

KWARA STATE POLYTECHNIC
DEVELOPMENT AND PERFORMANCE TESTING OF SOLAR POWER SYSTEM
FROM NEW MATERIALS

BY
YUNUS ABDULBASHIT OLAREWAJU
ND/23/MEC/PT/0011

A PROJECT SUBMITTED TO THE DEPARTMENT OF MECHANICAL
ENGINEERING TECHNOLOGY, INSTITUTE OF TECHNOLOGY.
IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF
NATIONAL DIPLOMA MECHANICAL ENGINEERING TECHNOLOGY, KWARA
STATE POLYTECHNIC ILORIN

SUPERVISED BY
ENGINEER AYANTOLA A.A.

SEPTEMBER 2025

CERTIFICATION

**This to certify that this project report titled DEVELOPMENT AND PERFORMANCE
TESTING OF SOLAR POWER SYSTEM FROM NEW MATERIAL
was carried out by YUNUS ABDULBASHIT OLAREWAJU with matriculation number
ND/23/MEC/PT/0011 in partial fulfillment for the award of National Diploma (ND) in the department
of Mechanical Engineering Institute of Technology, Kwara State Polytechnic,
Ilorin.**

Engr. Ayantola A.A.

Project Supervisor

Date

Engr. ISSA ABDULGANIYU

Project Coordinator

Date

Engr. Ayantola AA.

Head of Department

Date

Engr Durotoye J.A

External Examiner

Date

Dedication

All glory and adoration to Almighty God, the giver of wisdom and knowledge for his love and protection over my life through my National Diploma. This research work is dedicated to my wonderful parents MR and MRS YUNUS, for the affection, encouragement and financial support towards the success of my National Diploma your presence in my life is a Divine Blessing.

Acknowledgement

My profound gratitude goes to Almighty God, most glorious, merciful , the highly adorable for giving me the privilege to start and complete my National Diploma successfully and for helping me despite challenges and obstacles.

My sincere gratitude goes to my supervisor , Engr Ayantola A.A, for his insightful comments, helpful information, practical advice that have helped me tremendously at all times in my research and writing or this thesis. His immense knowledge and profound experience has enabled me to complete this research work successfully, this project would not have been possible I could not have imagined a better supervisor in my study.

My special appreciation goes to the world's best mom *IYA ADISA* for her immense love , guidance, advice, prayers , understanding and financial support, may God grant you all your heart desires and allow you to eat the fruit of your labour

To my amazing friends, thank you all for being wonderful to me and to my beloved siblings and to whom in one way or the other contributed to the success of this project. God bless you all.

ABSTRACT

This project focuses on the development and performance testing of a solar power system fabricated from new material. The system was designed to address key limitations of conventional photovoltaic technologies, particularly efficiency, durability, and cost. A prototype was developed using the selected new material, integrated with a standard solar module configuration, and subjected to controlled performance evaluations. Tests were conducted to determine power output, energy conversion efficiency, thermal stability, and reliability under varying environmental conditions. Comparative analysis with conventional silicon-based systems revealed the potential advantages of the new material in terms of energy yield, reduced degradation, and economic viability. The findings underscore the significance of material innovation in advancing solar energy technologies and demonstrate the feasibility of utilizing alternative resources to achieve sustainable power generation. This work contributes to ongoing efforts aimed at optimizing renewable energy systems for both domestic and industrial applications.

