Computational Modeling of a Small-scale Agrivoltaic System in a Poultry Farming Facility

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Abstract

Agrivoltaic systems represent an innovative and sustainable solution that integrates solar energy generation with agricultural activities, optimizing the use of natural resources such as land and sunlight. This study proposes the three-dimensional modeling and simulation of an agrivoltaic system within a poultry farming facility, aiming to evaluate electricity generation and assess the impacts of factors such as shading, electrical losses, and irradiance. Based on a practical case study in Brazil, evaluating the feasibility of a photovoltaic small-scale generation plant, the research demonstrates that the installation of a photovoltaic system could generate, on average, the equivalent of 92% of the facility's monthly electricity consumption, thus promoting greater operational efficiency and enhanced sustainability within the poultry sector.

Keywords: agrivoltaic, photovoltaic simulation, photogrammetry, *PVsyst, poultry farming.*

1. Introduction

Agrivoltaic systems (AgriPV) have emerged as an innovative and sustainable solution for integrating photovoltaic (PV) energy production with agricultural activities. These systems combine electricity generation from solar radiation with the simultaneous use of the same land for both crop cultivation and livestock farming (Campana et al., 2021; Goetzberger; Zastrow, 1982). By doing so, AgriPV optimizes the utilization of natural resources such as sunlight and available land. The deployment of AgriPV systems represents a promising strategy to enhance land-use efficiency by enabling the concurrent production of agricultural goods and renewable energy (Dinesh; Pearce, 2016; Dupraz et al., 2011).

The literature highlights significant quantifiable synergies enabled by this dual-use model. In addition to clean energy production, AgriPV has been documented to generate land use efficiency gains reaching up to 200%, particularly when agricultural and energy outputs are aggregated (Mamun et al., 2022). Furthermore, in arid and semi-arid environments, AgriPV provide shelter that substantially affects the water balance, leading to enhanced Water Use Efficiency improvements ranging from 150% to 300% and an observed reduction in irrigation demand by 14% in certain studies (Pandey et al., 2025). Beyond physical resource savings, the system offers revenue diversification, which is critical for enhancing enterprise resilience against economic shocks and climatic stresses, such as drought.

Within the context of livestock farming, the integration of photovoltaic systems has demonstrated significant potential, particularly in the poultry industry (Vidotto et al., 2024). Driven by continuous technological advancements, the poultry industry has experienced a substantial increase in electricity demand. Factors such as the automation of production processes, the implementation of temperature control systems within production facilities, and the adoption of increasingly modern equipment have directly contributed to the rising energy consumption in this sector (Handler; Pearce, 2022).

Quantitative performance analysis in poultry productions, particularly in regions characterized by high thermal stress, indicate that Photovoltaic (PV) adoption functions as a crucial thermal management tool. Studies demonstrate that PV adopters achieve a statistically significant (approximately 8.9%) increase in poultry production quantity compared to non-adopters, translating directly to a 5.8% increase in farm sales revenue (Lee; Liou; Chang, 2025). This gain is primarily driven by improved productivity due to microclimate mitigation, rather than price increases.

The economic imperative remains complex. AgriPV implementations inherently incur higher Capital Expenditure (CAPEX), estimated to be 5-40% greater than conventional ground-mounted PV systems, primarily due to the necessary elevation and specialization of structural components. Therefore, financial viability is contingent upon the accurate internalization and monetization of these non-energy co-benefits—such as increased production yield,

10.18086/swc.2025.06.09 Available at http://proceedings.ises.org

reduced water use—and the implementation of supportive policy mechanisms, such as tailored Feed-in Tariffs (Chalgynbayeva et al., 2024).

Furthermore, a critical barrier to securing financing and advancing projects involves the scarcity of scientific data specifically examining AgriPV impact on agronomic parameters, including animal production yield and performance (Sollazzo et al., 2025). There is an absence of comprehensive, quantified data hinders and development of robust quantitative models necessary to support stakeholders in regulatory and investment processes (Agyekum, 2024). Especially in Brazil, one of the largest exporters of agricultural products, there is a lack of scientific docummentation on AgriPV systems and its advantages (Stefani; Felema, 2022).

