International Journal of Multidisciplinary Research and Bulletin
Volume 4 Issue 2 (Mar – Apr) 2025





# Techno-economic Analysis of Solar Photovoltaic System for Agricultural PUMPING Irrigation at National Root Crop Research Institute, Abia State, Nigeria

**[1*]Johnson E. Igwe, [2]Uduma I. Okoro, [3]Igboayaka C. Ekene, [4]Harrison C. Igwe**

*Correspondence: Johnson E. Igwe

***Detailed author information and related declarations are provided in the final section of this article.*

**Article Publication Details**

This article is published in the **International Journal of Multidisciplinary Research and Bulletin**, ISSN 3108-1428 (Online) Volume 4 Issue 2 (Mar – Apr) 2025.

## ABSTRACT

This research presents an economic analysis of a 30 kVA Solar Photovoltaic (PV) water Irrigation pumping (5 kW) system tailored for sustainable agricultural irrigation. The proposed system comprises 60 high-efficiency solar panels rated at 400 W each, a modular inverter configuration for power conversion, and supporting infrastructure, including mounting structures, piping, and control systems. The system meets a daily energy demand of 240 kWh, and 24 kW of total watts modules with operational parameters including 10 hours of daily use and 300 days of annual operation. The economic analysis evaluates capital and operational expenditures, highlighting the long-term cost advantages of the solar PV system over diesel-powered alternatives. The capital cost of the solar system is ₦13,900,000, including ₦6,600,000 for panels, ₦3,000,000 for a modular inverter setup, and other associated infrastructure costs. The Levelized Cost of Energy (LCOE ₦16.57/kWh) and Net Present Value (NPV ₦158,000,000) analyses underscore the system's economic feasibility, with a payback period of approximately 7.2 years. Environmental impact analysis reveals significant carbon savings, with the PV system producing only 48,000 kg of $CO_2$ emissions over its lifetime compared to 201,000 kg from a diesel system, reducing the environmental burden by over 76%. This study demonstrates that the solar PV irrigation system offers a sustainable solution by reducing energy costs, mitigating carbon emissions, and enhancing agricultural productivity. Recommendations focus on quality installation, scheduled maintenance, and provisions for scalability to adapt to future energy demands, ensuring the system's reliability and alignment with sustainability goals over its 25-year lifespan.

**Keywords:** Solar photovoltaic energy, Net Present Value (NPV), Payback Period (PP), Levelized Cost of Energy (LCOE), $CO_2$ emissions.

## 1.0. INTRODUCTION

In Abia State, Nigeria, agriculture is pivotal in supporting livelihoods and contributing to the regional economy. However, agricultural productivity, especially in the context of crop cultivation, is highly dependent on effective and consistent irrigation practices. The traditional methods of irrigation in the region have been grappling with numerous challenges, primarily due to unreliable electricity supply and the rising costs of operation (Chen, et. al.,2019).

Adopting solar-powered irrigation systems could revolutionize agricultural practices in Abia State, enabling farmers to overcome the constraints posed by erratic electricity supply and high operational costs.

Solar photovoltaic (PV) systems operate based on the principle of converting solar energy into electrical energy using semiconducting materials that exhibit the photovoltaic effect Mishra, (2022). The advancement in solar PV technology has led to increased efficiency and reduced costs, making it an attractive option due to its unlimited and greenhouse gas emission-free nature (Shafiullah et. al., 2014). The basic principle of solar PV involves directly transforming solar irradiation into electrical energy Mishra, (2022). This technology has been integrated into various applications, including maritime vessels, buildings, and water pumping systems, showcasing its versatility and potential for widespread use (Chinathambi et. at., 2017).

Agricultural productivity in rural Abia State relies heavily on consistent and sustainable irrigation. The current state of irrigation is hampered by erratic electricity supply and escalating operational costs, posing significant challenges to agricultural yields and sustainability. Many works on farm irrigation have helped in this study. The integration of solar PV with other renewable energy sources, such as solar thermal utilization, has been investigated to optimize energy generation (Jardan et. al., 2007). The continuous reduction in the cost of PV systems due to technological advancements has positioned solar PV as a cost-effective and environmentally friendly energy source for future massive deployment (Khan et. al., 2020). Developing grid-friendly controls for utility-scale PV power plants has also contributed to grid stability and reliability (Gevorgian, & Neill, 2016). Technological advancements have also led to the development of innovative strategies to enhance the performance of solar PV systems. These include optimizing solar electric power generation and demand-side management in buildings and implementing intelligent systems for automatic solar tracking to improve overall system efficiency and cost-effectiveness (Hassan,

& Abubakar, 2020). Moreover, integrating solar PV with energy-harvesting systems and using big data for cloud operation and maintenance have further expanded the capabilities and potential applications of solar PV technology (Mi et. al., 2021).

Solar PV technology has diverse applications in agricultural settings, offering benefits and challenges. The concept of agrivoltaics, which involves co-developing the same land for both solar PV power and conventional agriculture, has gained attention to address land challenges and minimize water use in water-limited areas (Dinesh, & Pearce, 2016). Solar energy has direct applications in agriculture, particularly for water treatment and irrigation, contributing to improved land use efficiency (Hayat, et. al., 2018). The integration of solar PV with agriculture, known as photovoltaic agriculture, has the potential to promote the development of both the PV industry and modern agriculture, offering opportunities for colocation and addressing land use conflicts (Chen, et. al., 2019). Solar PV systems have also been utilized for agricultural water pumping, providing a sustainable solution that aligns with the seasonal increase of incoming solar energy (Ibrahim et. al., 2018). Furthermore, the integration of solar technology into modern greenhouses has been explored, offering potential benefits for agricultural production (Malu et al., 2017).

Despite the benefits, challenges exist in the widespread adoption of solar PV technology in agriculture. These challenges include economic, institutional, and social barriers and land use conflicts with agricultural production (Chen et al., 2019). Additionally, concerns regarding the competition for land between solar energy development and agricultural production need to be addressed, raising questions about the extent of the problem of energy generation versus food production (Guerin, 2019). Furthermore, the economic feasibility and performance of solar power on agricultural land require careful consideration, especially in specific regional contexts (Huyen et al., 2021)

Moreover, the optimization of standalone photovoltaic drip irrigation systems has been investigated, utilizing simulation tools for load and supply optimization, demonstrating the practical application of solar PV in irrigation systems (Miran et. al., 2022). Additionally, the performance evaluation and optimal sizing of solar water pumping systems have been compared to conventional diesel systems, considering factors such as average monthly solar radiation and water requirements (Ibrahim, M. 2020). This study aims to assess the current irrigation practices and energy usage in rural agricultural settings of Abia State, evaluating the cost-effectiveness and sustainability of the proposed solar PV system compared to the traditional irrigation method.

