

**EVALUATING THE ECONOMIC VIABILITY OF SOLAR FARMS FOR
POWERING RESIDENTIAL COMMUNITIES**

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OF

**BEING A PROJECT SUBMITTED TO THE DEPARTMENT OF
ELECTRICAL/ELECTRONICS ENGINEERING IN PARTIAL FULFILLMENT OF
THE REQUIREMENT FOR THE AWARD OF B.ENG DEGREE IN FACULTY OF
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FEBURARY, 2025

CERTIFICATION

This is to certify that this project work was carried out by OBED ONYEKACHI OKOH, OLUCHUKWU JOSEPH OKOLIE, DANIEL-CLARENCE CHINAZA OKONKWO and DAVID OGHENEORHIE EBUANEKPE of the department of ELECTRICAL/ELECTRONICS Engineering, Faculty of Engineering, University of Benin, in partial fulfillment of the requirements of the award of the Bachelor of Engineering (B.Eng) Degree in ELECTRICAL/ELECTRONICS Engineering.

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ENGR. PROF. K. O. OGBEIDE

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DEDICATION

This report is offered to the God, the Wellspring of life and wisdom. We extend our heartfelt dedication to our parents, cherished ones, and supporters, whose unwavering presence have been a beacon of support, especially during challenging times.

ACKNOWLEDGEMENT

We extend our deepest gratitude to the Almighty God for making this journey possible. Our heartfelt thanks go to ENGR. DR. N.S. Idiagi, our project supervisor, whose unwavering commitment and guidance were instrumental in the completion of this report. His constant support was invaluable throughout the project.

We also wish to express our appreciation to the Department of Electrical/Electronic Engineering for fostering an environment conducive to our success. Special thanks to all the lecturers whose teachings have enriched our knowledge over the years. We must acknowledge the head of the department, ENGR. PROF. K. O. OGBEIDE, for his invaluable support and guidance.

We owe a special debt of gratitude to our friends who stood by us during countless study sessions and shared in our journey. We are deeply grateful to God for bringing these amazing people into our lives.

Our most profound thanks go to our parents, Mr. and Mrs. Okolie Anyaonicha, Mr and Mrs Frank Okoh, Mr and Mrs Okonkwo, Mr and Mrs Richardson Ebuankpe whose unwavering financial and emotional support has been indispensable during this project and throughout our entire degree program and life journey.

ABSTRACT

This study evaluates the economic viability of solar farms as a sustainable energy solution for residential communities in Nigeria. The research aims to determine whether solar farms can provide a cost-effective alternative to the national grid by analyzing key economic factors, including initial investment, operational costs, and long-term financial benefits. The study also explores the environmental impact of solar farms, highlighting their potential to reduce carbon emissions and enhance energy security for households. By assessing various ownership models and financial incentives, the research provides insights into the feasibility of large-scale solar adoption in residential areas.

The methodology involves a detailed load analysis for a 100-household community, calculating daily energy consumption and peak load demand. The study designs a solar farm using 806 monocrystalline solar panels, a 400 kVA inverter, and necessary protection devices. Cost estimation covers component procurement, labor, land acquisition, and annual maintenance. Financial modeling incorporates revenue generation from surplus energy sales to the grid and cost comparisons with traditional electricity tariffs. A sensitivity analysis evaluates the impact of rising grid electricity prices on the long-term economic benefits of solar farms.

Findings reveal that the total project cost is approximately ₦433,695,000, with each household contributing ₦4,336,950. The estimated payback period is about 4.3 years, and the solar farm can generate ₦15,439,500 annually from surplus energy sales. Over a 25-year lifespan, the community is projected to save over ₦2.37 billion compared to reliance on the national grid. The study concludes that, despite the high initial investment, solar farms offer a financially and environmentally viable solution for residential energy needs, ensuring cost savings, energy independence, and sustainability.

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CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND TO THE STUDY

Electricity is crucial for modern development, impacting socio-economic activities across all sectors, including residential, commercial, and industrial domains. However, in Nigeria, the electricity supply crisis remains one of the largest challenges to national growth. With a population exceeding 213 million people, only around 47% of Nigerians have access to electricity via the national grid, and even then, power outages occur frequently, resulting in an average daily supply of just four hours (Aliyu, 2023; IEA, 2023). The consequences are widespread, affecting education, healthcare, industrial activities, and overall quality of life.

Given these challenges, solar energy presents a compelling solution, especially for residential communities that are under-served or entirely off-grid. Solar photovoltaic (PV) systems convert sunlight into electricity and can provide a reliable, renewable energy source, mitigating the power supply problems faced by Nigerians. The sun's abundant energy—estimated at 5.25 kWh/m²/day across Nigeria—makes solar energy an economically viable option (Nigeria Energy, 2023). Despite the promise, the adoption of solar PV technology has been slow, largely due to high initial investment costs, lack of public awareness, and inconsistent government support (Aliyu, 2023; Nigeria Energy, 2023).

This study focuses on evaluating the economic viability of solar farms for powering residential communities in Nigeria. Solar farms, which can be built to supply power to multiple homes or small communities, offer an efficient alternative to conventional electricity generation. However, their widespread deployment faces economic, technical, and logistical challenges. This project aims to assess the overall cost-effectiveness of solar farms, including installation

and maintenance costs, energy output, and potential long-term savings for residents. Additionally, it will examine factors such as government incentives, financing mechanisms, and policies to encourage solar adoption.

Recent government initiatives to expand solar power include plans to install up to 3 GW of solar energy across 25 states by 2025 (World Energy, 2024). These efforts, supported by international bodies like the World Bank, underscore the need to explore the full economic potential of solar farms. This project will contribute by providing an in-depth analysis of the financial sustainability of such solar installations, as well as their impact on improving energy security for residential communities in Nigeria.

1.1 STATEMENT OF PROBLEM

Despite Nigeria's abundant solar resources, the country faces a persistent electricity supply crisis. This situation has severely affected domestic households and the industrial sector, limiting economic growth and development. There is an urgent need to explore alternative and sustainable energy sources, such as solar farms, to address these energy challenges. The primary problem is evaluating whether the establishment of solar farms is economically viable for powering residential communities, given the high initial investment and various infrastructural and policy challenges. Additionally, comparing the cost-effectiveness and reliability of solar farms to the existing power grid infrastructure is critical.

1.2 AIM

The aim of this study is to evaluate the economic viability of solar farms for powering residential communities in Nigeria and to compare this with the traditional power grid system over a 25-year period.

1.3 OBJECTIVES

The objectives of this study are as follows:

1. To assess the current state of electricity supply and demand in Nigeria, with a focus on residential communities.
2. To evaluate the economic viability of solar farms as an alternative energy source for residential areas.
3. To estimate the initial investment and operational costs of setting up solar farms for 100 households.
4. To compare the cost-effectiveness of solar farms versus the traditional power grid.
5. To analyze potential savings from reduced dependency on fossil fuels.
6. To examine the environmental and social benefits of adopting solar farms in residential communities.

1.4 METHODOLOGY

The methodology for this study includes:

1. **Literature Review:** Comprehensive review of existing studies, reports, and data on Nigeria's energy sector, solar energy potential, and economic analyses of solar farms.
2. **Data Collection:** Gather data on the average electricity consumption per household in the area. Collect information on the local electricity rates from the grid.
3. **Cost Analysis:** Estimation of the initial investment, operational costs, and maintenance costs of setting up solar farms using current market prices sourced from platforms like Jiji.ng, alibaba.com etc.
4. **Energy Consumption Estimation:** Calculation of the average energy consumption per household to determine the required capacity of the solar farms.