The design and sizing of agrivoltaic projects require the consideration of several critical factors. These include ohmic losses, site shading, photovoltaic module tilt angles, positioning relative to the solar trajectory, geographic location, and temperature-related losses (Abo-Khalil et al., 2023). Furthermore, forecasting climatic variables remains particularly challenging due to their inherent uncertainties (Esposito et al., 2023). Given the complexity in predicting all these factors simultaneously, specialized software for three-dimensional modeling and photovoltaic system simulation is essential for supporting project design. Such tools enable the integration of multiple variables into a comprehensive analysis, providing more accurate evaluations of agrivoltaic system performance.

This study proposes the three-dimensional modeling and simulation of an agrivoltaic project for photovoltaic small-scale generation associated with a private poultry farming facility. The primary objective is to develop a virtual model to assess the optimal location in the terrain, analyze shading impacts, and the potential for electricity generation. It further aims to estimate electrical and irradiance losses and evaluate key performance metrics. The research is based on a practical case study currently under development through a partnership between the Center for Training and Research in Renewable Energies of Piauí (NUFPERPI) and a private-sector energy company. The technical and economic evaluation demonstrates that the installation of the photovoltaic system could generate, on average, the equivalent of 92% of the facility's monthly electricity consumption, thus promoting enhanced sustainability and greater operational efficiency within the poultry sector. The following sections detail the methodology for the three-dimensional modeling and PV system simulation, present the energy production results, and discuss the economic assessment of the project.

2. Modeling Methodology

The modeling of the agrivoltaic system involved the stages of three-dimensional modeling and photovoltaic system modeling, utilizing a set of software tools aimed at providing greater accuracy and realism to the model. The modeling and simulation stages are presented in the following sections.

2.1. Three-dimensional modeling

The initial approach for three-dimensional modelling involved the use of digital photogrammetry techniques. Photogrammetry is a method that enables the creation of accurate 3D models from two-dimensional photographs. This process involves capturing multiple images of an object or scene from different angles. These images are then processed using photogrammetry algorithms that identify common points across the photographs and calculate their positions in three-dimensional space. Through a sequence of photographs taken by Unmanned Aerial Vehicles (UAVs), it is possible to model three-dimensional objects, determine distances, enhance geographical accuracy, and extract topographic data.

In addition to its use in creating 3D models and geographic data, photogrammetry is also a powerful tool for generating highly detailed mesh geometries. The process begins with the alignment of the input photographs and the reconstruction of the camera positions in space. This is followed by the creation of a dense point cloud, which is a collection of millions of data points representing the surface of the object. These points are then used to build a mesh, which is a triangulated surface that accurately represents the object's geometry. This methodology offers several advantages for this study, including the ability to capture complex, irregular geometries, such as the varied topography of the agricultural landscape and the intricate structure of the agrivoltaic system. The resulting models are precise, providing a reliable foundation for subsequent computational simulations and solar radiation analyses. This level of detail is crucial for accurately assessing the microclimate effects and energy performance of the system.

Photographs were captured at 40 points distributed along a linearly spaced route by a UAV, all taken at an altitude of approximately 300 meters. The images were processed using Agisoft Metashape, a software specialized in three-dimensional modeling through digital photogrammetry. Using this tool, a three-dimensional model of the poultry farming sheds and the area designated for the photovoltaic plant installation was generated, including basic dimensions and topographic information of the site. Using the model generated, the best location for the PV plant was selected according to the following criteria: minimal ohmic losses, minimal leveling requirements, minimal shading, and minimal deforestation.