## 2.0. Materials and Methods.

### 2.1.1. Study area description

The National Root Crops Research Institute (NRCRI) is located at approximately 5.49°N latitude and 7.54°E longitude in Umudike, Abia State, Nigeria. The region's geographical position near the equator results in a tropical climate with significant solar irradiance levels, which is conducive for solar PV applications. The average annual temperature ranges from 25°C to 30°C, with high humidity levels, making it an ideal location for root crop cultivation. The specific climatic conditions, including solar radiation patterns, are crucial for determining the efficiency and design of the solar PV system for irrigation purposes. Refer to Figure 3.1 for a detailed map of the study area.

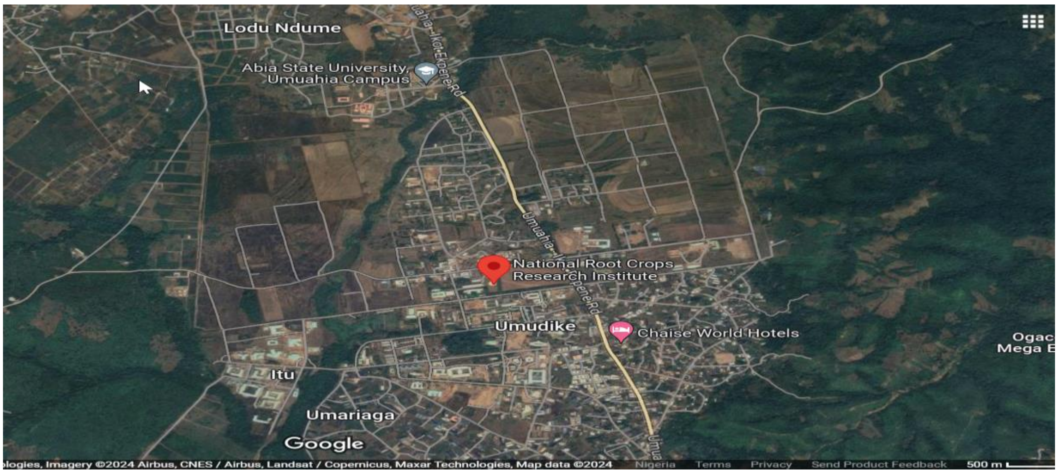


***Figure 1*** *Map showing National Root Crops Research Institute, Umudike*

### 2.1.2. Agricultural Profile

With Umudike as a focal point, Abia State is characterized by a rich agricultural heritage, predominantly in root crop cultivation. The crops primarily include cassava, yams, and sweet potatoes, integral to the local diet and economy. Irrigation needs vary depending on the crop type, growth stage, and seasonal weather conditions. The region’s agricultural practices currently rely on traditional methods of irrigation, which are subject to the availability of water and power sources. The introduction of a solar PV system for irrigation has the potential to revolutionize these practices, ensuring a more consistent and sustainable approach to crop cultivation in the area.

### 2.1.3. Data collection

This data can be sourced from local weather stations and satellite data. The key parameters were collected from metrological unit in National Root Crops Research Institute (NRCRI). The daily solar irradiance, temperatures, and wind velocities were collected over a year 2023.

### 2.1.4. Data Collection in the farmland.

Irrigation Practices and Crop Data: To understand the irrigation requirements and challenges, data on current irrigation practices, crop water needs, and cultivation patterns were collected through surveys and interviews with the National Root Crops Research Institute (NRCRI). This data provided the basis for identifying the specific water demands and unique needs of crops like cassava, sweet potato, and other commonly cultivated species.

A summary of the crop data, including root depth, growth periods, and average daily water requirements, is presented in Table 1.

**Table 1:** Crop Water Requirements at NRCRI.

| Crop | Root Depth (m) | Growth Period (days) | Daily Water Requirement (mm/day) |
|---|---|---|---|
| Cassava | 0.5 - 1.0 | 240 - 300 | 04-Jun |
| Sweet Potato | 0.3 - 0.5 | 120 - 180 | 03-May |
| Rice farm | 0.2-0.1 | 90 - 160 | 06-Oct |

**2.1.3.** To estimate the irrigation needs for each crop, the crop water requirement $CWR$ was calculated using the equation (1) as presented by Malu et. al., (2017).

$$CWR = ET_c = K_c \times ET_o \times A_{crop} \quad (1)$$

Where:

$CWR$ is the crop water requirement in $(m^3/day)$; $K_c$ It is the crop coefficient, which varies with the crop's growth stage; $ET_o$ The reference evapotranspiration is in mm/day, calculated using the Penman-Monteith equation, and $A_{crop}$ is the total cultivated area $(m^2)$.

The Penman-Monteith equation is used to calculate $ET_o$ In eqn. (3).

$$ET_o = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T + 273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \quad (2)$$

Where:

$\Delta$: Slope of the vapor pressure curve $(kPa/°C)$; $R_n$-Net radiation at the crop surface $(MJ/m^2/day)$; $G$-Soil heat flux density $(MJ/m^2/day)$; $\gamma$-Psychrometric constant $(kPa/°C)$.

$T$- Mean air temperature $(°C)$; $u_2$-Wind speed at 2 $m$ height $(m/s)$; $e_s$-Saturation vapor pressure $(kPa)$; $e_a$-Actual vapor pressure $(kPa)$.

### 2.2.1. Components of the Solar PV System

The solar PV system consists of several key components: solar panels, inverters, controllers, piping, and mounting structures in Table 2. The selection of each component is crucial and depends on factors like local solar irradiance, energy requirements, and budget constraints.