5. **Economic Viability Assessment:** Using Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period methods to evaluate the economic viability of the solar farms.
6. **Comparative Analysis:** Comparison of the long-term costs, benefits, and reliability of solar farms versus the existing power grid over a 25-year period.
7. **Risk Analysis**
 - a. Identify potential risks and uncertainties in both solar power and grid power scenarios (e.g., technology failures, price fluctuations, policy changes).
 - b. Assess the reliability and stability of the solar power system versus the grid.
8. **Sensitivity Analysis**
 - a. Perform sensitivity analysis to understand how changes in key assumptions (e.g., cost of solar panels, electricity rates) affect the overall economic viability.

1.5 SCOPE

The scope of the study is limited to:

- Residential communities comprising 100 households.
- Estimation of energy consumption based on average household usage.
- Cost analysis using current prices of solar panels, inverters, batteries, and installation costs.
- Economic viability assessment considering financial, environmental, and social factors.
- Comparative analysis of solar farms and the traditional power grid in terms of long-term cost, reliability, and sustainability.

1.6 RELEVANCE OF WORK

The significance of this study lies in its potential to advance renewable energy adoption within residential communities by demonstrating the economic viability of solar farms. By identifying

the cost-effectiveness and feasibility of solar energy, the research promotes sustainability and energy independence, reduces greenhouse gas emissions, and supports communities in transitioning to clean energy. Furthermore, it highlights the importance of community-based ownership models and government incentives in facilitating access to solar power, making renewable energy more inclusive and equitable for all residents.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews previous research and findings related to the economic viability of solar farms in residential communities. It presents an analysis of works that have explored various aspects of solar energy systems, including their cost-effectiveness, community ownership models, and integration of energy storage solutions. Furthermore, this chapter outlines how the current study improves upon previous efforts by addressing critical gaps, particularly in the Nigerian context, where grid reliability, policy support, and financial models require tailored solutions.

2.1 SOLAR ENERGY

Solar energy is the radiant light and heat harnessed from the sun, which can be converted into usable forms of energy through technologies like photovoltaic (PV) cells or concentrated solar power. Solar energy is a renewable and clean energy source, making it a key technology in the global transition toward sustainable energy systems (World Energy, 2024).



Figure 2.1: A Solar Farm

2.2 SOLAR PANELS AND PHOTOVOLTAIC (PV) TECHNOLOGY

A solar panel, also known as a photovoltaic (PV) module, consists of a series of PV cells that convert sunlight directly into electricity through the photovoltaic effect. The types of solar panels include:

1. **Monocrystalline Panels:** These are made from a single crystal of silicon, making them highly efficient in converting sunlight into electricity. They are known for their longevity but are also relatively expensive (Muhammad, Saeed & Khan, 2021).



Figure 2.2: Monocrystalline panel

2. **Polycrystalline Panels:** These panels are made from multiple silicon crystals melted together. They are less efficient than monocrystalline panels but are more cost-effective and commonly used in residential settings (Cranfield University, 2020).



Figure 2.3: Polycrystalline panel

3. **Thin-Film Panels:** These panels are made by depositing one or more layers of photovoltaic material on a substrate. Thin-film panels are generally less efficient but are more flexible and lighter than crystalline panels, making them suitable for installations where weight and flexibility are concerns (Dağtekin, Kaya & Öztürk, 2022).

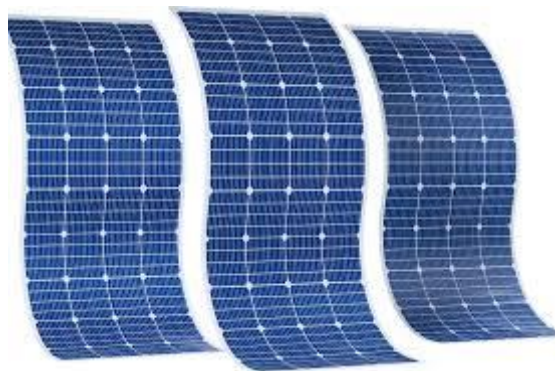


Figure 2.4: Thin film panel

2.3 INVERTERS

Inverters are critical components in solar energy systems that convert the direct current (DC) generated by solar panels into alternating current (AC), which is the form of electricity used by most household appliances and for grid distribution.



Figure 2.5: An inverter

There are several types of inverters used in solar energy systems:

4. **String Inverters:** These are the most commonly used inverters in residential solar systems. They are connected to a series of solar panels (a "string"), and the entire string is managed as a unit. However, string inverters are susceptible to performance losses if any panel in the string is shaded (Cranfield University, 2020).
5. **Microinverters:** These small inverters are attached to individual solar panels. Microinverters convert DC to AC at each panel, improving efficiency by mitigating the effect of shading or malfunctioning panels on the entire system. They are typically more expensive than string inverters but provide better monitoring and flexibility (Muhammad et al., 2021). Power optimizers work alongside string inverters. They are installed at the panel level and adjust the voltage and current to maximize power output, improving overall system efficiency. While not as effective as microinverters in certain cases, they provide a balance of cost-effectiveness and improved efficiency (World Energy, 2024).

2.4 BATTERIES AND ENERGY STORAGE

Energy storage plays a vital role in solar energy systems, helping address the intermittent nature of solar power by storing excess electricity generated during sunny periods for use at night or during cloudy days.



Figure 2.6: Lead Acid Batteries

Types of batteries commonly used for energy storage in solar systems include:

1. **Lead-Acid Batteries:** These are traditional batteries that have been widely used for energy storage for many years. Lead-acid batteries are relatively inexpensive but have a shorter lifespan and lower energy density compared to modern battery types (Dağtekin et al., 2022).
2. **Lithium-Ion Batteries:** Lithium-ion batteries are the most commonly used for residential solar energy storage. They have high energy density, longer lifespan, and better efficiency compared to lead-acid batteries. The downside is their higher cost, although prices have been decreasing with advancements in technology (Cranfield University, 2020).
3. **Flow Batteries:** Flow batteries store energy in a liquid electrolyte solution. They are known for their scalability and long lifecycle but are more complex and costly, making them suitable primarily for larger installations rather than typical residential setups (World Energy, 2024).

Batteries increase the self-sufficiency of residential solar farms, allowing participants to use more of their generated energy and reducing dependence on the grid during non-productive solar periods.

2.5 SOLAR FARMS

A solar farm is a large-scale solar power installation used to generate electricity for community or utility use. In residential communities, solar farms are often designed as shared energy resources, allowing participants to access clean energy without the need for individual rooftop installations.

1. **Utility-Scale Solar Farms:** These are typically large and contribute electricity directly to the grid.
2. **Community Solar Farms:** Smaller in scale, these solar farms serve specific communities. They are advantageous for people who do not have suitable roofs for solar panels or cannot afford individual installations. Members either own a share of the solar farm or subscribe to a portion of its energy output (World Energy, 2024).

2.6 ECONOMIC VIABILITY OF SOLAR FARMS

The economic viability of solar farms is influenced by factors such as capital cost, operational expenses, government subsidies, and community ownership models.

1. **Capital and Installation Costs:** The cost of acquiring solar panels, inverters, batteries, and other equipment constitutes the major part of the investment in a solar farm. The decreasing cost of PV panels and improvements in inverter and battery technology have been making solar farms increasingly viable (Muhammad et al., 2021).
2. **Operational and Maintenance Costs:** Solar systems typically have low operational costs since they require minimal maintenance, with only periodic cleaning and occasional inverter or battery replacements.

3. **Government Incentives:** Government incentives such as tax credits, rebates, and grants significantly reduce the financial burden on individuals and communities adopting solar energy. These incentives can make solar projects more affordable, enhancing their economic feasibility (World Energy, 2024).