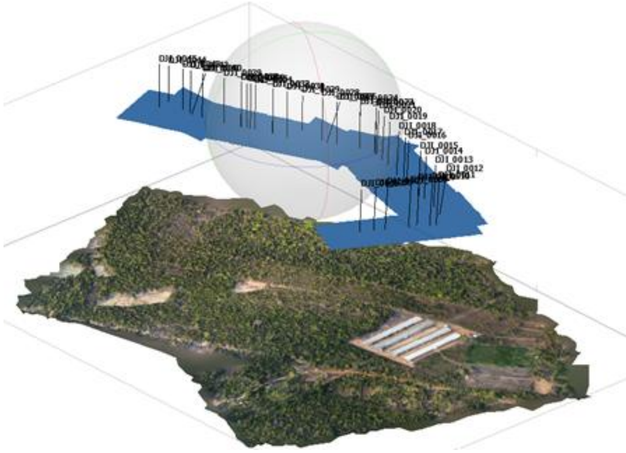

Figure 1. The digital photogrammetry processing in Agisoft Metashape

Based on the three-dimensional model of the enterprise area obtained through photogrammetric modeling, the three-dimensional modeling of the photovoltaic plant was initiated using SketchUp software. The dimensions of all components were obtained from the technical datasheets of the equipment selected for the plant. Spacings were defined according to technical specifications and designed to avoid shading effects with minimal distancing.

Figure 2. 3D modeling in SketchUp of the poultry facility

The total area of the poultry production facility is approximately 240,000 m², with 31,478 m² occupied by the sheds used for poultry farming and 208,000 m² consisting of unused land, resulting in 13.1% land usage. The photovoltaic plant was designed as a ground-mounted system and allocated specifically in the unused portion of the property, utilizing 2,097 m² of previously unproductive land. Therefore, with the new PV plant, the land usage increases to 14.0%.

2.2. Photovoltaic Modeling

Typically, photovoltaic systems are sized to compensate for a percentage (often 100%) of the unit's average monthly electrical consumption. However, in Brazil, the tariff regulations of the electrical system can limit system sizing based on other factors, such as electrical power demand and transformer size.

For this poultry facility, we chose to design the PV system to maximize the installed power capacity without replacing the already installed 112 kVA transformer. This approach allows the client to remain a low-voltage consumer (220/380 V), subject to a single-component tariff. A larger system, requiring a transformer upgrade, would reclassify the client as a medium-voltage consumer (13.8 kV) under a two-component tariff. We later demonstrate that this second option results in a less economically viable solution.

Based on the three-dimensional model of the physical space and the PV plant, the spatial information was exported to initiate the PV system performance modeling. The PVsyst software (version 7.2.4) was used to input all relevant variables for the simulation. The system includes 285 bifacial 570 W PV panels (SOLAR N PLUS SP-N16/144HG-

570) with a total nominal power of 162.45 kWp.

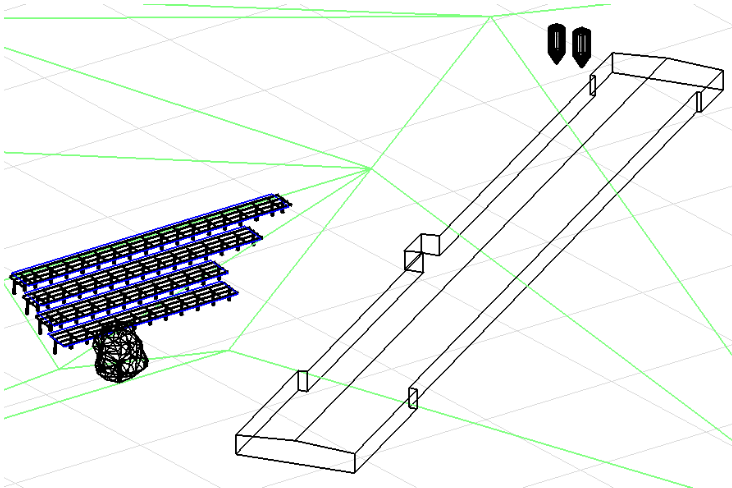

Figure 3. Simplified 3D model imported to PVsyst to make the shading study

Two three-phase inverters were integrated into the system: a SAJ C6-100K-T9 with a nominal power of 100 kW and a DC overload capacity of 45%; and a DEYE SUN-12K-G06P3-EU-AM2 with a nominal power of 12 kW and a DC overload capacity of 43%. The combined nominal power of the inverters (112 kW) was specifically chosen to remain within the limits of the existing 112 kVA transformer.

