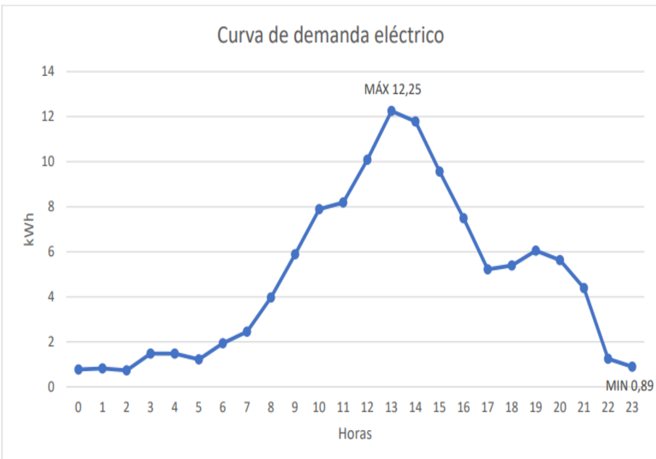

Fig. 2 Electricity demand curve in the poultry farm. In original language: Spanish

3. Results

Selection of photovoltaic panels

For the correct sizing of the photovoltaic generator, it is necessary to calculate the number of panels in series per row and the parallel strings, for which the data of the technical characteristics of the 72-cell polycrystalline photovoltaic panel with 340Wp will be used, taking into account that an ERA SOLAR POLYCRISTALLINE 72 CELL SERIES panel will be used.

In the calculation of the number of solar panels, the data obtained from the solar peak hours and equation (1) are used, from which a total of 10 photovoltaic panels are obtained

$$(1)\boldsymbol{Número\ Paneles} = \frac{\boldsymbol{Energía}}{\boldsymbol{HSP * Wp}}$$

Where:

Energy = Energy in Wh of the company.

HSP= Solar peak hours.

Wp=Panel power in W.

The calculation of the maximum generation power is determined from the power of each panel and the number of panels, which is equivalent to a value of 3400 W. Equation (2) determines the number of solar panels that will be connected in series.

$$\boldsymbol{P_{serie}} = \frac{\boldsymbol{V_{sistema}}}{\boldsymbol{V_{panel}}} \ (2)$$

Where:

$\boldsymbol{P_{serie}} =$ Number of solar modules that will be connected in series.

$\boldsymbol{V_{panel}} =$ Nominal voltage of the selected solar module based on the voltage that the system will have in direct current of 24 V, according to what is recommended for power.

$$\boldsymbol{P_{serie}} = \frac{\mathbf{48\ V}}{\mathbf{24\ V}}$$

$$\boldsymbol{P_{serie}} = \mathbf{2}\ \boldsymbol{paneles}$$

The number of solar panels that will be connected in parallel is also determined, where equation (3) is used.

$$(3)\boldsymbol{P_{paralelo}} = \frac{\boldsymbol{Tpaneles}}{\boldsymbol{Pserie}}$$

$$\boldsymbol{P_{paralelo}} = \frac{\mathbf{10}}{\mathbf{2}}$$

$$\boldsymbol{P_{paralelo}} = \mathbf{5}\ \boldsymbol{grupos}$$

Battery bank

To determine the appropriate capacity of the battery bank, the energy demand, the desired range, the discharge efficiency of the batteries and the environmental conditions must be considered. [12]

The following equation (4) is proposed, the same one that allows determining the value of the nominal capacity of the battery bank.

$$(4)\boldsymbol{Ibn} = \boldsymbol{Ib} * \boldsymbol{n}$$

Where:

Ibn: It represents the nominal capacity of the battery bank that is going to be considered in this case.

n: number of days equal to the unit and a value of 369.82 Ah is obtained

The batteries proposed are 12V of the Monoblock Solar Open Lead Acid (VLA) type that comply with DIN 40736-1 Standards. As the DC voltage of the system is 48 V and the batteries are 12 V, it will be necessary to connect 4 batteries in series

maker

Equation (5) determines the number of battery groups that are connected in parallel.

$$(5)\boldsymbol{Bparalelo} = \frac{\left(\frac{\boldsymbol{Ibn}}{\boldsymbol{Prof.desc}}\right)}{\boldsymbol{In}}$$