2.7 OWNERSHIP MODELS FOR RESIDENTIAL SOLAR FARMS

Ownership models determine how solar farms are financed, owned, and managed. The three main ownership models are:

1. **Cooperative Ownership:** In this model, community members collectively own the solar farm. Each participant contributes financially and receives a proportional share of the benefits. This model fosters local engagement and distributes financial burdens across multiple households (Cranfield University, 2020).
2. **Third-Party Ownership:** Here, an external developer owns, installs, and maintains the solar farm, while community members buy the electricity generated. This model is ideal for communities that cannot afford the high initial costs (Dağtekin et al., 2022).
3. **Subscription Model:** The subscription model allows individuals to buy into the energy output of the solar farm, providing the benefits of solar energy without requiring ownership of the panels or systems. This model provides flexibility and accessibility for lower-income households (World Energy, 2024).

2.8 GOVERNMENT INCENTIVES AND POLICY SUPPORT

Government incentives are crucial in promoting residential solar farms. Examples include:

1. **Investment Tax Credits (ITC):** These credits provide tax benefits that reduce the overall cost of solar installations, significantly improving their economic attractiveness (Muhammad et al., 2021).

2. **Feed-in Tariffs (FiTs):** FiTs guarantee payments for electricity fed into the grid, ensuring a steady revenue stream for solar farm investors (Cranfield University, 2020).
3. **Net Metering:** Net metering allows solar energy producers to receive credit for excess electricity fed into the grid, further enhancing the financial returns of solar projects (World Energy, 2024).

2.9 SOLAR PV TECHNOLOGY AND HYBRID ENERGY SYSTEMS

Solar farms primarily rely on PV technology to convert sunlight into electricity. Hybrid systems that combine solar PV with other renewable sources, like wind or biomass, enhance the reliability of the power supply by mitigating the intermittency of solar energy. These systems often integrate battery storage to ensure consistent availability of power, even during periods of low solar output (Dağtekin et al., 2022).

2.10 CHALLENGES IN ADOPTING RESIDENTIAL SOLAR FARMS

The challenges to adopting solar farms in residential communities include:

1. **High Initial Costs:** The upfront capital needed for installing solar panels, inverters, and batteries can be prohibitive. Government subsidies and incentives are key to overcoming this barrier.
2. **Community Engagement:** Successful adoption requires active community involvement. A lack of awareness or misconceptions about renewable energy can hinder participation (Cranfield University, 2020).
3. **Regulatory Barriers:** Permitting requirements and grid connection issues can be obstacles. Supportive government policies are necessary to facilitate the successful implementation of community solar projects (World Energy, 2024).

2.11 REVIEW OF RELATED STUDIES

2.11.1 ECONOMIC VIABILITY OF SOLAR PV SYSTEMS

Muhammad, Saeed & Khan (2021) conducted an economic analysis of solar PV systems in urban settings, focusing on the cost-benefit dynamics for individual households. The study illustrates that the declining prices of solar panels, coupled with government incentives, make solar installations a competitive alternative to conventional grid electricity. However, the research was limited to individual household installations and did not explore community-owned solar projects or their financial sustainability.

Unlike Muhammad et al.'s focus on urban households, this research explores community solar farms—a collective approach where multiple households share a central solar system. This model is particularly suited to Nigerian residential communities, where individual solar installations may be unaffordable. By analyzing cooperative and third-party ownership models, this study addresses the long-term economic sustainability of community-based solar projects.

2.11.2 COMMUNITY OWNERSHIP AND POLICY SUPPORT

Cranfield University (2020) explored community solar projects, highlighting how ownership and government policy support have enabled widespread adoption in various European countries. The report emphasized cooperative ownership, where communities pool resources to build and maintain solar farms. While informative, this report mostly covered well-developed regions with stable government incentives and reliable grid infrastructure.

Unlike Cranfield University's focus on European regions with strong policy frameworks, this study tailors the concept of community solar ownership to Nigeria's context. Here, solar adoption faces unique challenges such as unreliable grid electricity and less consistent government support. This research proposes ownership models that can thrive even with

limited policy incentives, by focusing on community resource pooling and subscription models, allowing broader access to solar energy.

2.11.3 GOVERNMENT INCENTIVES AND FINANCIAL MODELS

Oluwole, Adewale & Balogun (2023) examined the role of government incentives in fostering solar energy development in Nigeria. Their research highlighted tax credits, rebates, and subsidies that make solar energy more financially accessible. While their work was significant, it focused primarily on the role of government in individual solar energy adoption rather than community-driven or large-scale solar projects.

In contrast to the sole reliance on government incentives discussed by Oluwole et al., this research offers alternative financial models, such as third-party ownership and subscription models. These approaches enable communities to establish solar farms without waiting for government support. By addressing the financial limitations of residents and focusing on collaborative funding models, this study makes solar energy more accessible and sustainable for low-income communities.

2.11.4 ECONOMIC VIABILITY AND PERFORMANCE OF SOLAR HOME SYSTEMS

Ali et al. (2022) conducted a detailed study on the economic viability of solar home systems (SHS) in Pakistan. The research used a questionnaire survey and structural equation modeling to assess the impact of SHS on small-scale industries. The findings indicated that SHS could significantly reduce energy costs and improve the quality of energy supply, thereby enhancing the economic performance of small enterprises. The study also emphasized the role of awareness and understanding of SHS technology in maximizing economic benefits. The study was limited to individual home systems and did not explore the potential benefits of larger-

scale solar farms. It also did not consider the broader social impacts of solar energy, such as job creation and community engagement.

This study will expand on Ali et al.'s work by examining the economic viability of large-scale solar farms rather than individual home systems. By focusing on community-wide solar farms, this research will explore the potential for greater economies of scale and shared infrastructure costs, leading to more significant economic benefits. Additionally, the study will incorporate the social impact of solar farms, including job creation, community engagement, and local economic development. By addressing these broader factors, the research will provide a more comprehensive understanding of the benefits of solar farms beyond just financial returns.

2.12 SUMMARY OF SIMILAR WORKS

Previous research has successfully highlighted the potential of solar energy in various contexts, from urban and rural households to community-level projects. However, these studies often lack a focus on community-driven solar farms, the role of energy storage, and tailored financial models that account for the unique economic and policy environment in Nigeria.

This study aims to fill these gaps by:

1. Focusing on community solar farms, rather than individual installations, making solar energy more accessible.
2. Offering alternative financial models such as third-party ownership and cooperative ownership systems, making solar energy viable even without significant government support.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter explains how we will evaluate the economic viability of solar farms in residential communities. It covers the steps we took to collect and analyze data, design the solar farm, and break down the costs involved.

First, we will look at the energy needs of residential homes through a load analysis. This helps us understand how much energy is required and when it is needed most. Next, we will design the solar farm to meet these energy needs and technical specifications for optimal performance. Additionally, we will explore the potential for selling excess energy back to the grid during off-peak periods, which can enhance the economic benefits of the solar farm.

Finally, we will provide a detailed cost breakdown, including initial setup costs and ongoing maintenance expenses. By the end of this chapter, you will have a clear understanding of our approach and the design considerations for the solar farm. This foundation is essential for interpreting the results and drawing meaningful conclusions in the following chapters.

3.1 LOAD ANALYSIS FOR RESIDENTIAL HOMES

Conducting a load analysis for residential homes involves evaluating the total electrical demand to ensure that the energy supply system can adequately meet the consumption needs of all household appliances and devices.