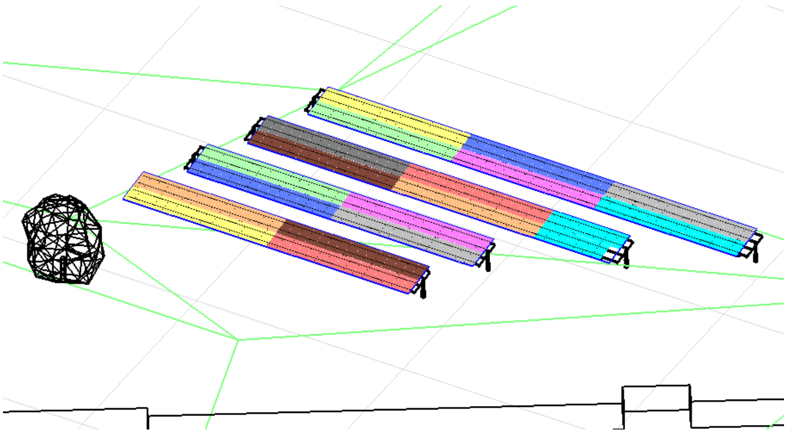

Figure 4. String configuration in PVsyst for the generation simulation

The meteorological database used was the Meteonorm 8.1, standard in PVsyst, with the irradiation information substituted with the data obtained from the nearest available point in the database of the Brazilian Center for Solar and Wind Energy Sérgio de S. Brito (CRESESB). The georeferenced coordinates of the installation site are latitude -5.415419° and longitude -42.903941°. Module dimensions, mounting structures, and other components were modeled based on the detailed project diagrams and manufacturers' datasheets. The simulation was performed with the modules on a fixed-tilt ground-mount system at an 8° inclination and a 0° azimuth, reflecting the minimum tilt available for commercially marketed ground-mount structures in Brazil. The PVsyst standard Perez-Ineichen model was used to perform energy production simulations.

3. Simulation Results

Following the methodology described in the previous section, this section presents the results obtained from the computational models. We provide a comprehensive overview of the simulated data, including the energy yield of the photovoltaic system and the main losses identified in the simulation. These results serve as the basis for the economic assessment of the system.

3.1. Overall energy results

Based on the simulation parameters mentioned, it was possible to obtain the simulation report from the software. The total annual energy yield was estimated at 266.6 MWh/year, resulting in a specific production of 1641 kWh/kWp/year. The yearly mean Performance Ratio (PR) was calculated as 81.7%, with a minimum of 74.9% in November and a maximum of 84.9% in May.

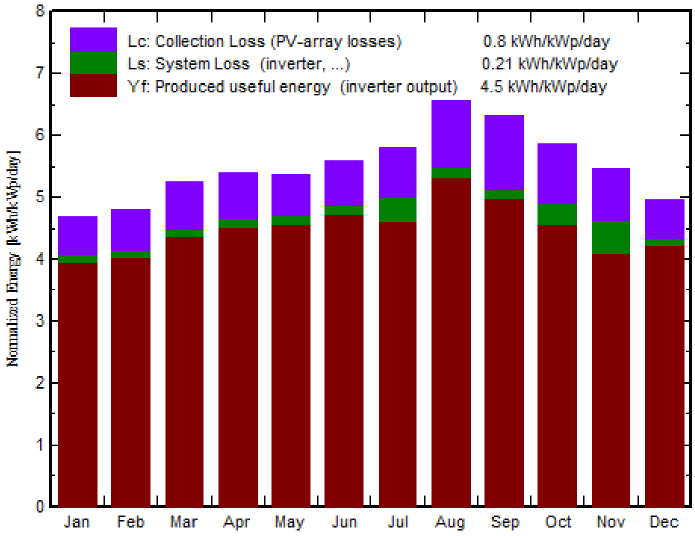

Figure 5. Normalized energy production (per installed kWp) and main lossess

The simulation results identified the following most significant loss factors affecting the performance of the agrivoltaic system.