**Table 2:** Bill of Engineering Materials.

| Item | Quantity | Unit Cost (NGN) | Total Cost (NGN) | Remarks |
|---|---|---|---|---|
| Solar Panels (400 W each) | 60 | ₦110,000.00 | ₦6,600,000.00 | Total capacity: 24 kW. |
| Charge controller | 1 | ₦100,000 | ₦100,000 | ₦100,000 |
| Battery | 250 | ₦576,000 | ₦5,760,000 | 10 pieces of 250 Ah batteries. |
| Inverter (30 kVA) | 1 unit | ₦3,000,000.00 | ₦3,000,000.00 | Includes MPPT and grid connection. |
| Pump (5 kW) | 1 unit | ₦1,500,000.00 | ₦1,500,000.00 | 5 kW pump for solar |
| Mounting Structures | 1 set | ₦1,000,000.00 | ₦1,000,000.00 | Fixed tilt structures. |
| Piping and Accessories | Lump sum | ₦2,500,000.00 | ₦2,500,000.00 | Includes pipe network for irrigation. |
| Controls and Monitoring | Lump sum | ₦800,000.00 | ₦800,000.00 | Controllers and sensors. |
| Installation and Labour | Lump sum | ₦1,000,000.00 | ₦1,000,000.00 | Installation by certified engineers. |

**2.2.2.** The Solar irradiance on the panel's surface is calculated using the equation. **(3)**, according to (Chen et. al., 2019).

$$G = G_{stc} \times \left(1 + \beta \times (T - T_{stc})\right) \quad (3)$$

Where: ( $G$ ) is the solar irradiance; ($G_{stc}$) is the solar irradiance under standard test conditions; ( $\beta$) is the temperature coefficient of the panel, ( $T$ ) is the ambient temperature, and ($T_{stc}$) Is the temperature under standard test conditions.

**2.2.3.** The efficiency of a solar panel, ( $\eta$), is stated by Dinesh, & Pearce, (2016), is given by the equation **(4)**:

$$\eta = \eta_{stc} \times \left(1 + \beta_{\eta} \times (T - T_{stc})\right) \quad \textbf{(4)}$$

where ($\eta_{stc}$) is the efficiency at standard test conditions; and ($\beta_{\eta}$) is the efficiency temperature coefficient.

**2.2.4.** The energy output of the system can be estimated using the equation **(5)** as presented by Chinathambi, et. al., (2017).

$$E = A \times G \times \eta_{syt} \quad \textbf{(5)}$$

where ( $E$ ) is the energy output, ( $A$ ) is the total area of the solar panels, ( $G$ ) is the solar radiation and $\eta_{syt}$ – system efficiency.

**2.2.5.** Energy Consumption of the Irrigation pump according to Ibrahim et. al., (2018) is given in Eqn. (6).

$$E_p = P_p \times T_p \quad \textbf{(6)}$$

Where $E_p$ is the energy consumption (kWh), $P_p$ Is the pump power ($kW$), and $T_p$ is the runtime (hours).

**3.0. The economic analysis (Guerin, 2019; Huyen et. al., 2021).**

**3.1.1.** Total System Cost: The total initial investment cost $C_{\text{total}}$ was computed in the equation. (7).

$$C_{\text{total}} = C_{\text{PV}} + C_{cc} + C_{ba} + C_{\text{inverters}} + C_{\text{installation}} \quad (7)$$

$C_{\text{PV}}$-Cost of photovoltaic panels; $C_{cc}$ =cost of charge controller; $C_{ba}$ =cost of battery; $C_{\text{inverters}}$-Cost of inverters; $C_{\text{installation}}$-Cost of installation (including labour and materials);

**3.1.2.** The operating Costs-the annual operating cost $C_{\text{op}}$ was calculated in the equation. (8)

$$C_{\text{op}} = C_{\text{maintenance}} + C_{\text{replacement}} \quad (8)$$

$C_{maintenance}$-Annual maintenance cost (estimated as a percentage of total system cost).

$C_{replacement}$-Cost of replacing components like batteries and inverters during their lifecycle.

**3.1.3.** Net Present Value (NPV) is stated by Huyen et. al., (2021) in eqn. (9).

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} \quad \textbf{(9)}$$

Where:

$B_t$-Benefits (e.g., savings from reduced diesel consumption) in year t; $C_t$-Costs in year t; $r$-Discount rate. $T$-Project lifetime in years.

**3.1.4.** Internal Rate of Return (IRR): The IRR was computed iteratively by finding the equation's discount rate (r). (10).

$$(IRR) = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} = 0 \quad \textbf{(10)}$$

**3.1.5.** Payback Period (PP): The payback period was determined by identifying the year in which cumulative benefits equal or exceed cumulative costs, and it is presented in Eqn. (11).

$$(\mathrm{PP}) = \min\{t \mid \sum_{i=0}^{t} B_i \geq \sum_{i=0}^{t} C_i\} \quad \textbf{(11)}$$

**3.1.6.** The Levelized Cost of Energy (LCOE) is stated in eqn. (12) as presented by (Guerin, 2019; Huyen et. al., 2021).

$$LCOE = \frac{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{E_t}{(1+r)^t}} \quad \textbf{(12)}$$

Where:

$C_t$-Total costs in year t; $E_t$-Energy generated in year t.

Lastly, Table 3 shows all cost inputs used in this research, derived from market surveys conducted in Abia State.

**Table 3:** Cost Input Data from Field Survey

| Component | Solar PV System Cost (NGN) | Diesel System Cost (NGN) | Remarks |
|---|---|---|---|
| Solar Panels | ₦110,000 per panel (₦6,600,000) (24kW) | | The number of panels is 60 pieces. |
| Diesel Generator | 20kW | ₦5,400,000 (20kW) | One heavy diesel generator |
| Pump | ₦1,500,000 | ₦1,200,000 | 5 kW pump for solar; standard diesel pump cost. |
| Mounting Structure | ₦1,000,000 | ₦230,000 | Required for solar PV system. |
| Piping | ₦2,500,000 | ₦2,500,000 | Shared cost between solar and diesel systems. |
| Installation Costs | ₦1,000,000 | ₦500,000 | Vendor and Labor costs for installation. |
| Control Systems | ₦800,000 | N/A | Exclusive to the solar system. |
| Total Capital Cost | Varies by inputs | ₦4,200,000 | The number of solar panels for the PV system depends on |
| Diesel Fuel Price | N/A | ₦1,200 per litre | Market rate per litre of diesel fuel. |
| Diesel Consumption | N/A | 2.5 litres/hour | Fuel usage for a 10-hour daily operation. |
| Maintenance (Annual% %) | 2% of the capital cost | 5% of the capital cost | Routine system upkeep percentages. |