3.1.1 DATA COLLECTION

To accurately design a solar farm that meets the energy needs of residential communities, it is essential to conduct a thorough load analysis. This involves collecting data on the energy consumption patterns of the homes within the community. The data collection process includes:

1. **Surveys and Questionnaires:** Residents of the community were surveyed to gather information on their daily usage of various household appliances. The survey included questions about the number of appliances, their power ratings, and the average duration of use each day.
2. **Smart Meters:** Smart meters were installed in a sample of homes to monitor real-time energy consumption. These meters provided detailed data on hourly energy usage, which helped in understanding peak load times and overall consumption patterns.
3. **Historical Data Analysis:** Historical electricity bills from the past year were analyzed to determine the average monthly and daily energy consumption. This data was cross-referenced with the survey and smart meter data to ensure accuracy.
4. **Interviews with Residents:** In-depth interviews were conducted with a subset of residents to gain insights into their energy usage habits, such as seasonal variations and the impact of energy-saving measures.

3.1.2 LOAD ANALYSIS TABLE

The collected data is compiled into a load analysis table, which summarizes the average energy consumption for different types of homes.

1. **Daily Energy Consumption:** The average amount of energy used by a household each day, measured in kilowatt-hours (kWh).
2. **Monthly Energy Consumption:** The total energy consumption for a month, providing a broader view of usage patterns.
3. **Peak Load:** The highest energy demand observed during specific times of the day, which is crucial for designing the capacity of the solar farm.
4. **Power Rating:** The power rating of an appliance is the amount of electrical power it consumes when operating, measured in watts (W).

3.1.3 TYPICAL HOUSEHOLD LOADS

Here is a list of common household appliances and their average power consumption:

Table 3.1: Average Power Consumption

Appliance	Quantity per Home	Power Rating (W)	Daily Usage (hours)	Daily Energy Consumption per Home (kWh)	Total Daily Energy Consumption for 100 Homes (kWh)
LED Lights	10	10	5	0.5	50
Refrigerator	1	350	6	2.1	210
Air Conditioner	1	1104	4	4.42	442
Washing Machine	1	500	1	0.5	50
Television	2	100	4	0.8	80
Computer	1	200	4	0.8	80
Water Pump	1	1000	2	2	200
Water Heater	1	3000	1	3	300

Appliance	Quantity per Home	Power Rating (W)	Daily Usage (hours)	Daily Energy Consumption per Home (kWh)	Total Daily Energy Consumption for 100 Homes (kWh)
Miscellaneous	-	-	-	2	200
Total	-	-	-	16.12	1612

3.1.4 PEAK LOAD CALCULATION

In designing an off-grid solar farm, accurately calculating the peak load is crucial to ensure the system can meet the highest demand for electricity during the day. The peak load represents the maximum power required by all the appliances in the residential community at any given time. This calculation helps in determining the capacity of the solar panels and inverters needed to supply sufficient power during periods of highest usage.

Given that this system does not include batteries for energy storage, the peak load calculation must focus on the daytime when solar energy is available. This ensures that the solar farm can meet the energy demands during daylight hours.

The following table provides a detailed breakdown of the peak load calculation for 100 homes, considering the power rating, quantity, and simultaneous usage of various appliances. A diversity factor is applied to account for the fact that not all appliances will be used simultaneously, providing a more realistic estimate of the peak load.

Table 3.2: Peak Load

Appliance	Quantity per Home	Power Rating (W)	Simultaneous Usage (hours)	Peak Load per Home (W)	Total Peak Load for 100 Homes (kW)
Air Conditioner	1	1104	4	1104	110.4
Refrigerator	1	150	1	150	15
Water Heater	1	3000	1	3000	300
LED Lights	10	10	1	100	10
Television	2	100	1	200	20
Computer	1	200	1	200	20
Water Pump	1	1000	1	500	50
Total	-	-	-	5254	525.4

3.1.5 ASSUMPTIONS AND CONSIDERATIONS

Diversity Factor: This is the ratio of the sum of the individual maximum demands of various appliances to the maximum demand of the entire system at any given time. Not all appliances

will be used simultaneously in every home. A diversity factor of 0.7 (IEEE Standard 141, 1993) is applied to the peak load to account for this.

$$\text{Diversity Factor} = \frac{\text{Sum of Individual Maximum Demands}}{\text{Maximum Demand of the System}}$$

Efficiency Improvements: Future improvements in appliance efficiency are considered, which may reduce overall energy consumption.

3.1.6 ADJUSTED PEAK LOAD

Applying the diversity factor:

$$\text{Adjusted Peak Load per Home} = \text{Peak Load per Home} \times \text{Diversity Factor}$$

$$\text{Adjusted Peak Load per Home} = 5254 \text{ W} \times 0.7 = 3,677.8 \text{ W}$$

$$\text{Total Adjusted Peak Load for 100 Homes} = 3,677.8 \times 100 = 367.78 \text{ kW}$$

3.2 SIZING OF SOLAR FARM COMPONENTS

To select the suitable components needed for the construction of the solar farm, we have to consider some factors including energy demand, solar source and technical specification of some components.

3.2.1 SOLAR PANELS

For a solar farm, the process of sizing solar panels is somewhat similar to residential systems, but on a larger scale. Solar farms require careful planning and design to ensure they meet the energy production goals while considering the vast area available for installation, system efficiency, and potential grid integration. Here's a detailed approach for sizing solar panels in the context of a solar farm:

Solar panel Specifications

- **Rated Power:** 400 W (Watt)
- **Panel Type:** Monocrystalline
- **Efficiency:** 18% (JinkoSolar, 2023)
- **Nominal Voltage (V_{mp}):** 40 V (Volts)
- **Open-Circuit Voltage (V_{oc}):** 46 V (Volts)
- **Short-Circuit Current (I_{sc}):** 10.5 A (Amps)
- **Maximum Power Current (I_{mp}):** 10 A (Amps)
- **Operating Temperature:** -40°C to +85°C

Sizing Calculation:

To determine the number of solar panels required, we need to calculate the total energy demand and then divide it by the energy output of a single panel.

Total Energy Demand:

From the load analysis, the total daily energy consumption for 100 homes is 1612 kWh.

Assuming an average of 5 peak sun hours per day (NASA POWER, 2023), the total energy demand per day from the table is 1612 kWh.

Energy Output per Panel:

For this study, we are using 400 W solar panels with an efficiency of 18%.

$$\text{Energy output per panel per day} = 400 \text{ W} \times 5 \text{ hours} = 2 \text{ kWh.}$$

Number of Panels Required:

To determine the number of panels needed for the solar farm, divide the total daily energy output demand by the energy output per panel.

$$\text{Number of Panels} = \frac{\text{Total Energy Demand (kWh/day)}}{\text{Energy Output per Panel (kWh/day)}}$$

$$\text{Number of Panels} = \frac{1612}{2}$$

$$\text{Number of Panels} = 806 \text{ panels}$$

Type and Efficiency:

Type: Monocrystalline panels are chosen for their higher efficiency and longer lifespan typically between 25 to 30 years.

Efficiency: The panels have an efficiency of 18%, which is suitable for the available space and sunlight conditions.

3.3.2 INVERTERS

Inverters are essential devices in solar power systems that convert direct current (DC) electricity generated by solar panels into alternating current (AC) electricity. Most household appliances and the electric grid operate on AC, making inverters crucial for usable power.

Sizing of the Inverter

For our solar farm design, we have chosen to use a central inverter due to its capability to handle large-scale power efficiently. The process involves determining the necessary inverter size based on the total load requirement of 367.78 kW. Given typical inverter efficiency (around 98%) and accounting for system oversizing (a factor between 1.2 and 1.3), we estimate the DC power requirement. The calculated inverter size would be approximately 300 kW. This

selection ensures optimal performance, reliability, and compatibility with high DC input voltages typical for central inverters used in large solar installations.