Table 1. Summary of most significant PV system losses

Loss Factor	Value	Primary Cause and Context
Temperature-related losses	-6.88%	Result from increased PV module temperature, which negatively affects conversion efficiency. This is often tied to high ambient temperatures typical of the installation site.
Inverter overload losses	-4.18%	Occurs because the DC nominal power (162.45 kWp) exceeds the combined AC nominal power of the inverters (112 kW). This design choice was made to remain within the limits of the existing 112 kVA transformer.
Soiling losses	-3.00%	Caused by the accumulation of dust, dirt, or other residues on the module surface, reducing the amount of solar irradiance reaching the cells.
Mismatch losses between modules and strings	-2.09%	Arise from slight differences in electrical characteristics or shading among individual modules and strings, leading to less-than-optimal power production.
Light induced degradation	-2.00%	A phenomenon where PV module efficiency slightly decreases during the first few hours or days of light exposure.

The computational modeling methodology employed, which integrates three-dimensional site mapping via Unmanned Aerial Vehicles (UAVs) and specialized photogrammetry software, proved to be highly effective in optimizing the photovoltaic plant's location. By utilizing the detailed digital terrain model generated through photogrammetry, the design team was able to strategically place the ground-mounted system to minimize potential shadowing from the surrounding terrain and facility structures. This precise placement resulted in near-zero losses due to shadings, as validated by the iso-shading curves presented in Figure 6. This successful outcome underscores the critical value of advanced 3D simulation tools in agrivoltaic project development for integrating multiple variables and achieving accurate performance evaluations.

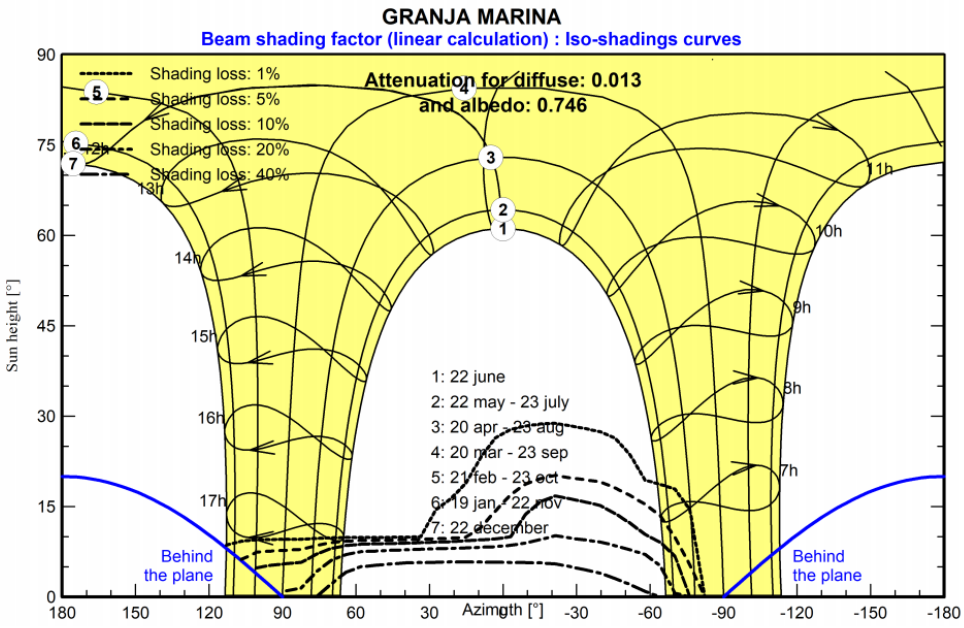

Figure 6. Iso-shadings curves obtained by the PVsyst software simulation

3.2. Economic Assessment

Based on the results from the computational modeling, the economic assessment of the project was conducted. This analysis evaluated the project's financial viability, considering its initial investment costs, operational and maintenance expenses, and the revenue from energy compensation.