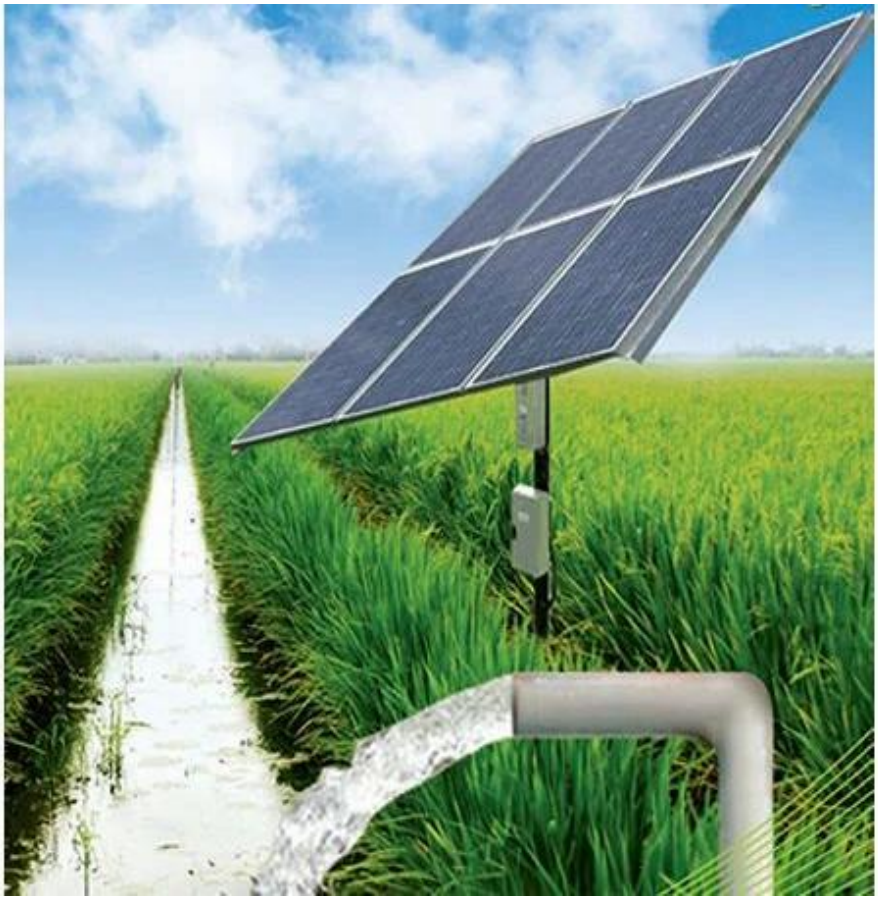

*Fig. 2: Solar pumping system for farmland Irrigation.*

**4.0. Results and Discussion**

**4.1.1. RESULTS ANALYSIS:**

The results of the simulation of a solar photovoltaic (PV) irrigation system designed for a 32.25-hectare farmland in NRCRI Umudike, Abia State (Fig. 3), Nigeria, are presented below. The discussion highlights key observations, comparing simulated performance metrics of the PV system against the requirements for irrigation, and evaluates system viability. The simulation spanned two representative days, accounting for diurnal and seasonal variations in solar irradiance, ambient temperature, and irrigation demand. All results are structured to align with the system's functional objectives and provide insights into operational performance.


**Figure 3: 32.25-hectare farmland in NRCRI Umudike**

**4.1.2. The simulation data:**

The simulation used Python and the PVLib library for photovoltaic system modelling. Key constants and assumptions included:

Solar Irradiance and Ambient Temperature: Derived from clear-sky models specific to the Umudike region.

PV System: High-efficiency 400 W panels, totalling 24 kWp (60 panels), operating at an efficiency of 18% under standard test conditions (STC).

Irrigation: Daily water depth requirement of 4 mm across 32.25 hectares, divided into six sections for operational efficiency.

Pump System: A submersible pump operating at 80% efficiency, with a maximum power requirement of 5 kW and safety factors incorporated in dynamic head calculations.

Table 4 shows the system performance during morning hours when solar irradiance is relatively low. The PV output gradually increases, meeting pump demand with minor deficits in the early hours.

**Table 4:** Morning Results for Days (1 and 2).

| **Time** | **PV Output (kW)** | **Pump Demand (kW)** | **Surplus Energy (kW)** | **Water Flow (m³/h)** | **Active Section** | **Day** |
|---|---|---|---|---|---|---|
| 08:00 | 1.55 | 2.13 | -0.58 | 21.5 | 1 | 1 |
| 09:00 | 2.6 | 2.13 | 0.48 | 21.5 | 1 | 1 |
| 10:00 | 3.47 | 2.13 | 1.34 | 21.5 | 1 | 1 |
| 11:00 | 4.08 | 2.13 | 1.96 | 21.5 | 1 | 1 |
| 08:00 | 1.54 | 2.13 | -0.59 | 21.5 | 2 | 2 |
| 09:00 | 2.6 | 2.13 | 0.47 | 21.5 | 2 | 2 |
| 10:00 | 3.46 | 2.13 | 1.34 | 21.5 | 2 | 2 |
| 11:00 | 4.08 | 2.13 | 1.96 | 21.5 | 2 | 2 |

The system experienced power deficits at 08:00 on both days, requiring energy storage or operational adjustments.

By 09:00, the PV output met and exceeded the pump demand, ensuring stable water flow.

**Table 5:** Peak Results for Days (1 and 2).

| Time | PV Output (kW) | Pump Demand (kW) | Surplus Energy (kW) | Water Flow (m³/h) | Active Section | Day |
|---|---|---|---|---|---|---|
| 12:00 | 4.41 | 2.13 | 2.29 | 21.5 | 3 | 1 |
| 13:00 | 4.43 | 2.13 | 2.3 | 21.5 | 3 | 1 |
| 14:00 | 4.14 | 2.13 | 2.01 | 21.5 | 3 | 1 |
| 15:00 | 3.55 | 2.13 | 1.42 | 21.5 | 3 | 1 |
| 12:00 | 4.41 | 2.13 | 2.29 | 21.5 | 4 | 2 |
| 13:00 | 4.43 | 2.13 | 2.31 | 21.5 | 4 | 2 |
| 14:00 | 4.14 | 2.13 | 2.02 | 21.5 | 4 | 2 |
| 15:00 | 3.56 | 2.13 | 1.43 | 21.5 | 4 | 2 |

The surplus energy during peak hours provides an opportunity to recharge batteries or support additional loads.