Determine Total DC Power Output:

The total DC power from the solar array will be greater than the total AC power needed to meet the 367.78 kW load. This is because of the inefficiencies in the power conversion process and the need to oversize the system to ensure optimal performance during variable sunlight conditions.

- **Total AC Load:** 367.78 kW (This is the AC power that the inverter needs to deliver to the grid or system)
- **Inverter Efficiency:** Central inverters typically have efficiencies around 98-99%. We will use 98% (SMA Solar Technology, 2023-) efficiency.

$$P_{dc} = \frac{P_{ac}}{\text{Inverter Efficiency}} = \frac{367.78 \text{ kW}}{0.98} \approx 375.0 \text{ kW}$$

The total DC power required from the solar array is approximately 375 kW.

Apply the Oversizing Factor:

Solar arrays are typically oversized by 1.2 to 1.3 times (Fraunhofer ISE, 2021) the inverter rating to account for inefficiencies, fluctuations in sunlight, and the fact that the inverter can't handle peak power continuously.

- **Oversizing Factor:** 1.2 to 1.3 (typical for central inverters)

If we use an oversizing factor of 1.2:

$$P_{dc} = \frac{375.0 \text{ kW}}{1.2} = 312.5 \text{ kW}$$

Thus, the inverter size should be able to accommodate a DC input power of 312 kW.

Choosing the Inverter:

- Central inverters are typically available in sizes ranging from 250 kW to 500 kW or higher, so you could choose an inverter in this range based on available models.
- A 400 kVA central inverter is an ideal choice for this load.

Voltage and Current Considerations:

- **Input Voltage:** Central inverters typically operate with input DC voltages in the range of 600V to 1500V. The voltage output of the solar panels should match the input voltage range of the inverter.

3.2.3 PROTECTION DEVICES

Overcurrent Protection: Overcurrent protection devices, such as fuses and circuit breakers, are essential to protect the system from excessive currents that can cause damage. When calculating protection devices for a solar farm, we focus on selecting appropriate circuit breakers, fuses, and disconnects to ensure the safety of the solar array, inverters, and other electrical components

Sizing Calculation:

Given:

- **Number of Panels:** 806
- **Power per Panel:** 400 W
- **Panel Voltage:** 40 V (Assumed typical for high-power solar panels)

Total Array Power (DC) = 806 panels \times 400 W = 322,400 W = 322.4 kW

To find the DC current:

- For a system voltage of 600 V (common for large systems):

$$\text{Total DC Current} = \frac{\text{Total Array Power}}{\text{System Voltage}}$$

$$\text{Total DC Current} = \frac{322.4 \text{ kW}}{600 \text{ V}} = 537.33 \text{ A}$$

Inverter AC Output Current

If the inverter output is 367.78 kW at peak load and it operates at 400 V AC:

$$\text{AC Current} = \frac{\text{Power Output}}{\text{Voltage} \times \text{Power Factor}}$$

Assuming a power factor of 0.9 (typical for inverters):

$$\text{AC Current} = \frac{367.78 \text{ kW}}{400\text{V} \times 0.9} = 1,019.36 \text{ A}$$

Protection Device Sizing

- **Circuit Breaker Sizing:**
 - Circuit breakers are typically sized at 125% of the maximum current (NEC 240.4(B)) to prevent nuisance tripping.
 - For the DC side:

$$\text{Breaker Size} = \text{Total DC} \times 1.25$$

$$\text{Breaker Size} = 537.33\text{A} \times 1.25 = 671.66 \text{ A}$$

- A 700 A DC breaker would be selected.
- For the AC side:

$$\text{Breaker Size} = \text{Total AC} \times 1.25$$

$$\text{Breaker Size} = 1,019.39 \text{ A} \times 1.25 = 1,274.24 \text{ A}$$

- A 1,300 A AC breaker would be appropriate.
- **Fuse Sizing:**
 - Fuses should be sized between 125% and 150% of the maximum current (NEC 240.4(B)).
 - For the DC array:

$$\text{Fuse Size} = \text{Total DC} \times 1.25$$

$$\text{Fuse Size} = 537.33\text{A} \times 1.5 = 806 \text{ A}$$

- Use an 800 A DC fuse.
- For the AC output:

$$\text{Fuse Size} = \text{Total AC} \times 1.25$$

$$\text{Fuse Size} = 1,019.39 \text{ A} \times 1.5 = 1,529 \text{ A}$$

- Use a 1,500 A AC fuse.

Surge Protection: Surge protection devices (SPDs) are used to protect the system from voltage spikes caused by lightning or other transient events.

- SPDs are essential to protect against lightning and transient over-voltages.
- For DC, select SPDs rated at least 20% higher (IEC 61643-31) than the open-circuit voltage (V_{oc}) of the solar array.
- For AC, use SPDs with a voltage rating matching the inverter output voltage (e.g., 400 V) (IEC 61643-11).

3.2.4 OTHER COMPONENTS

Mounting Systems:

- **Ground-Mounted Systems:** Suitable for large-scale installations, providing flexibility in panel orientation and spacing.

Tracking Systems: Single-axis trackers can be considered to increase energy capture by following the sun's movement.

Wiring and Connectors:

- **Wiring:** High-quality, weather-resistant wiring is essential for durability and safety.
- **Connectors:** MC4 connectors are commonly used for their reliability and ease of installation.

Monitoring Systems:

- **Performance Monitoring:** Real-time monitoring systems to track the performance of the solar farm, detect issues, and optimize maintenance.
- **Energy Management:** Systems to manage the distribution of generated power and integration with the grid

3.3 DETAILED COST BREAKDOWN

A comprehensive cost breakdown is essential to evaluate the economic viability of the solar farm. This section will cover the component costs, operational and maintenance costs, financing costs, and potential revenue streams. For this study the exchange rate is pegged at ₦1700/\$1 and the prices were sourced from Alibaba.

3.3.1 COMPONENT COSTS

Table 3.3: Component Costs

Component	Specification	Unit Price (USD)	Unit Price (NGN)	Quantity	Total Cost (NGN)
Monocrystalline Solar Panels	400W, 40V Nominal Voltage, 18% Efficiency	\$250	₦425,000	806	₦342,650,000
Central Inverter	400 kVA, 98% Efficiency, AC Output 400V	\$12,000	₦20,400,000	1	₦20,400,000
DC Circuit Breakers	Overcurrent Protection for DC Circuits	\$150	₦255,000	10	₦2,550,000
AC Circuit Breakers	Overcurrent Protection for AC Circuits	\$200	₦340,000	4	₦1,360,000
Surge Protection Devices	Protection Against Voltage Spikes	\$500	₦850,000	5	₦4,250,000
Fuses (DC & AC)	Protection for Individual String and AC Protection	\$30	₦51,000	20	₦1,020,000
Isolation Switches	For Disconnecting Systems During Faults or Maintenance	\$350	₦595,000	3	₦1,785,000
Ground Fault Protection	Detects Ground Faults in the System	\$2,000	₦3,400,000	1	₦3,400,000
Overvoltage Protection	Prevents System Damage from Overvoltage	\$300	₦510,000	5	₦2,550,000