Where:

Desc= Represents the depth of discharge of the battery

In= Represents the nominal capacity of the battery, this data is given by the manufacturer

$$\boldsymbol{Bparalelo} = \frac{\left(\frac{\mathbf{369,82}\ \boldsymbol{Ah}}{\mathbf{0,60}}\right)}{\mathbf{260}\ \boldsymbol{Ah}} = \frac{\mathbf{616,36}\ \boldsymbol{Ah}}{\mathbf{260}\ \boldsymbol{Ah}}$$

$$\boldsymbol{Bparalelo} = \mathbf{2,37} = \mathbf{2}\ \boldsymbol{grupo}$$

Once the number of batteries connected in series and also form the group in parallel is known, then we already know that the total number of batteries to be used will be eight.

Investor Selection

Sizing and selecting the right inverter for the system is important for the proper functioning and efficiency of the system. In this case, a power for the inverter of 2037 W is obtained, but when considering the utilization factor and the power reserve, a hybrid inverter with a power of 3000 W of the Growatt Brand of 3000 W is selected that, in addition to regulating the battery charge, can manage the priorities in the use of the different energy sources to deliver to the load, to the system and charge the batteries.

The selection of photovoltaic system protection devices and the use of appropriate conductors to ensure the safety and proper functioning of the system will also be considered. In this way, the total budget of the project is detailed in Table II, taking into account each requirement of the design of the photovoltaic solar system, and in the same way, the value of labor for assembly and maintenance is considered according to the work category of the electrical technicians.

TABLE II PROJECT BUDGET

Specification	Total Cost (USD)
Photovoltaic generator with power of 3400 Wp at 48 V and 1300 Ah batteries	$5810.22
Installation Accessories & Protections	$452.85
Other	$70.00

Total Cost	$6333.07

Profitability Indicators

Profitability indicators should be considered for the measurement of the effectiveness of the project, where the cost and expense data is handled to determine if the project is profitable.

The calculation of the Net Present Value (NPV) allows determining the profitability of the project, where it is based on an initial investment and at a discount rate. Equation (6) is determined for the calculation of the NPV Indicator where the initial investment, income and expenditures during a period of time to be analyzed are detailed. [13]

$$(6)\boldsymbol{VAN} = \sum_{t=1}^{n} \frac{Ft}{(1+k)^t} - I$$

Where:

Ft = Money flow for each period

I = Initial investment of the project

n = Amount of time period (project life)

k = Effective discount rate, interest rate

The IRR (Interest Rate of Return) profitability indicator calculates the profitability of a project and indicates whether or not it is convenient to carry out the project. [11]

Equation (7) is used to calculate the IRR indicator. [12]

$$(7)\boldsymbol{TIR} = \sum_{t=1}^{n} \frac{Ft}{(1+d)^t} = 0$$

Where:

Ft = Money flow for each period

n = Number of Time Periods

d = Discount rate that makes the result zero

The NPV indicator establishes two conditions; the first is when you have a positive NPV, it indicates that the project is viable and is suitable to execute it; and the second condition is when you have a negative NPV indicates that the project is not viable and therefore the project is rejected. [13 , 14]

The payback time of the investment is defined according to the cost of the energy in kWh established by the electricity company EEASA in its tariff specifications, where in Table III

V the energy billing for the year 2023 is specified.

TABLE III ENERGY BILLING IN THE YEAR 2023

Months (2023)	Total [kWh]	Total [$]
January	620	60,56
February	434	41,40
March	411	39,03
April	458	43,87
May	574	55,82
June	404	38,31

July	510	49,23
August	230	21,16
September	340	31,72
October	378	35,63
November	423	40,27
December	502	48,41
Total turnover		$505.41

It is contemplated that the photovoltaic system must have adequate maintenance for each of its equipment, and therefore this work also represents an expense that is included for its realization once a year.