The financial return on this investment is entirely derived from savings accrued on the monthly electricity bill. The poultry production facility has an average monthly electricity consumption of 24,138 kWh. However, the facility exhibits a distinct temporal pattern of electrical consumption throughout the annual operational cycle.

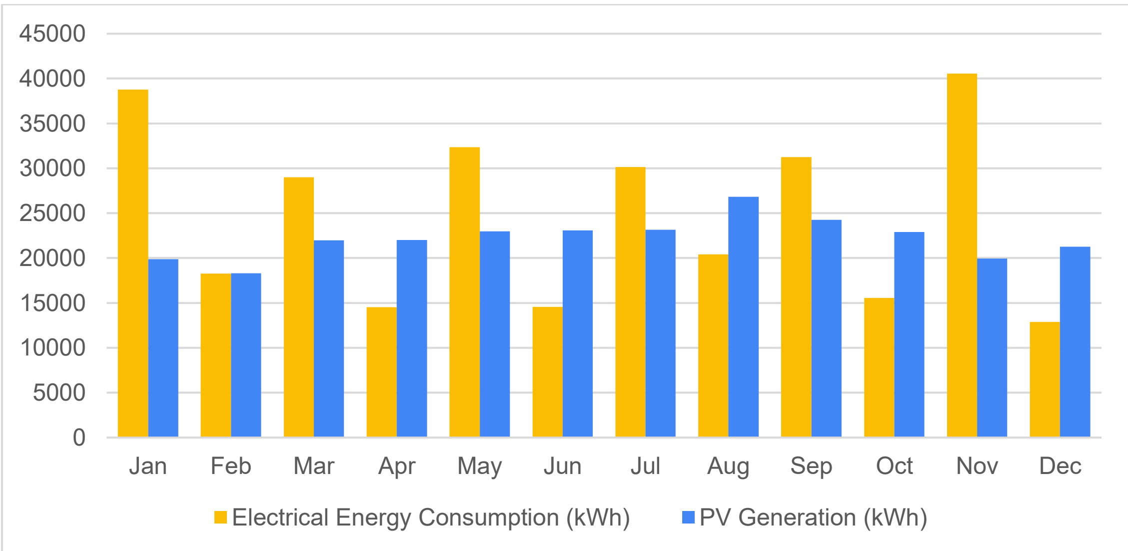

Figure 7. Monthly electrical energy consumption and PV generation of the poultry plant

The pattern observed suggests the poultry plant has one month of lower consumption and the following month with significantly higher energy consumption. This pattern can be explained by the requirements of the poultry activity. The economic success of broiler production depends heavily on maintaining a thermally comfortable environment for the animals to ensure they express their full productive potential.

The period from one to 21 days of age is explicitly characterized by the need for heating the growth environment. The first few weeks of the production cycle (Month 1) demand intensive energy use because the heating systems must operate continuously to maintain the high initial temperatures (around 31.3 °C for the first week) (Cassuce et al., 2013). This high energy usage is necessary to keep the chicks within their thermal comfort zone. As the chickens enter the subsequent month, they are older, and their thermal comfort needs have decreased significantly. Since the ambient temperature required is much lower, the heating systems require less operation, or cooling systems may become sufficient if temperatures rise, depending on the season. This substantial reduction in the required temperature setpoint translates directly into a significantly lower energy demand for environmental control systems in the following period.

In Brazil, the net cost of the energy bill is governed by the compensation mechanism, wherein the energy injected into the electric grid serves to offset the facility's subsequent energy consumption. Following Federal Law 14,300/2022, the simultaneity factor between generation and consumption has become a relevant parameter in calculating the return on photovoltaic investments. This is because, under this new legal framework for distributed generation, the accrued generation credits will progressively no longer be able to compensate for the tariff component known as "Fio B" (B Wire) of the Distribution System Use Tariff (TUSD). This specific tariff component remunerates the energy company for the administration and maintenance of the distribution system.