Component	Specification	Unit Price (USD)	Unit Price (NGN)	Quantity	Total Cost (NGN)
	Monitors System Faults				
Monitoring Relays	(Overcurrent, Ground, Earth Faults)	\$400	₦680,000	4	₦2,720,000
Disconnecting Switches (AC/DC)	Used to Isolate Sections of the System	\$600	₦1,020,000	3	₦3,060,000
Inverter Output Cables	35 mm ² to 70 mm ² Copper Cables, rated for 600V to 1000V AC	0.65	1,105	500 meters	552,500
Panel to Inverter DC Cables	4 mm ² to 6 mm ² Copper, Rated for 400V to 1500V DC, Short Distance	0.50	850	3000 meters	2,550,000
Earthing and Grounding Cables	6 mm ² to 10 mm ² Copper Cables for Grounding	0.35	595	500 meters	297,500
DC Combiner Boxes	Combines multiple DC circuits, with MC4 connectors	150	255,000	5	1,275,000
AC Distribution Panels	Distribution Panels with Circuit Breakers and	2,000	3,400,000	2	6,800,000

Component	Specification	Unit Price (USD)	Unit Price (NGN)	Quantity	Total Cost (NGN)
	Fuses for Grid Connection				
Total					397,220,000

3.3.2 LABOR COST ESTIMATION

Table 3.4: Labor Cost Estimation

Labor Activity	Description	Total Cost (NGN)
Project Management	Overseeing project execution	2,000,000
Site Preparation	Clearing land, excavation, and leveling	1,750,000
Panel Installation	Mounting and connecting solar panels	1,500,000
Inverter Installation	Installing inverters and electrical connections	900,000
Wiring and Cabling	Laying and connecting cables	1,000,000
Electrical Testing & Commissioning	Testing system performance	700,000
Civil Works	Construction of foundations and structures	1,800,000

Labor Activity	Description	Total Cost (NGN)
Supervision and Quality Control	Monitoring labor and quality standards	825,000
Miscellaneous Labor Costs	Additional unforeseen labor costs	500,000
Total Labor Cost		10,975,000

3.3.3 LAND ACQUISITION AND SITE PREPARATION

Table 3.5: Land Acquisition and Site Preparation

Component	Specification	Unit Price (USD)	Unit Price (NGN)	Quantity	Total Cost (NGN)
Land Acquisition	50,000 m ² Land for Solar Farm Site	\$10,000	₦17,000,000	1	₦17,000,000
Site Preparation	Includes clearing, grading, and leveling land	\$5,000	₦8,500,000	1	₦8,500,000
Total Land Cost					₦25,500,000

3.3.4 OPERATION AND MAINTENANCE (O&M) COSTS (ANNUAL)

Table 3.6: Operation and Maintenance Cost

Cost Item	Specification	Unit Price (USD)	Unit Price (NGN)	Quantity	Total Cost (NGN)
Annual O&M Costs	Includes cleaning, monitoring, and system checks	\$1,000	₦1,700,000	1	₦1,700,000
Total O&M Costs					₦17,000,000

3.3.5 TOTAL PROJECT COST SUMMARY (IN NAIRA)

Table 3.7: Total Project Cost

Item	Total Cost (NGN)
Component Cost	₦397,220,000
Labour Cost	₦10,975,000
Land & Site Preparation	₦25,500,000
Total Project Cost	₦433,695,000

3.4 FINANCING COSTS

For the financing of the project the 100 households are to make equal contributions towards its construction

Total cost of project = ₦432,920,000

Number of household = 100

$$\text{Amount per household} = \frac{\text{₦}433,695,000}{100} = \text{₦}4,336,950$$

This means that each household is to make a contribution of ₦4,336,950

3.4.1 REVENUE ESTIMATION FROM ENERGY SALES (ANNUAL)

To calculate the revenue gotten from selling electricity back to the grid, we need to first get the amount of excess energy

Daily consumption for the 100 household = 1,612kWh

Inverter size = 400kVA (Power factor of 0.9)

$$\text{Maximum Active Power (kW)} = 400 \times 0.9 = 360\text{kW}$$

Total Energy Generated by the Solar System

Assuming the solar farm is designed to match the inverter's maximum capacity for optimal usage:

$$\text{Daily Energy Generation} = 360\text{kW} \times 5\text{hours} = 1,800\text{kWh}$$

Surplus Energy for Export

Surplus Energy that can be sold back to the grid, using band A tariff of ₦225/kWh (Nigerian Electricity Regulatory Commission (NERC), 2024):

$$\text{Surplus Energy} = \text{Daily Generation} - \text{Daily Consumption}$$

$$\text{Surplus Energy} = 1,800\text{kWh} - 1,612\text{kWh} = 188\text{kWh}$$

$$\text{Annual Export} = 188\text{kWh/day} \times 365\text{days} = 68,620\text{kWh}$$

$$\text{Annual Revenue} = 68,620\text{kWh} \times \text{₦}225/\text{kWh} = \text{₦}15,439,500/\text{year}$$

3.4.2 ANNUAL REVENUE

Table 3.8: Annual Revenue

Revenue Stream	Specification	Surplus Energy (kWh)	Unit Price (NGN)	Duration	Total Revenue (NGN)
Energy Sales	Energy generated at ₦225 per kWh	188	₦225	1 year	₦15,439,500
Total Annual Revenue					₦15,439,500

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the results of the analysis conducted to evaluate the economic viability of implementing a solar farm for a community of 100 households compared to reliance on grid electricity. The findings are derived from the solar farm's design, energy production capabilities, cost structure, and comparison to the current electricity tariff system. The results highlight the potential benefits, challenges, and financial feasibility of transitioning to renewable energy for the estate (Ali et al., 2022). The analysis considers the following key aspects:

1. **Energy Generation:** The solar farm, equipped with 806 panels each rated at 400 W, is designed to produce approximately 1,612 kWh daily. This matches the estate's daily energy consumption while generating surplus energy of 188 kWh annually.
2. **System Design:** The proposed system includes an inverter capable of accommodating 312 kW DC input and delivering an AC output current of 1,019.36 A, ensuring efficient energy conversion and distribution.
3. **Cost Structure:** The project requires significant initial investment, including ₦397,220,000 for components, ₦10,975,000 for labor, and ₦50,000,000 for land acquisition. Annual operation and maintenance costs are estimated at ₦17,000,000. Each household is expected to contribute ₦4,336,950 toward the setup.
4. **Revenue Potential:** By selling surplus energy, the project could generate an estimated ₦15,439,500 annually, providing a financial cushion for maintenance and future upgrades.
5. **Grid Comparison:** With a grid electricity tariff of ₦225 per kWh (Band A customers, minimum of 20 hours/day), the cost of reliance on the grid significantly impacts long term affordability

This chapter also explores the environmental advantages of adopting solar energy, including reduced carbon emissions and energy independence. Additionally, the revenue potential from surplus energy sales and cost comparisons with grid electricity are discussed to establish the project's financial viability. Lastly, challenges such as high upfront costs and system maintenance are considered. Through detailed analysis and data interpretation, this chapter provides the foundation for informed decision-making regarding the estate's energy future. It concludes with recommendations for optimizing the solar farm's efficiency and economic returns.

4.1 ENERGY GENERATION ANALYSIS

The solar farm's energy production capabilities were analyzed to determine its adequacy in meeting the estate's daily energy consumption of 1,612 kWh. The design of the farm features 806 solar panels, each with a power rating of 400 W and an estimated energy output of 2 kWh per panel daily. This configuration allows the farm to generate approximately 1,612 kWh daily, matching the community's needs.

4.1.1 DAILY ENERGY PRODUCTION VS. CONSUMPTION

With a daily energy output of 1,612 kWh, the solar farm can fully support the energy requirements of the 100 households without relying on external power sources. On days with optimal sunlight, the system may even generate surplus energy of 188 kWh annually, which could be stored or sold back to the grid to provide additional revenue.

4.1.2 SEASONAL AND DAILY VARIATIONS

Solar energy production is influenced by weather conditions and seasonal changes. During periods of prolonged sunlight, such as the dry season, energy generation is expected to surpass daily consumption, creating a buffer for cloudy or rainy days. Conversely, production may dip during the wet season due to reduced sunlight exposure.