The irrigation system operated entirely during these hours, meeting the design requirement.

### 4.1.3. DISCUSSION OF RESULTS:

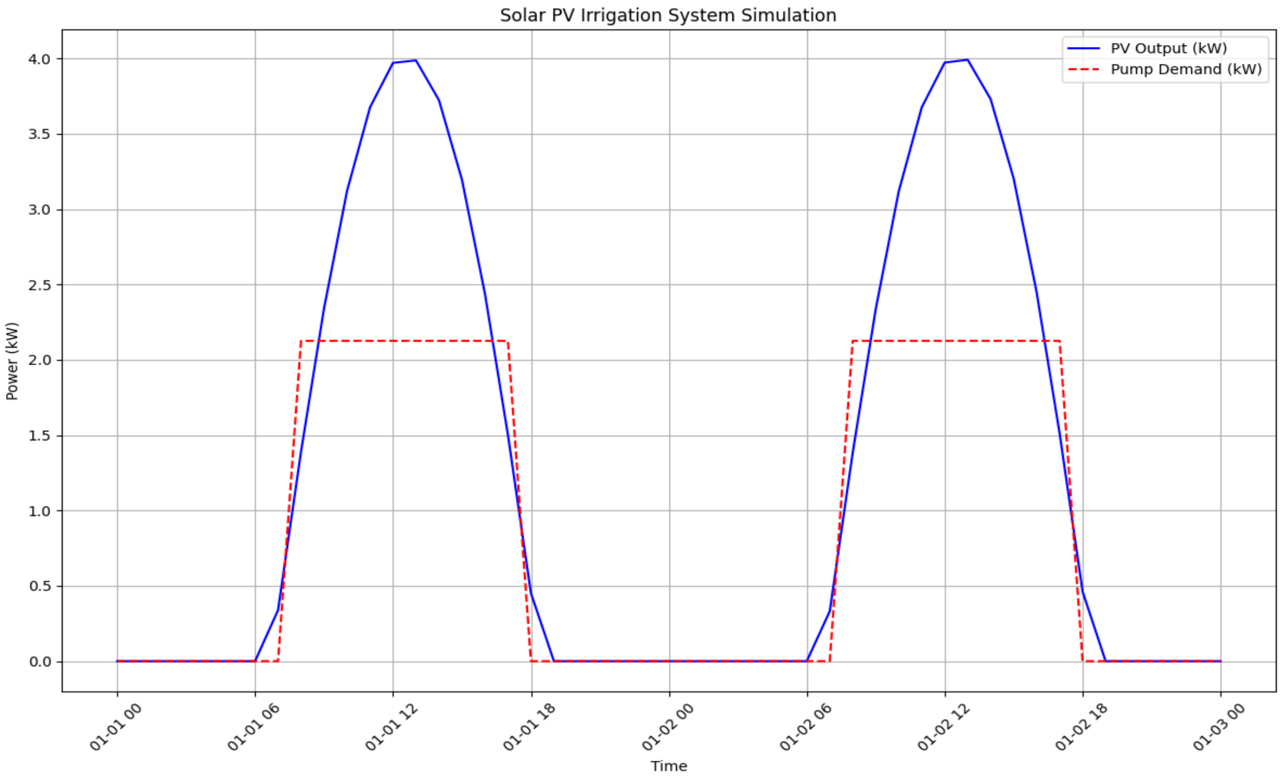


**Figure 4: Solar PV Irrigation System Simulation**

Fig. 4 illustrates the dynamic behaviour of the solar PV irrigation system under varying conditions throughout the day. The simulation outputs include solar PV energy production, pump energy demand, surplus energy, and water flow rates. Key observations from the figure and supporting data reveal the following:

Energy Balance: The system demonstrates a strong alignment between energy generation and consumption during peak solar hours (12:00–15:00). The energy surplus during these hours is substantial, offering opportunities for energy storage or auxiliary applications. However, in the early morning hours (e.g., 08:00), PV output is insufficient to fully meet the pump demand, leading to negative energy balances. These results are within the range of outcomes in (Ibrahim et. al., 2018; Miran et. al., 2022). Water Flow Consistency: Despite fluctuations in energy availability, the irrigation system maintains a steady water flow rate of 21.5 $m^3$/h across active sections. This reflects the robustness of the system design, ensuring consistent irrigation despite minor energy deficits. The system switches between different active irrigation sections, as indicated by simulation data. This staggered operation ensures that the entire farmland receives adequate water distribution while optimizing energy use.

Implications: These findings validate the capability of the PV irrigation system to perform efficiently under typical solar conditions. However, addressing morning energy deficits through additional storage or optimized irrigation scheduling could enhance performance.