Table IV details the final values of the calculation of the NPV where a positive value is obtained and the IRR whose value is higher than the interest rate, which indicates that the project is profitable and has a payback time of 8 years. The value of the rate of U.S. Treasury bonds, also known as the risk-free rate, is considered, this is given for very safe investments since it is a reference point for the pricing of financial assets. [14 , 15]

TABLE IV MONTHLY CONSUMPTION KWH DURING THE YEAR 2023

Net Present Value (NPV)	$154.00
Internal rate of return (IRR)	9,00%
Interest rate	4,2%

Levelized Cost of Energy (LCOE) Calculation

The levelized cost of energy LCOE [16] is a measure of the average cost of electricity generated by the PV system over its lifetime shown in equation (8), and the following information is needed:

Initial CAPEX cost: Total cost of installing the photovoltaic system.

OPEX Operating and Maintenance Costs: Annual operating and maintenance costs of the photovoltaic system.

Annual energy production: The amount of energy that the photovoltaic system generates annually, measured in kWh.

System Lifespan: Number of years the solar system will be in operation

Discount rate: Interest rate used to discount future cash flows at their present value.

$$\boldsymbol{LCOE} = \frac{\sum_{t=1}^{T} \frac{CAPEX_t + OPEX_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{E_t}{(1+r)^t}} \quad (8)$$

LCOE calculation for solar panels

For the calculation of LCOE for solar panels, equation (8) is used, where both the total cost of installation and operation and the total amount of energy generated during the useful life of the system are considered. Table V details the data that will be used for the calculation of the LCOE, where the value of the solar irradiance is taken from the database obtained previously by means of the PVsyst software and the final calculation of LCOE for the solar panels is visualized, which is $0.29 USD/kWh

TABLE V DATA FOR LCOE CALCULATION IN SOLAR PANELS

Power	3,4	Kw
Radiation	174,96	kWh/yearm^2 ·
Discount rate	4,20%	0,042
Efficiency	30,0%	0,3
Production	1784,592	kWh/year
Life	20	years
LCOE	0,29	USD/kWh

LCOE Calculation for Battery Bank

The LCOE of a Battery Bank represents the average cost of storing and delivering a unit of energy over the lifetime of the storage system, considering all associated costs, such as initial investment, operation and maintenance, depth of discharge, and battery life.

Table VI details the data and the final calculation of the LCOE of the battery bank, where the value of 0.28 $USD/kWh is determined.

TABLE VI DATA FOR LCOE CALCULATION IN THE BATTERY BANK

Initial cost	2446,32	$USD
Maintenance cost	5	$USD
Storage capacity	520	Ah
System Voltage	48	V
Number of cycles	2400	-
Depth of discharge	60%	-
Life	12	years
Storage capacity	6,24	Kwh
Total Cost	2506,32	$ USD
Total Power Supplied	9216,00	Kwh
LCOE	0,27	$USD/kWh

Mathematical optimization model

The methodology proposed for the optimization problem is linear programming, with a view to maximizing the economic benefits and therefore achieving the efficient use of photovoltaic generation and the resources invested in it. [13]

Fig. 3 shows the flow diagram of the optimization process, where the inputs and outputs of data are defined, in the same way the equations are proposed and the results of the investment of the photovoltaic system are presented with the model proposed by [17].

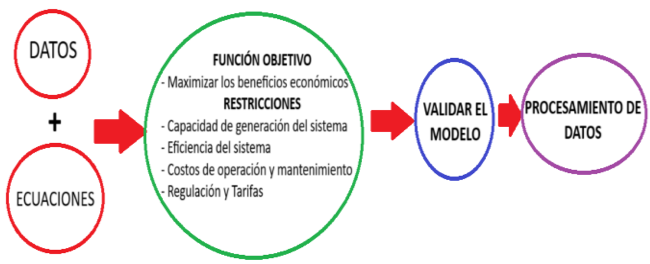

Fig. 3. Work methodology. In original language: Spanish

Objective function

In the context of optimization, the objective function expressed by Equation (9). It serves to represent the maximization, the economic benefits and the data that will be used are shown in Table VII.

$$\boldsymbol{Max} = \sum_{t=1}^{T}\left[\left[P_{Pr} \cdot E_{Pr} + P_c(E_c + E_b + E_R)\right] - \left[P_{CR}(E_R + CNE \cdot G_T + CNA \cdot E_{Eb})\right]\right] \quad (9)$$

Where:

P_{pr}= Price of energy sold.

P_c = Price of energy consumed.