The farm's design, including an inverter capable of handling a 312 kW DC input power, ensures that the system operates efficiently even under fluctuating conditions. The estimated AC output current of 1,019.36 A indicates sufficient capacity to handle peak demand periods, typically occurring in the mornings and evenings when household energy use is highest.

By achieving parity between production and consumption, the solar farm eliminates the community's dependency on the national grid during optimal conditions while reducing overall energy costs. The surplus energy generation also provides an opportunity to enhance financial returns through energy sales.

4.2 COST-BENEFIT ANALYSIS

The financial viability of the solar farm was evaluated by comparing the costs of implementation and maintenance against the potential savings and revenue generation over its lifespan.

4.2.1 INITIAL COSTS AND FUNDING

The total upfront cost for the solar farm amounts to ₦458,195,000, including ₦397,220,000 for components, ₦10,975,000 for labor, and ₦50,000,000 for land acquisition. Each household is expected to contribute ₦4,336,950 toward this investment. While the initial expense is significant, it is a one-time cost that lays the foundation for long-term energy independence.

4.2.2 ANNUAL OPERATING COSTS

The annual Operation and Maintenance (O&M) costs are estimated at ₦17,000,000, which is relatively low compared to the high and variable costs of relying on grid electricity.

4.2.3 REVENUE POTENTIAL

The farm's surplus energy generation, estimated at 188 kWh annually, can yield revenue of ₦15,439,500 based on the current electricity tariff of ₦225 per kWh for Band A customers. While this revenue is modest, it can offset a portion of the O&M costs.

4.2.4 PAYBACK PERIOD

To calculate the payback period:

1. Total upfront cost = ₦458,195,000
2. Annual savings from avoiding grid tariffs = ₦123,151,060 (1,612 kWh/day × 365 days × ₦209.50/kWh)
3. Net annual savings (after O&M) = ₦106,151,060 (₦123,151,060 - ₦17,000,000)

The payback period is approximately 4.32 years (₦458,195,000 ÷ ₦106,151,060), indicating that the solar farm will recoup its initial investment within five years of operation.

4.2.5 LIFETIME SAVINGS

Over the system's expected lifespan of 25 years, the community stands to save approximately ₦2,378,776,500 (net annual savings × 25 years). This figure excludes any potential increases in grid electricity tariffs, which would further enhance the farm's financial attractiveness.

4.2.6 COST PER KWH COMPARISON

The solar farm offers a significantly lower long-term cost per kWh compared to grid electricity:

- Solar Cost per kWh: Total 25-year costs (including O&M) divided by lifetime energy output.
- Grid Cost per kWh: ₦209.50 per kWh as of July 2024, subject to tariff increases.

The grid's rising tariffs make the solar farm a more sustainable and economically viable option for the estate in the long run.

4.3 RELIABILITY AND MAINTENANCE

The reliability of the solar farm and its maintenance requirements are critical factors in assessing its long-term viability. This section delves into the operational resilience of the solar

farm, the associated maintenance practices, and compares its reliability to that of grid power, which is currently the primary source of energy for the community.

4.3.1 RELIABILITY OF THE SOLAR FARM

Solar farms are generally regarded as highly reliable energy systems due to their simplicity and lack of moving parts. The primary components of the proposed solar farm include 806 solar panels, an inverter capable of handling 312 kW DC input power, and other auxiliary equipment like mounting structures and electrical wiring. Each of these components is engineered for durability and designed to perform effectively over decades. Key factors contributing to the solar farm's reliability include:

1. **Panel Durability:** The solar panels are expected to operate efficiently for at least 25 years, with minimal degradation. Over time, output typically decreases by 0.5–1% annually, meaning they would still produce about 80–85% of their original capacity after 25 years.
2. **Inverter Efficiency:** The inverter plays a critical role in converting the DC power generated by the panels into usable AC power. While inverters have shorter lifespans (10–15 years) compared to panels, regular maintenance and replacement plans ensure continued operation.
3. **Energy Consistency:** By carefully designing the system to generate 1,612 kWh daily, the solar farm matches the estate's energy needs while producing an annual surplus of 188 kWh. This demonstrates that the system is robust enough to handle minor disruptions, such as brief periods of cloudy weather.

However, solar farms are weather-dependent, which means reliability can vary based on environmental conditions. For instance:

1. **Seasonal Variability:** Energy production may decline during the rainy season or on overcast days.
2. **Storage Limitations:** Without battery storage, any excess energy produced cannot be stored for later use. This may affect reliability during periods of prolonged low sunlight.

4.3.2 MAINTENANCE PRACTICES AND COSTS

The maintenance of a solar farm is straightforward compared to conventional power generation systems, but it is still essential to ensure optimal performance. The annual Operation and Maintenance (O&M) costs for the solar farm are estimated at ₦17,000,000, covering routine inspections, cleaning, and minor repairs.

Maintenance Activities:

1. **Panel Cleaning:** Dust, dirt, and bird droppings can reduce panel efficiency. Regular cleaning, especially in dry and dusty climates, is vital to maintain energy output.
2. **Inverter Servicing:** Ensuring the inverter operates within its specifications is crucial, as it is the most vulnerable component. Periodic servicing and eventual replacement are planned within the system's lifecycle.
3. **Electrical System Checks:** Inspecting wiring, connections, and protective devices ensures there are no faults or inefficiencies in energy transmission.
4. **Structural Integrity:** Regular inspections of the mounting structures protect against wear and tear caused by wind or other environmental factors.

Benefits of Proactive Maintenance:

1. Extends the lifespan of key components, particularly the inverter and panels
2. Reduces the likelihood of unexpected breakdowns, ensuring consistent power supply.
3. Keeps the system operating at peak efficiency, maximizing energy output and financial returns.

4.3.3 COMPARISON WITH GRID POWER RELIABILITY

When compared to the national grid, the solar farm offers several advantages in reliability for the estate. Grid power in Nigeria, although improving, still faces significant challenges, including:

1. **Frequent Outages:** Power interruptions remain common, even in Band A areas, where customers are promised a minimum of 20 hours of electricity per day.
2. **Voltage Fluctuations:** Irregular voltage levels can damage household appliances and lead to inefficiencies in energy use.
3. **Dependence on Fossil Fuels:** The grid is heavily reliant on gas-fired power plants, which are subject to supply disruptions, infrastructure issues, and rising costs.

By contrast, the solar farm provides:

Energy Independence: Once operational, the community becomes largely selfsufficient, relying on the grid only as a backup during prolonged low-sunlight periods.

Stable Output: Solar energy systems deliver consistent power during daylight hours, eliminating the risks of outages or fluctuations associated with grid power.

Predictable Costs: The community is shielded from fluctuating energy tariffs, which have risen significantly in recent years and are expected to continue increasing.

4.3.4 CHALLENGES IN SOLAR FARM RELIABILITY

Despite its many advantages, the solar farm is not without its challenges:

1. **Weather Dependency:** While solar farms are highly reliable in sunny climates, prolonged periods of bad weather can temporarily reduce output.
2. **Component Failures:** Inverter failures or wiring issues, though rare, can disrupt energy supply if not promptly addressed.

3. **Lack of Energy Storage:** Without a battery system, the farm cannot store excess energy for nighttime use or periods of reduced sunlight.

These challenges can be mitigated through a combination of regular maintenance, a robust grid backup plan, and potential future investments in battery storage solutions.

4.3.5 SUMMARY OF RELIABILITY AND MAINTENANCE

In conclusion, the solar farm offers a reliable and efficient energy solution for the estate, with maintenance requirements that are manageable and cost-effective compared to traditional power systems. While the solar farm's reliability is occasionally impacted by weather conditions, its overall performance and consistency far surpass the current grid's limitations.