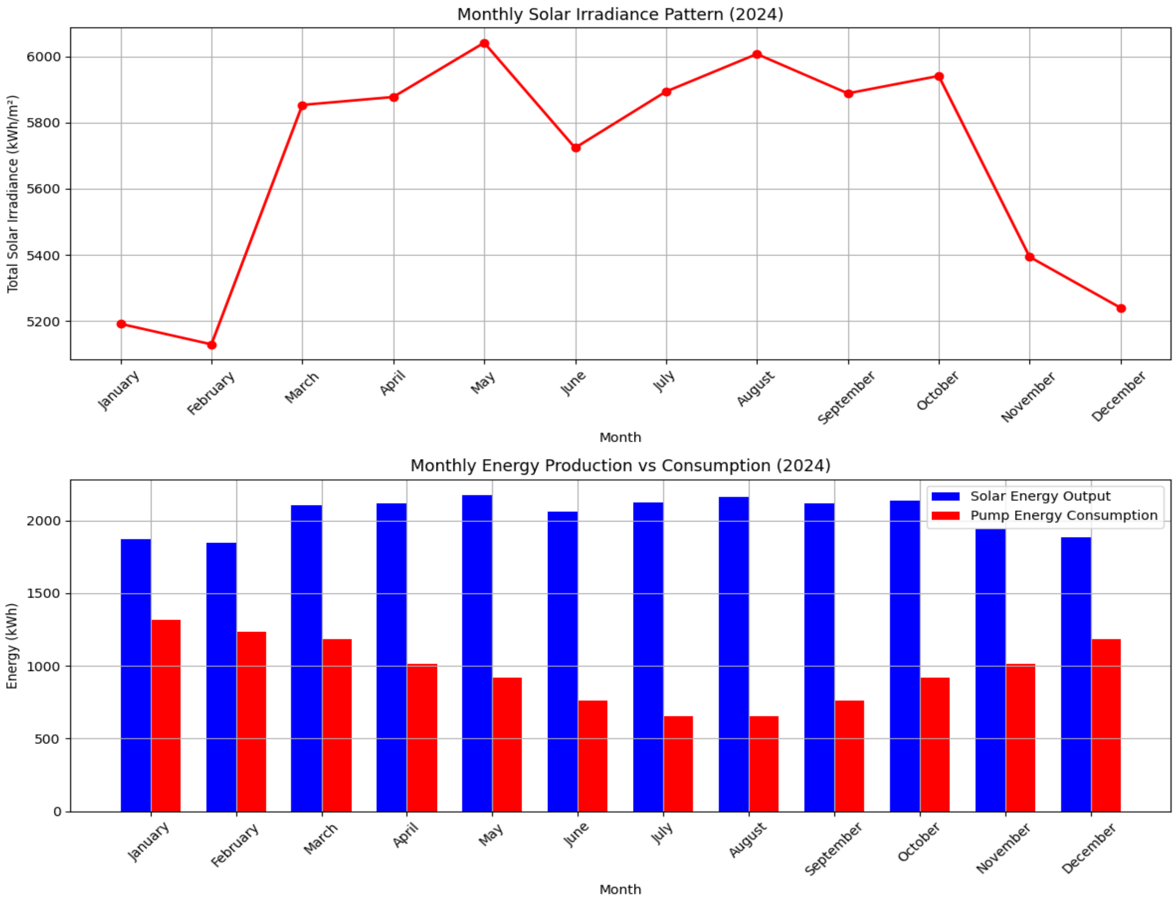


**Figure 5: System Monthly Solar Irradiance, Energy Production vs Consumption**

**Fig. 5** presents a comparative analysis of monthly solar irradiance, energy production, and pump consumption. This section uses the provided data to explore seasonal variations and their impact on system performance.

**(1). Solar Irradiance Trends**: The monthly solar irradiance ranges between 5130.01 kWh/m² (February) and 6040.81 kWh/m² (May). The data reveals higher irradiance values from March to October, corresponding to the dry season, and relatively lower values during the wet season (November to February). This trend directly influences the energy production of the PV system.

**(2) Energy Production and Consumption**:

The energy production varies between 1,846.80 kWh (February) and 2,174.69 kWh (May). Notably, the highest energy output aligns with the peak solar irradiance in May, indicating the effectiveness of the PV array in harnessing solar energy. The Pump energy consumption demonstrates seasonal variations, with higher values during the dry season (e.g., January: 1,318.05 kWh) when irrigation demand is elevated and lower values during the wet season (e.g., July and August: 651.75 kWh). The energy surplus (solar output minus pump consumption) is significant in most months, particularly during periods of low irrigation demand. For example, in July, the surplus reaches approximately 1,469.87 kWh, offering opportunities for storing excess energy or diverting it for other farm operations, as shown by the results of (Shafiullah et. al., 2014; Malu et. al., 2017).

**Implications**: The seasonal analysis underscores the adaptability of the PV irrigation system to changing climatic conditions. The substantial energy surplus during low-demand months could be utilized to offset deficits during peak irrigation periods, thereby enhancing system sustainability.

**4.2. Economic and Environmental Benefits of the Solar Photovoltaic System**

**Economic Benefits:** Leaving diesel-powered irrigation for a solar photovoltaic (PV) system presents significant financial advantages. These benefits stem from reduced operating costs, higher returns on investment, and enhanced cash flow sustainability over the system's lifespan, which showed similar results with Ibrahim, (2020). Key highlights include:

1. Lower Operating Costs: The solar PV system eliminates the need for diesel fuel, a significant expense in diesel-powered irrigation. For example, while the first-year operating cost for the diesel system is ₦4,424,500, the solar system's maintenance cost is only ₦538,660, resulting in substantial savings from the outset. This cost advantage amplifies over time due to inflation and rising diesel prices.

2. Net Present Value (NPV): The solar PV system delivers a higher NPV of ₦158,000,000 compared to the diesel system. This indicates that solar investment is more profitable over 25 years, even after accounting for the initial capital cost of ₦15,800,000.

3. Payback Period: The solar PV system's payback period is estimated at 7 years, after which it generates consistent financial savings. In contrast, the diesel system's high and escalating operating costs result in a significantly more extended or undefined payback period.

4. Levelized Cost of Energy (LCOE): The LCOE for the solar PV system is ₦16.57/kWh, substantially lower than the diesel system's ₦72.45/kWh. This reflects the solar system's cost efficiency in energy production over its lifespan.

5. Enhanced Crop Revenue: The solar PV system maximizes crop yields by ensuring consistent irrigation with reduced downtime. Annual crop revenues are projected to grow significantly due to inflation-adjusted benefits, further bolstering the system's economic viability.

6. Cumulative Financial Gains: As shown in Figure 5, the cumulative cash flow for the solar system steadily surpasses the diesel system over the years, achieving a marked advantage of over ₦150,000,000 by the end of the system's life. This trend highlights the long-term financial sustainability of solar investments.