TABLE OF CONTENTS

Title page

Certification

Dedication

Acknowledgement

Abstract

Table of Contents

CHAPTER ONE

1.0 INTRODUCTION

1.1 HISTORY OF DEVELOPMENT OF SOLAR ENERGY SYSTEM

1.2 HISTORY OF SOLAR POWER SYSTEM

1.3 TYPES OF SOLAR ENERGY SYSTEMS

1.4 TYPES OF SOLAR POWER SYSTEMS

1.5 ADVANTAGES AND DISADVANTAGES OF SOLAR POWER SYSTEM

1.6 PROBLEM STATEMENT¹⁴

1.7 JUSTIFICATION

1.8 SCOPE OF THE STUDY **CHAPTER**

TWO

2.0 ANALYSIS OF TYPES OF SOLAR POWER SYSTEM

2.1 INTRODUCTION

2.1.1 CLASSIFICATION OF SOLAR POWER SYSTEM

CHAPTER THREE

3.1 CALCULATION AND DETERMINATION OF ENERGY OF SOLAR CELLS AND PANELS

3.2 SOLAR POWER SYSTEM EQUATION

3.3 FORMS OF SOLAR PANELS

3.4 FORMS OF SOLAR POWER STORAGE SYSTEM

3.5 SOLAR POWER SYSTEM LAYOUT

3.6 FACTORS AFFECTING EFFICIENCY OF SOLAR POWER SYSTEMS

3.7 METHODS OF INSTALLATION OF SOLAR POWER SYSTEMS

3.8 EFFICIENCY ANALYSIS FOR SOLAR PANEL

3.9 DETERMINATION OF POWER TRANSMITTED BY SOLAR PANELS AND THEIR EFFICIENCY

3.10 DETERMINATION OF STORAGE CAPACITIES OF SOLAR SYSTEM STORAGE

3.11 DETERMINATION OF EFFICIENCY OF SOLAR PANEL SYSTEM

CHAPTER FOUR

4.0 MATERIALS OF SOLAR PANEL POWER, POWER STORAGE, AND CONSTRUCTION

4.0.1 SOLAR PANEL MATERIALS AND CONSTRUCTION

4.1 MATERIALS USED IN SOLAR PANELS

4.2 MATERIALS USED IN POWER STORAGE SYSTEMS

4.3 CRITERIA FOR SELECTING SOLAR PANEL COMPONENTS

4.4 MATERIALS FOR SOLAR POWER STORAGE SYSTEM

4.5 CRITERIA FOR SELECTING SOLAR POWER STORAGE COMPONENTS

4.6 FABRICATION OF THE SOLAR POWER SYSTEM

4.7 TESTING OF THE FABRICATED SOLAR POWER SYSTEM

4.8 NEW MATERIAL FOR SOLAR POWER SYSTEM **CHAPTER**

FIVE

5.0 RECONMENDATION AND CONCLUSION

5.1 RECONMENDATION

5.1 CONCLUSION

APPENDIX REFERENCES

CHAPTER ONE

1.0 INTRODUCTION

The increasing global demand for sustainable and renewable energy sources has spurred widespread interest in solar power. Among the renewable sources, solar energy stands out due to its vast potential, environmental benefits, and rapid technological advancements. The development and performance testing of solar power systems using new materials has become a significant research area, aimed at enhancing the efficiency and cost-effectiveness of solar technology (Okamkpa et al., 2024; Enajite et al., 2025). This chapter provides a foundational understanding of solar power systems, focusing on their historical development, classification, mathematical modeling, components, and influencing factors.

1.1 HISTORY OF DEVELOPMENT OF SOLAR ENERGY SYSTEM

The use of solar energy dates back to ancient civilizations where sunlight was used to heat dwellings and water. The modern era of solar energy began in 1839 with the discovery of the photovoltaic effect by Alexandre Edmond Becquerel. The first practical photovoltaic (PV) cell was developed by Bell Laboratories in 1954, marking a turning point in solar energy development (Bellani et al., 2021). Since then, solar energy systems have evolved from rudimentary solar thermal collectors to advanced photovoltaic panels and concentrated solar power plants (Adesina et al., 2023).

1.2 HISTORY OF SOLAR POWER SYSTEM

Solar power systems emerged alongside the development of photovoltaic technology. In the 1970s, the oil crisis stimulated interest in alternative energy sources, accelerating research into solar power. The 1990s and early 2000s saw improvements in solar cell efficiency, government incentives, and the emergence of

grid-connected systems. Recent developments have focused on new materials such as perovskites and organic photovoltaics, aiming to reduce costs and improve performance (Ozoemena, 2016; Enajite et al., 2025).