P_{CR} = Price of purchased energy.

E_{Pr} = Energy produced by the photovoltaic system.

E_b = Energy stored by batteries.

E_R = Energy consumed from the Electric System.

E_{Eb}= Energy sent to the Storage System.

E_c = Energy consumed by the poultry farm.

G_T = Total generation of the photovoltaic system

CNE = Levelized cost of energy (solar panel).

CNA = Cost Levelized storage (battery bank).

TABLE VII.DATA OBJECTIVE FUNCTION

Data	Value
P_{pr}	\$0.07/kWh
P_c	\$0.07/kWh
P_{CR}	\$0.10/kWh
E_{Pr}	4946.17 kWh
E_b	5.12 kWh
E_R	3.07 kWh
E_{Eb}	5.12 kWh
E_c	1120.55 kWh/year
G_T	1116.9 kWh/year
CNE	0.26 \$USD/kWh
CNA	0.28 \$USD/kWh

Decision variables

The decision variables are established, which are key elements to solve the optimization problem, in this case the power capacity () in Kilowatts peak kWp to be installed in the photovoltaic system and the storage capacity of the battery bank () in kWh are defined.$X_1 X_2$

Restrictions

Constraints in the optimization model are conditions that must be met for the solution to be valid.

$$P_C < P_{CR} \qquad (15)$$

Where the price of the energy consumed must be lower than the price of the energy purchased.

$$G_T = (\eta \cdot R_T \cdot A)X_1 (16)$$

Where:

$\eta =$ System efficiency.

$R_T =$ The amount of solar radiation that radiates in a square meter over time.

$A =$ Panel layout area in m^2

Programming Optimization in AMPL Software.

To perform optimization programming in AMPL (A Mathematical Programming Language), it is necessary to define the optimization model, data, and command file to solve the problem [19].

The use of AMPL allows to obtain optimal values for and , as well as the energies produced, stored, consumed and sent. These results are crucial to understanding the efficiency and economic viability of the system.$X_1 X_2$

Photovoltaic Power Capacity ():X_1 Provides the optimal amount of generation capacity to maximize profits.

Storage Capacity ():X_2 Indicates the optimal amount of energy that should be stored to minimize costs and maximize revenue.

Total Generation ():G_T Calculated from efficiency, radiation and area, it shows the maximum generation capacity.

Economic Benefits: Shows the profitability of the system considering revenues and costs.

The model in AMPL is clearly structured with a precise separation between parameters, variables and constraints, making it easy to understand and modify. It can be easily adapted to different scenarios and sizes of PV and storage systems by adjusting parameter values and variables and provides a robust tool to solve complex optimization problems, ensuring accurate and efficient solutions.

The study of the poultry loads is carried out to determine the number of solar panels, where an average consumption of 12258 Wh/day was obtained as real daily energy, and the radiation values and peak solar hours are considered for the total calculation of solar panels in the system, which are 10 solar panels of 340 Wp and whose configuration is 5 groups in parallel and 2 panels in series.

As 100% autonomy is considered by the battery bank, whose nominal capacity for the photovoltaic system is 520 Ah, then a group of 4 Lead acid batteries is necessary, whose connection is 4 batteries in series with 2 groups in parallel.

The calculation of the project's profitability indicators is obtained, where a positive value of the NPV and the percentage value of the IRR of 9% is determined, which is higher than the interest rate of 4.8%.

The levelized cost of energy produced and the levelized cost of storage directly influence the operating costs of the system. Optimization has shown that it is possible to reduce these costs through more efficient technologies in order to increase the profitability of the generation system.

Optimal capacity of the Photovoltaic System ().X_1

The generation capacity of the photovoltaic system has not been modified in the optimization process, which indicates that the initial generation capacity is adequate and does not need adjustments to improve the efficiency or profitability of the system.

Maintaining the same capacity indicates that the initial configuration was already optimal for the energy needs of the poultry farm, ensuring a proper balance between energy generation and consumption.

The generation capacity of the PV system remains constant at 4946.17 kWh before and after optimization. This implies that the proposal for the initial capacity of the generator was successful to cover the energy needs of the farm. There was no need to vary its capacity, which suggests that the amount of energy generated is sufficient to cover the energy consumption of the farm, so we can consider that solar energy generation is well aligned with consumption, avoiding both deficit and excess energy that could result in waste or additional costs and providing an optimal balance between generation and storage.