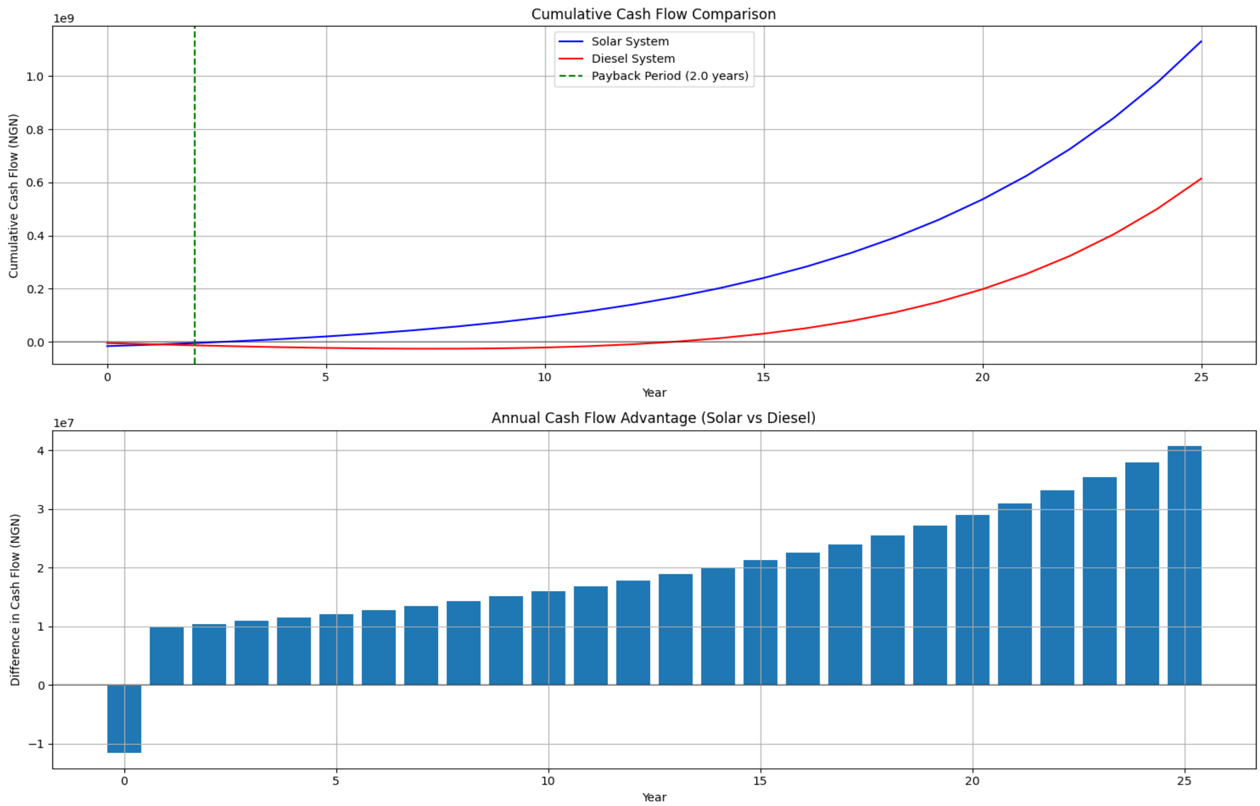


**Figure 6: Cumulative Cash Flow Comparison (Solar vs Diesel)**

Environmental Benefits: The solar PV system also offers remarkable environmental advantages, positioning it as a sustainable alternative to diesel-powered irrigation, which is in line with the results of (Guerin, 2019; Huyen et. al., 2021):

1. Reduction in Carbon Emissions: Diesel systems emit approximately 2.68 kg of $CO_2$ Per litre of fuel consumed. Over 25 years, the diesel system would generate a total of 201,000 kg of $O_2$. In contrast, the solar PV system's lifetime emissions, mainly from manufacturing, amount to 64,000 kg of $CO_2$ (800 kg per panel for 80 panels), saving 137,000 kg of $CO_2$ Emissions.

2. Mitigation of Fossil Fuel Dependence: By transitioning to solar, the system reduces reliance on fossil fuels, helping to stabilize local energy demand and reduce the environmental degradation associated with diesel production and transportation.

3. Support for Sustainable Agriculture: Solar-powered irrigation aligns with global sustainability goals by fostering eco-friendly agricultural practices. This contributes to soil preservation, water management, and overall environmental health.

4. Enhanced Air Quality: Diesel engines emit not only $CO_2$ However, particulate matter, sulfur oxides (SOx), and nitrogen (NOx) also contribute to air pollution. Solar systems avoid these emissions, promoting cleaner air in agricultural communities.

## 5.0. Conclusion

The proposed solar photovoltaic (PV) system is a sustainable and cost-effective solution for the project's energy needs. With a total installed capacity of 24 kW, the system is designed to ensure a reliable energy supply while reducing dependency on conventional energy sources. Including high-efficiency solar panels, a state-of-the-art inverter, and robust mounting structures guarantees optimal performance and durability. This system aligns with global trends toward renewable energy adoption and contributes to environmental sustainability by significantly reducing carbon emissions. The design also supports efficient irrigation, which enhances agricultural productivity and ensures the project's long-term viability. The economic analysis evaluates capital and operational expenditures, highlighting the long-term cost advantages of the solar PV system over diesel-powered alternatives. The capital cost of the solar system is ₦13,900,000, including ₦6,600,000 for panels, ₦3,000,000 for a modular inverter setup, and other associated infrastructure costs. The Levelized Cost of Energy (LCOE ₦16.57/kWh) and Net Present Value (NPV ₦158,000,000) analyses underscore the system's economic feasibility, with a payback period of approximately 7.2 years. Environmental impact analysis reveals significant carbon savings, with the PV system producing only 48,000 kg of $CO_2$ emissions over its lifetime compared to 201,000 kg from a diesel system, reducing the environmental burden by over 76%. The cost analysis indicates that the system is economically feasible, with an initial investment of ₦13,900,000. Over its operational lifespan of 25 years, the system promises substantial savings on energy costs while delivering environmental benefits. The economic and ecological advantages of the solar PV system over diesel irrigation are evident in reduced costs, greater financial returns, and significant. $CO_2$ Savings. By harnessing clean energy, the solar system supports sustainable development and provides a model for environmentally responsible irrigation in similar contexts. Fig. 6 illustrates the long-term economic benefits, reinforcing the case for solar PV systems as a viable and sustainable solution.