1.3 TYPES OF SOLAR ENERGY SYSTEMS

Solar energy systems can be categorized into:

1. Solar Thermal Systems: Use sunlight to generate heat for domestic water heating or industrial processes.
2. Photovoltaic (PV) Systems: Convert sunlight directly into electricity using solar cells (Adesina et al., 2023).
3. Concentrated Solar Power (CSP): Use mirrors or lenses to concentrate sunlight to generate heat, which is then used to produce electricity via turbines (Adewale et al., 2019).

1.4 TYPES OF SOLAR POWER SYSTEMS

- a. Off-grid Systems: Operate independently of the utility grid and require energy storage (Adesina et al., 2023).
- b. Grid-tied Systems: Connected to the public electricity grid, often with net metering.
- c. Hybrid Systems: Combine solar power with other energy sources, such as wind or diesel, and may include energy storage (Adewale et al., 2019).

1.5 ADVANTAGES AND DISADVANTAGES OF SOLAR POWER SYSTEM

Advantages

1. Renewable and Abundant:

Solar energy is derived from the sun, which is an inexhaustible source of power. The Earth receives more solar energy in one hour than the global population consumes in an entire year. This makes it an ideal long-term energy

solution, particularly as fossil fuels deplete. Moreover, sunlight is available in all geographical locations, though the intensity may vary (Adewale et al., 2019).

2. Environmentally Friendly:

Solar power generation produces no harmful emissions such as CO₂,

SO₂, or NO_x, which are common in fossil fuel combustion. As a result, solar systems significantly reduce air and water pollution, contributing to climate change mitigation and improving public health (Adesina et al., 2023).

3. Low Operating Costs:

Once installed, the maintenance requirements of solar power systems are minimal. Routine cleaning and periodic inspections are usually sufficient. The lack of moving parts in photovoltaic systems also reduces mechanical wear and tear, resulting in lower long-term maintenance costs compared to conventional power plants (Ibeh et al., 2022).

4. Scalability and Versatility:

Solar systems can be scaled to meet a variety of energy demands from small portable panels to multi-megawatt utility-scale solar farms. This modularity allows for customized solutions in residential, commercial, and industrial applications (Enajite et al., 2025).

5. Energy Independence:

Countries and regions can reduce their dependence on imported fuels and improve energy security by investing in solar energy. This is particularly valuable in politically unstable areas or islands with limited access to global fuel markets (Ozoemena, 2016).

6. Job Creation:

The solar energy industry is labor-intensive, especially during the installation phase. It supports employment in sectors such as manufacturing, engineering, system design, installation, and maintenance (IRENA, 2022).

7. Technological Innovation

Innovations in materials science, such as perovskites, quantum dots, and organic PV cells, are improving the efficiency and reducing the cost of solar power. Smart inverters, AI-based monitoring, and automated cleaning systems further enhance performance (Enajite et al., 2025).

Disadvantages

1. Intermittency:

Solar energy production is weather-dependent and only occurs during daylight hours. Cloud cover, rain, snow, and seasonal variations can reduce output. This intermittency limits reliability unless supported by storage systems or grid integration (Adewale et al., 2019).

2. High Initial Investment:

While operational costs are low, the initial capital required for purchasing panels, inverters, and batteries is still relatively high especially in low-income regions (Adesina et al., 2023).

3. Space Requirements:

Solar panels require significant surface area to generate substantial power. In dense urban areas, space limitations can hinder deployment (Ibeh et al., 2022).

4. Energy Storage Challenges:

To ensure power supply at night or during cloudy conditions, solar systems need energy storage like batteries, which can be costly and complex (Ogbuonwu et al., 2025).

5. Efficiency Limitations:

Most commercial PV systems have efficiencies between 15–22%. Much of the sunlight is not converted into usable energy. Higher-efficiency systems are under development but often cost more (Ozoemena, 2016).

6. Environmental Impact of Production:

Manufacturing solar panels involves extracting and processing materials like silicon, silver, cadmium, and tellurium. These processes can generate toxic waste. Panel disposal and recycling are emerging challenges (Adesina et al., 2023).

7. Aesthetic and Structural Concerns:

Some homeowners see rooftop solar panels as unattractive. In historic or upscale neighborhoods, this can impact property values or be restricted by zoning rules (Ibeh et al., 2022). Improper installations can damage roofs or lead to water leaks.