By implementing a proactive maintenance strategy and exploring supplementary technologies like battery storage, the solar farm can sustain the estate's energy needs for decades, ensuring a stable and sustainable power supply.

4.4 IMPACT OF GRID TARIFF INCREASES

The rising cost of grid electricity significantly influences the attractiveness of solar energy systems. In recent years, grid electricity tariffs in Nigeria have shown a steady upward trend, driven by inflation, increased operational costs, and the challenges associated with maintaining the national power infrastructure.

4.4.1 SENSITIVITY ANALYSIS OF GRID ELECTRICITY PRICES OVER TIME

A sensitivity analysis reveals the potential long-term financial burden of relying on grid electricity. Assuming an average annual tariff increase of 5-10%, the cost of grid electricity could reach approximately ₦265.50 per kWh within five years and continue climbing. Such increases would amplify the cost of energy for households, making the already expensive grid power even less sustainable for many communities.

4.4.2 IMPACT ON SOLAR FARM ATTRACTIVENESS

The upward trajectory of grid tariffs directly enhances the economic appeal of the proposed solar farm. While the solar system requires a significant upfront investment, it offers stable and predictable energy costs over its 25-year lifespan. Rising grid prices shorten the payback period for the solar farm, allowing households to recover their contributions more quickly. Additionally, the ability to sell surplus energy at higher tariffs further boosts the financial returns of the project.

By insulating the community from fluctuating and escalating grid tariffs, the solar farm provides a financially viable, long-term energy solution that promotes economic stability and energy independence.

In conclusion, the analysis clearly demonstrates that transitioning to a solar farm offers substantial long-term benefits for the estate compared to continued reliance on the national grid. Despite the significant upfront costs involved in installing the solar system, including the purchase of components, labor, and land acquisition, the financial returns outweigh these initial investments within a relatively short period of time. The solar farm, with its estimated annual energy production of 1,612 kWh, meets the energy consumption needs of the 100 households and generates surplus energy, providing the potential for additional revenue from energy sales.

The operation and maintenance (O&M) costs are modest and manageable, ensuring that the farm remains cost-effective and sustainable throughout its 25-year expected lifespan. When compared to the rising cost of grid electricity, the solar farm becomes an even more attractive option, offering long-term savings by insulating the community from future tariff increases. The sensitivity analysis on grid tariff increases underscores the increasing financial burden of relying on traditional electricity sources, highlighting the significant advantage of solar energy as a fixed-cost, environmentally-friendly alternative.

Furthermore, the solar farm provides added value beyond financial savings. It contributes to the community's energy independence, reducing reliance on grid power, and offers a cleaner, more sustainable energy solution, which helps reduce carbon emissions and promotes environmental stewardship.

The key takeaway from this analysis is that the solar farm is not just a viable alternative to grid power but also an economically and environmentally prudent choice for the community's future. By making the switch to solar energy, the estate is investing in a more predictable, affordable, and sustainable energy source that can benefit both the current and future generations. The project proves that, despite the initial challenges and investment, solar energy offers a reliable, cost-effective, and impactful solution for communities seeking energy independence and long-term financial stability.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The evaluation of a solar farm designed to power 100 homes reveals a substantial initial investment, with a total cost of ₦433,695,000, translating to ₦4,336,950 per household. Despite the upfront expense, the economic benefits become evident over time, particularly through the sale of surplus energy back to the grid, which generates an annual revenue of ₦15,439,500 per year. This recurring income helps offset the installation cost and reinforces the financial feasibility of the project.

Solar farms offer a long-term, cost-effective energy solution by providing households with stable electricity prices while reducing reliance on traditional power sources, which are subject to market volatility. Over time, advancements in solar technology and declining costs of installation will make these systems even more attractive and accessible. Although the initial financial commitment may seem high, the consistent savings on energy bills and income from surplus power demonstrate that solar farms are a viable and sustainable solution for residential areas. With proper planning and support, these projects can enhance energy independence while delivering significant economic and environmental benefits for the community in the long run.

Renewable energy, particularly solar power, has become increasingly affordable due to technological advancements and declining costs of installation and maintenance. Over time, solar farms can significantly reduce energy bills for residents by providing a more stable and predictable alternative to traditional utility prices, which are often subject to market fluctuations and the rising costs of fossil fuels.

In addition to being economically beneficial, solar farms contribute to environmental conservation by reducing dependence on non-renewable energy sources and lowering greenhouse gas emissions. It also encourages local economic developments through job creation in construction, operations and maintenance. Incentives such as tax credits and energy rebates further improve the financial feasibility of solar farms, particularly in regions with strong solar potential.

While challenges like high initial investment and intermittency must be addressed, advancements in energy storage and grid infrastructure are helping to overcome these barriers. By providing a long-term, sustainable, and increasingly affordable energy source, solar farms are well-positioned to drive the transition toward greener and more self-reliant residential communities. Their adoption not only supports global sustainability goals but also delivers tangible economic and environmental benefits to local populations.

This growing affordability and scalability make solar farms an indispensable part of the future energy landscape for residential areas. With careful planning and continued innovation, they hold the potential to reshape the way communities access and utilize electric power.

5.2 RECOMMENDATION

To ensure the successful implementation and long-term sustainability of solar farms for powering residential areas, several recommendations should be considered. These steps will not only improve the economic viability of solar farms but also maximize its impact on the community and the environment.

1. **Adopt Subsidies and Financial Incentives:** Governments and private stakeholders should provide financial incentives such as tax credits, grants, or low-interest loans to reduce the burden of the initial investment on households. This support can significantly enhance affordability and encourage wider adoption of solar energy solutions.

2. **Establish Community Financing Models:** Introducing cooperative financing options, such as shared ownership or installment payment plans, can make solar farms more accessible to middle and lower income households. Community solar programs, where residents collectively own or lease the farm, can distribute costs equitably while sharing the benefits of energy savings and revenue from surplus electricity.
3. **Encourage Public-Private Partnerships:** Partnerships between local governments, private investors, and energy providers can help streamline the development of solar farms. Such collaborations can provide technical expertise, secure funding, and ensure efficient operations, leading to more robust and scalable energy solutions.
4. **Invest in Advanced Energy Storage Systems:** To address the challenge of intermittency, integrating modern battery storage technologies is crucial. Energy storage solutions enable communities to store excess power for use during night time or low-sunlight periods, ensuring a consistent energy supply and reducing reliance on the grid.
5. **Enhance Grid Infrastructure:** Local authorities and energy providers should invest in upgrading grid infrastructure to accommodate the integration of solar farms. A modernized grid will facilitate the seamless transfer of surplus energy, increasing revenue and reliability for the community.
6. **Raise Awareness and Provide Training:** Educating residents about the benefits and operation of solar farms is vital for community buy-in. Additionally, training local workers in solar farm installation and maintenance can create jobs and build a skilled workforce, ensuring long-term project sustainability.
7. **Monitor and Evaluate Performance:** Regular monitoring and evaluation of the solar farm's performance are essential to identify areas for improvement. Implementing smart monitoring systems can optimize energy production, detect faults, and reduce maintenance costs.

8. **Leverage Carbon Credits and Renewable Energy Certificates:** The project should explore opportunities to monetize environmental benefits through carbon credit trading or the sale of renewable energy certificates. This additional income can help offset costs and support future renewable energy projects in the community.

By following these recommendations, residential communities can effectively adopt solar farms as a sustainable energy solution. These measures will enhance affordability, promote energy independence, and contribute to a greener and more resilient future for all.

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