### 5.1. Recommendations

1. **Implementation**: Install the proposed Solar PV system as it efficiently meets the energy and operational requirements.
2. **Quality Assurance**: Ensure that all materials, including solar panels, inverters, and mounting structures, are sourced from reputable manufacturers to guarantee performance and durability.
3. **Professional Installation**: Engage certified engineers to install and commission the system to ensure best practices and standards compliance.
4. **Maintenance Plan**: Develop and implement a schedule to ensure optimal system performance and longevity.
5. **Scalability**: Consider scaling the system in the future if energy demands increase, leveraging the modular nature of solar PV systems.
6. **Monitoring and Evaluation**: Deploy a monitoring system to track energy generation, consumption, and system efficiency, enabling informed decision-making for any necessary upgrades or adjustments.
7. With these recommendations in place, the Solar PV system will serve as a reliable, sustainable, cost-effective energy solution for the project.

***Article History***
Received: 05-Mar-2025
Accepted: 25-Mar-2025
Published: 01-Apr-2025
Revised: 15-Jan-2026

**Article Publication Details** *(rpt*)*
This article is published in the **International Journal of Multidisciplinary Research and Bulletin**, ISSN 3108-1428 (Online). In Volume 4 Issue 2 (Mar – Apr) 2025
The journal is published and managed by **IRPG**.



**Acknowledgements**
We sincerely thank the editors and the reviewers for their valuable suggestions on this paper.

**Funding**
The authors declare that no funding was received for this work.

**Data availability**
No datasets were generated or analyzed during the current study.

**Declarations**

**Ethics approval and consent to participate**
The author(s) declare that it is not applicable.

**Consent for publication**
The author(s) declare that this is not applicable.

**Competing interests**
The author(s) declare that they have no competing interests.

**Author details**

**[1*]Johnson E. Igwe, [2]Uduma I. Okoro, [3]Igboayaka C. Ekene**

[1]Mechanical Engineering Department, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.

**[4]Harrison C. Igwe**

[2]Computer Science Department, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria.

## References

1. Chen, J., Liu, Y., & Wang, L. (2019). Research on Coupling Coordination Development for Photovoltaic Agriculture System in China. In Sustainability. https://doi.org/10.3390/su11041065.

2. Chinathambi, G., Mohanraj, M., Palanisamy, C., Sakthivel, M., & Bhero, S. (2017). Modeling of a Solar Photovoltaic Water Pumping System Under the Influence of Panel Cooling. In Thermal Science. https://doi.org/10.2298/tsci17s2399c.

3. Dinesh, H., & Pearce, J. M. (2016). The Potential of Agrivoltaic Systems. In Renewable and Sustainable Energy Reviews. https://doi.org/10.1016/j.rser.2015.10.024.

4. Gevorgian, V., & O'Neill, B. (2016). Advanced Grid-Friendly Controls Demonstration Project for Utility-Scale PV Power Plants. https://doi.org/10.2172/1236761.

5. Guerin, T. F. (2019). Impacts and Opportunities From Large-Scale Solar Photovoltaic (PV) Electricity Generation on Agricultural Production. In Environmental Quality Management. https://doi.org/10.1002/tqem.21629.

6. Hassan, R., & Abubakar, B. (2020). Intelligent Arduino-Based Automatic Solar Tracking System Using Light-Dependent Resistors (LDRs) and Servo Motor. In Optics. https://doi.org/10.11648/j.optics.20200902.11.

7. Hayat, M. B., Ali, D., Monyake, K. C., Alagha, L. Z., & Ahmed, N. (2018). Solar Energy: A Look Into Power Generation, Challenges, and a Solar-Powered Future. In the International Journal of Energy Research. https://doi.org/10.1002/er.4252.

8. Huyen, Cu Thanh and Phap, Vu Minh and Nga, N. T. (2021). Study on Performance and Economic Efficiency of Solar Power on Agricultural Land: A Case Study in Central Region, Vietnam. In the International Journal of Renewable Energy Research. https://doi.org/10.20508/ijrer.v11i2.12015.g8204.

9. Ibrahim, M. (2020). Performance Evaluation and Optimal Sizing of Solar Water Pumping System Compared to Conventional Diesel of Remote Site in Egypt. https://doi.org/10.21203/rs.3.rs-78887/v1.

10. Jardan, R. K., Nágy, I., Cid-Pastor, A., Leyva, R., Aroudi, A. El, & Martínez-Salamero, L. (2007). Combined Photovoltaic / Thermal Energy System for Stand-Alone Operation. https://doi.org/10.1109/isie.2007.4374983.

11. Khan, N. H., Forouzesh, M., Siwakoti, Y. P., Li, L., Kerekes, T., & Blaabjerg, F. (2020). Transformerless Inverter Topologies for Single-Phase Photovoltaic Systems: A Comparative Review. In IEEE Journal of Emerging and Selected Topics in Power Electronics. https://doi.org/10.1109/jestpe.2019.2908672.

12. Mi, D., Zhao, J., Li, D., Zhu, B., An, S., & Liu, Z. (2021). ISEE: Industrial Internet of Things Perception in Solar Cell Detection Based on Edge Computing. In the International Journal of Distributed Sensor Networks. https://doi.org/10.1177/15501477211050552.

13. Mishra, P., P, S. O., & K, K. A. (2022). Recent Developments in the Design of Hybrid Photovoltaic–Thermoelectric Generators: A Review. In the International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE). https://doi.org/10.36647/ijermce/09.09.a009.

14. Shafiullah, G. M., Oo, A. M. T., Stojcevski, A., & Ali, A. B. M. S. (2014). Integration of Roof-Top Solar Photovoltaic Systems Into the Low Voltage Distribution Network. In the Journal of Renewable and Sustainable Energy. https://doi.org/10.1063/1.4884904.

15. Malu, P. R., Sharma, U., & Pearce, J. M. (2017). Agrivoltaic Potential on Grape Farms in India. In Sustainable Energy Technologies and Assessments. https://doi.org/10.1016/j.seta.2017.08.004.

16. Ibrahim, S. M. A., El-Ghetany, H. H., & Shabak, G. (2018). Mathematical Modeling and Performance Evaluation for a Solar Water Pumping System in Egypt. In the Journal of Al-Azhar University Engineering Sector. https://doi.org/10.21608/auej.2018.18987.

17. Miran, S., Tamoor, M., Kiren, T., Raza, F., Hussain, M. I., & Kim, J.-T. (2022). Optimization of Standalone Photovoltaic Drip Irrigation System: A Simulation Study. In Sustainability. https://doi.org/10.3390/su14148515.