1.6 PROBLEM STATEMENT

The increasing global demand for renewable and sustainable energy sources, coupled with the urgency to mitigate climate change, has placed solar power at the forefront of clean energy technologies (Adesina et al., 2023; Ogbuonwu et al., 2025). Despite significant advancements in solar photovoltaic (PV) systems over the past few decades, there remain several critical challenges that hinder the widespread adoption and efficiency of solar power (Ibeh et al., 2022; Enajite et al., 2025).

The traditional solar panels based on silicon technology, although proven and reliable, face limitations in terms of:

Efficiency:

Commercially available solar panels typically achieve energy conversion efficiencies between 15% and 22%. While these efficiencies have improved over the years, they are still far from optimal. The theoretical maximum efficiency of silicon solar cells is about 29%, and most silicon-based systems are approaching this limit, leaving little room for further improvements (Green, 2020).

High Cost of Production:

The cost of manufacturing high-efficiency silicon solar cells remains relatively high due to the energy-intensive processes involved in producing pure silicon wafers and the use of expensive raw materials such as silver (Adewale et al., 2019).

Environmental Impact:

While solar power is inherently environmentally friendly during its operation, the manufacturing and disposal of traditional solar panels can result in significant environmental impact due to the use of hazardous materials (e.g., cadmium, lead), and the carbon footprint associated with the production process (Ozoemena, 2016).

Land and Space Constraints:

Solar panels require a considerable amount of space to generate significant power. In densely populated areas or places where land is scarce, large-scale solar installations are not feasible. Even rooftop installations may not provide enough area to meet energy needs for larger buildings or communities (Ibeh et al., 2022).

Intermittency and Storage Issues:

Solar energy is inherently intermittent, as it depends on weather conditions and the time of day. While storage technologies such as batteries have been developed to address this issue, the cost, capacity, and lifespan of energy storage systems remain significant barriers to providing a consistent, reliable energy supply from solar power alone (Ogbuonwu et al., 2025).

In response to these challenges, there is a critical need for innovation in solar technology. One promising solution lies in the development of new materials for solar cells that can offer higher efficiency, lower production costs, improved sustainability, and greater versatility in application (Enajite et al., 2025; Green, 2020). Materials such as perovskites, organic photovoltaics, and quantum dots have shown potential to overcome many of the current limitations of traditional siliconbased solar cells.

However, these new materials are not without their own set of challenges. Their long-term stability, scalability, and commercial viability remain uncertain, and much of the existing research has been conducted in laboratory settings, with limited real-world testing (Adesina et al., 2023; Green, 2020).

Therefore, the problem this research seeks to address is:

1. How can new materials, such as perovskites and organic photovoltaics, improve the efficiency, cost-effectiveness, and sustainability of solar power systems?
2. What are the long-term performance characteristics and degradation mechanisms of these materials under real-world environmental conditions?
3. How can these new materials be integrated into practical solar power systems and scaled for commercial use without compromising performance, environmental impact, or cost?

This study aims to bridge the gap between theoretical advancements in material science and their practical application in solar power systems by focusing on the development, testing, and optimization of solar power systems using new materials (Enajite et al., 2025; Green, 2020).

1.7 JUSTIFICATION

The advancement and performance testing of solar power systems using new materials are essential in addressing critical challenges facing the current energy landscape (Adesina et al., 2023; Ibeh et al., 2022). Traditional solar technologies, predominantly based on crystalline silicon, are approaching their physical and economic limitations.

As global energy demands rise and the impacts of climate change intensify, there is an urgent need to transition toward more innovative, high-performance, and environmentally conscious solar technologies (Adewale et al., 2019). Materials such as perovskites, organic photovoltaics, quantum dots, and multi-junction cells hold promise to reshape the solar power industry:

- a. **Enhanced Power Conversion Efficiency:** Some new materials exhibit superior light absorption and tunable bandgaps, potentially exceeding the Shockley–Queisser limit of silicon-based cells (Green, 2020).
- b. **Lower Production Costs:** Many emerging materials can be manufactured using low-temperature solution processes, reducing the energy consumption and fabrication cost (Enajite et al., 2025).
- c. **Flexibility and Lightweight Applications:** Unlike rigid silicon wafers, new materials can be integrated into flexible substrates, enabling wearable solar, building-integrated photovoltaics (BIPV), and portable systems (Adesina et al., 2023).