The distribution system usage fee will progressively increase over the coming years in accordance with Law No. 14,300/2022, for solar energy projects installed after 2023. The percentage applied to the energy injected into the grid is 45% in 2025, rising to 60% in 2026, 75% in 2027, and 90% in 2028, reaching 100% from 2029 onward. This charge applies exclusively to the surplus energy injected into the grid, not to instantaneous consumption. Consequently, the higher the power injection into the grid and the larger the credit compensation, the greater the B Wire portion that must be paid on the energy bill. All these nuances must be considered in the economic assessment.

Based on the historical data of the consumer unit, a simultaneity rate of approximately 47% between PV generation and consumption was calculated for the agrivoltaic plant. This signifies that close to half of the energy generated will not be consumed instantaneously by the poultry facility. This low simultaneity is primarily attributed to the high energy demand required during nighttime hours to maintain the necessary thermal conditions for broilers.

A second relevant factor for this simulation is the existence of a differentiated discount on the electricity tariff, as the consumer unit engages in irrigation activities. The discount for irrigators is a Brazilian tariff benefit on the electricity bill, granted to rural properties that use energy specifically for irrigation and aquaculture, aiming to reduce costs for the rural producer. The poultry facility in question receives an average tariff discount of 69%.

The set of parameters used in the economic analysis is displayed in Table 2.

Table 2. Parameters used for economic assessment

Parameter	Valued assumed	Motivation
Inflation rate	3%	Official Brazilian inflation target
CAPEX	U$ 406,98/kW	Average kW price in the state in 2025
O&M Cost	U$ 661,14 annually	Estimated based on local company quotations
Simultaneity rate	47%	Calculated
Annual efficiency loss	1%	Estimated from technical datasheets

To derive the projected financial metrics, the economic assessment necessitates the detailed calculation of the operational financial variables that form the basis for the cash flow projection and the final financial return analysis. These variables—which account for the interplay between PV generation, instantaneous consumption, grid interaction, and tariff components—are presented and defined in Table 3.

Table 3. List of variables to the economic assessment of the AgriPV system

Variable	Calculation
Instantaneous consumption	Monthly amount of PV energy, in kWh, consumed instantaneously by the poultry plant (approximately 45% of the PV generation);

Grid consumption	Monthly amount of electric energy, in kWh, consumed from the electric grid by the poultry plant;
Grid injection	Monthly injection of PV energy into the electric grid (approximately 55% of the PV generation);
Compensated consumption	Amount of energy, in kWh, that is used to offset the monthly grid consumption;
Accumulated credit	Amount of accumulated credit, in kWh, that can be used to offset grid consumption up to the following 60 months;
Registered consumption	Amount of energy, in kWh, not offset by the grid injection or accumulated credit in that month. There is a minimal value of 100 kWh;
Energy consumption tariff	Tariff established by the Brazilian National Electric Energy Agency (ANEEL), with tax application. Adjusted annually by the inflation parameter;
B Wire	Tariff component that remunerates the energy company for the administration and maintenance of the distribution system. Initial value calculated as 27.4% of the TUSD tariff (established by ANEEL); Adjusted annually by the inflation parameter and application percentage defined by Law No. 14,300/2022;
Irrigation discount	Discount on the energy consumption tariff as the consumer unit engages in irrigation activities. Approximately 69% discount;
COSIP	Individual contribution to the public lighting system. The calculation is defined independently for each city in Brazil. Here it was defined as 0.48% of the grid consumption;
Reactive energy consumption	Amount of monthly reactive energy consumed by the unit, in kVAr. We projected a monthly average of 400 kVAr based on previous values.

Therefore, the projected financial return metrics indicate a payback period of 9.1 years. The results also show an Internal Rate of Return (IRR) of 5.6%. These values suggest that, while the photovoltaic system is projected to generate energy equivalent to 92% of the facility's monthly consumption, the overall economic return of the project is moderate. Comparatively, this return is closely aligned with those typically associated with low-risk fixed-rate investments.