It is verified that increasing the generation capacity beyond 4946.17 kWh may not be economically viable, since the additional cost would not bring a significant improvement in efficiency or profitability. Although today the costs of electricity generation are close to the costs of the energy purchased from the national electrical energy system, it cannot be ignored that the presence of subsidies in the energy sold in the country is a factor that affects the viability of the introduction of alternative energy systems. However, it must be said that being able to generate energy with alternative energy sources is more environmentally friendly than the use of conventional generation sources, which cause a greater impact due to the exploitation of natural resources and emissions into the environment

Optimal storage capacity ().X_2

The optimal battery bank capacity () in Kilowatt-hours (kWh) determines the amount of energy that can be stored and used during periods of low solar generation or high demand.$\boldsymbol{X_2}$

4. DISCUSSION OF RESULTS

Table VIII shows that the optimization has reduced the capacity of the battery bank from 5.12 kWh to 3.17 kWh from the initial capacity of 5.12 kWh, which was established to ensure sufficient energy reserve for periods without solar generation, such as night or cloudy days. The optimized capacity of the energy stored in the bank has been determined through an analysis of the farm's energy consumption and the generation capacity of the photovoltaic system. This suggests that a lower capacity is much more economically feasible than trying to cover the daily energy needs of the farm at 100%, considering that there is a resource from the central electricity grid.

Table VIII OPTIMAL STORAGE CAPACITY

Initial Battery Bank Capacity	5.12 kWh
Optimized Battery Bank Capacity	3.17 kWh

As a result of the optimization, it is evident that the economic benefits can be maximized, obtaining a value of $ $ 5585.87 vs the original initial investment cost whose value is $ 6333.07, this shows us the possibility of savings

A clear difference between the initial investment and the optimisation value is highlighted, indicating a significant improvement in the efficiency and profitability of the poultry farm's energy system. The optimisation has made it possible to reduce the initial investment by 12%, freeing up capital and improving the financial sustainability of the project. This reduction in initial costs, combined with better utilization of energy resources, ensures a more efficient and economically viable operation in the long term. These results are similar in terms of the economic viability obtained in the works [10, 14, 17] and should be used in the analysis processes for the viability of self-consumption systems, customer segmentation and the planning of the injection of energy into the grid by the different types of customers [20, 21]

5. CONCLUSIONS

In the analysis carried out for the supply of electricity through the photovoltaic system in the poultry farm, the demand and levels of solar radiation in the area are studied for the sizing of the photovoltaic generator and the selection of the different components of the system. According to the data obtained through the NASA application, it is determined that the location of the poultry farm is feasible to obtain electrical energy due to the levels of solar radiation of the site, which is an average of $174.96.\frac{KWh}{m^2} \cdot mes$

PV system and battery bank optimization using AMPL provides a robust strategy to maximize economic benefits. The results suggest that generation and storage capacity, along with efficient management of energy costs and prices, are crucial for system profitability. Sensitivity to energy prices and reduced operating costs must be considered in the planning and execution of the project to ensure its long-term success.

The generation capacity of the photovoltaic system was adequately sized from the beginning, and the optimization of the system confirmed this adequacy. The similar values of 4946.17 kWh before and after optimisation underline that no changes in generation were required, focusing optimisation efforts on other system components, such as energy storage. A clear difference between the initial investment and the optimisation value is highlighted, indicating a significant improvement in the efficiency and profitability of the poultry farm's energy system. The optimization has made it possible to reduce the initial investment by approximately 12%, freeing up capital and improving the financial sustainability of the project. This reduction in initial costs, combined with better utilization of energy resources, ensures a more efficient and economically viable operation in the long term

The reduction of the energy capacity in the storage of the battery bank from 5.12 kWh to 3.317 kWh has allowed an optimization to be considered in the energy system of the poultry farm, since it reduces investment and maintenance costs and at the same time improves operational efficiency and contributes to the sustainability of the system. The optimized capacity ensures an adequate balance between energy generation and storage to allow an efficient and economically viable operation in the medium and long term.

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