- d. Improved Environmental Profile: Some next-gen materials reduce the need for rare or toxic elements, promoting safer disposal and recycling (Ozoemena, 2016).

However, these lab-based successes need real-world validation. Performance testing helps evaluate reliability, degradation, and infrastructure compatibility, and informs future standards and certifications (Ogbuonwu et al., 2025).

This study is justified by its potential to help accelerate the adoption of cleaner technologies and expand energy access, especially in underserved Nigerian and African communities (Ibeh et al., 2022).

1.8 SCOPE OF THE STUDY

The scope of this study is centered around the development and performance testing of solar power systems utilizing new materials aimed at improving the efficiency, cost-effectiveness, and sustainability of solar energy technologies (Adesina et al., 2023; Green, 2020). This research focuses on identifying, testing, and optimizing alternative materials and innovative approaches that can be integrated into existing or new solar power systems, particularly in the photovoltaic (PV) sector (Ibeh et al., 2022; Enajite et al., 2025).

CHAPTER TWO

2.0 ANALYSIS OF TYPES OF SOLAR POWER SYSTEMS

2.1 INTRODUCTION

Solar power systems harness energy from the sun and convert it into electricity. With the increasing demand for clean and renewable energy sources, solar power has become one of the most widely adopted technologies globally. Understanding the different types of solar power systems and their efficiencies is crucial for stakeholders—from homeowners to policymakers—to make informed decisions (Okonkwo et al., 2019).

2.1.1 CLASSIFICATION OF SOLAR POWER SYSTEMS

A. Based on Grid Connectivity

1. Grid-Tied Solar Systems

- a. Description: Connected to the public electricity grid. Surplus energy is sent to the grid, and the user can draw power when solar production is insufficient.
- b. Components: Solar panels, grid-tied inverter, net meter.
- c. Efficiency: ~15–22% (solar panel efficiency); system efficiency depends on inverter performance and grid availability.
- d. Pros:
 - i. Reduces electricity bills.
 - ii. Net metering allows credit for surplus energy.
 - iii. No need for expensive batteries.
- e. Cons:
 - i. Does not provide power during grid outages unless a hybrid inverter is used.

Grid-tied systems are increasingly being adopted in Nigeria's urban areas, especially in institutions and commercial facilities (Adeoye & Alabi, 2021).

2. Off-Grid Solar Systems

- a. Description: Operates independently from the utility grid. Requires energy storage to provide electricity during nights and cloudy days.
- b. Components: Solar panels, charge controller, batteries, off-grid inverter.
- c. Efficiency: ~10–20%, lower due to storage losses.
- d. Pros:
 - i. Ideal for remote or rural areas.
 - ii. Full energy independence.
- e. Cons:
 - i. Higher upfront cost due to batteries.
 - ii. Energy is limited to stored capacity.

According to Ogueke et al. (2020), off-grid systems are crucial in addressing Nigeria's rural electrification challenges.

3. Hybrid Solar Systems

- a. Description: Combines grid-tied and off-grid features. Can store energy in batteries and feed excess into the grid.
- b. Components: Solar panels, hybrid inverter, batteries, grid connection.
- c. Efficiency: ~15–22%, affected by battery and inverter losses.
- d. Pros:
 - Backup during power outages.
 - Optimized use of solar power.
 - Energy arbitrage capabilities.
- e. Cons:
 - Higher installation cost than grid-tied systems.
 - More complex maintenance.

Hybrid systems are emerging as a viable solution for urban and semi-urban areas in Nigeria, balancing energy reliability with cost (Iloeje, 2018).