However, this moderate financial return is not a consequence of system inefficiency—either of the photovoltaic technology or the agrivoltaic modality—but rather results from specific tariff constraints within Brazilian regulation, which already provides significant financial incentives for rural consumer units engaged in irrigation activities. As the poultry facility already receives a 69% discount on its energy consumption tariff, additional improvements in economic return are less impactful when compared to other investment options. This also constitutes one of the primary reasons why it is more economically attractive to remain served by the existing 112 kVA transformer. The irrigation discount is not granted to clients supplied at medium voltage (13,8 kV). Consequently, the application of a substantially higher consumption tariff would be incurred. Expanding this service capacity would only become economically viable if justified by a substantial expansion of the agrivoltaic plant's operation.

Furthermore, the economic viability is affected by the progressive charge of the B Wire component of the Distribution System Use Tariff TUSD, as regulated by Federal Law 14,300/2022. This charge applies exclusively to surplus energy injected into the grid. The project operates with a low simultaneity rate of approximately 47% between PV generation and consumption. This low rate means that a substantial portion of the generated energy is injected into the grid as credit, exacerbating the regulatory impact of the progressive B Wire charge on the accumulated energy credits. Consequently, these tariff and consumption constraints are the main drivers behind the moderate financial metrics.

4. Conclusion

The present investigation performed the three-dimensional modeling and simulation of an agrivoltaic system at a poultry production unit, evaluating electricity generation and the impact of factors such as shading, electrical losses, and irradiance. The simulation results indicate an annual energy yield of 266.6 MWh, with a specific production of 1,641 kWh/kWp/year and an average annual Performance Ratio (PR) of 81.7%. In a practical case study, it was demonstrated that the photovoltaic system could generate the equivalent of 92% of the facility's monthly electricity consumption, thereby promoting greater sustainability and operational efficiency in the poultry sector.

The study contributes to general knowledge by providing a detailed technical and economic evaluation of a small-scale photovoltaic generation system integrated with an animal production activity, highlighting the potential of agrivoltaic solutions for optimizing land and natural resource use. The methodology employed, which involved the use of digital photogrammetry via Unmanned Aerial Vehicles (UAVs) and specialized software for 3D modeling, followed by energy performance simulation, is crucial for integrating multiple variables and obtaining accurate evaluations in agrivoltaic projects. Crucially, this three-dimensional modeling approach proved highly effective in determining the optimal plant location and analyzing shading effects, which resulted in near-zero losses due to shading.

The economic analysis projects a moderate return on investment, with a payback period of 9.1 years and an Internal Rate of Return (IRR) of 5.6%, despite the high energy generation. This moderation does not stem from the inefficiency of the agrivoltaic system, but rather from specific tariff constraints within Brazilian regulation for distributed generation, including the impact of the progressive charge of the B Wire component of the Distribution System Use Tariff on energy credits and the pre-existing tariff benefit for the consumer unit due to irrigation activities. Furthermore, the low simultaneity rate between generation and consumption —primarily attributed to the high night-time energy demand for thermal control in broiler farming—exacerbates the regulatory impact.

A methodological limitation lies in the inherent difficulty in simultaneously predicting climatic variables due to their uncertainties, making the reliance on meteorological databases a critical point. Future work can focus on analyzing the microclimatic impact of the photovoltaic installation on the poultry production environment, aiming to optimize the system positioning and design to enhance the simultaneity rate between generation and consumption and mitigate temperature-related losses, which represented the largest percentage of identified losses (-6.88%) in the simulation. Other studies can also include the use of Battery Energy Storage Systems to mitigate the impacts of the low simultaneity between PV generation and consumption, seeking to maximize the financial return under the current tariff regulation.

5. Acknowledgments

The authors wish to express their gratitude to the Núcleo de Formação e Pesquisa em Energias Renováveis do Piauí (NUFPERPI) for the institutional support provided during the development of this research. Special acknowledgement is extended to Cruze Energia e Engenharia for their crucial cooperation in granting access to the detailed technical specifications and design data necessary for the photovoltaic system simulation.

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