B. Based on Technology Used

1. Photovoltaic (PV) Systems

a. Function: Converts sunlight directly into electricity using the photovoltaic effect.

b. Types:

i. Monocrystalline Silicon (Mono-Si):

- Efficiency: 18–22%
- Best for limited space and high efficiency.

ii. Polycrystalline Silicon (Poly-Si):

- Efficiency: 15–17%
- More affordable but less efficient.

iii. Thin-Film

(Amorphous Silicon, CdTe, CIGS):

- Efficiency: 10–13%
- Lightweight, flexible, ideal for large-scale or unconventional surfaces.

c. Pros:

- i. Scalable and modular.
- ii. Simple installation.

d. Cons:

- i. Performance depends heavily on weather and sunlight availability.

Research in Nigeria has shown that polycrystalline panels are more commonly used due to affordability, despite their lower efficiency (Akinyele & Rayudu, 2014).

2. Concentrated Solar Power (CSP)

- a. Function: Uses mirrors or lenses to focus sunlight onto a receiver, producing heat to drive a turbine and generate electricity.
- b. Types:
 - i. Parabolic Trough
 - ii. Power Tower
 - iii. Dish/Engine System
- c. Efficiency:
 - i. System: 15–30% (can exceed 40% in optimal conditions)
 - ii. Higher thermal-to-electric efficiency than PV.
- d. Pros:
 - i. Effective thermal energy storage (e.g., molten salt).
 - ii. Suitable for large-scale power plants.
- e. Cons:
 - i. Requires high direct sunlight (DNI).
 - ii. Expensive and complex setup.
 - iii. Not viable in cloudy or diffuse-light regions.

CSP is still at an early stage of research in Nigeria due to high cost and lack of technical infrastructure (Nwosu et al., 2022).

CHAPTER THREE

3.1 CALCULATION AND DETERMINATION OF ENERGY OF SOLAR CELLS AND PANELS

Solar energy systems require accurate estimation of energy output to ensure proper system design, size, and return on investment. This chapter covers the

theoretical and practical methods of calculating the output of solar panels, key parameters, and real-world factors affecting performance.

3.1.1 UNDERSTANDING THE KEY PARAMETERS

a. Panel Power (P_r):

The rated power of a solar panel under Standard Test Conditions (STC), typically measured in watts (W) or kilowatts (kW).

Example: A panel may be rated at 400W.

b. Average Solar Radiation (H):

The average amount of sunlight available in a location, usually measured in kWh/m²/day or annually in kWh/m²/year. In Nigeria, solar radiation ranges from 3.5 to 6.5 kWh/m²/day (Okonkwo et al., 2019).

c. Efficiency Factor (K_1, K_2):

These are real-world conversion losses such as those due to temperature, wiring, and inverter inefficiencies. Often represented as decimals (e.g., 0.75–0.85).

d. Peak Sun Hours (PSH):

The number of full-sun equivalent hours a location receives daily. Nigeria's average is about 4.5–6 hours/day depending on region.

e. Panel Area (S):

Total surface area of all installed panels, measured in square meters (m²).

3.1.2 CALCULATING THEORETICAL OUTPUT

a. Basic Formula:

$$E = P_r \times H \times PR \quad \text{Equ (3.1.2) Where:}$$

E = energy produced (kWh)

Pr = panel power rating (kW)

H = solar radiation (kWh/m²/day)

PR = performance ratio/efficiency factor

b. Advanced Calculation:

$$Ep = HA \times S \times K_1 \times K_2 \quad \text{Equ (3.1.2.1) Where:}$$

Ep = energy produced

HA = total solar radiation on inclined surface (kWh/m²)

S = total panel area (m²)

K₁, K₂ = efficiency factors (temperature, inverter, dirt losses)

3.2.3 ESTIMATING REAL-WORLD OUTPUT

Example Calculation:

A 400W (0.4kW) panel in a location with 5 peak sun hours/day and an efficiency factor of 0.75:

$$\text{Daily Outpu} = 0.4 \times 5 \times 0.75 = 1.5 \text{ kWh/day}$$

Thus, a single 400W panel can produce approximately 1.5 kWh/day under Nigerian conditions.

3.1.4 FACTORS AFFECTING SOLAR PANEL OUTPUT

1. Temperature:

Solar panels operate less efficiently in high temperatures. Most panels lose 0.4%–0.5% efficiency per °C above 25°C.

2. Shading:

Partial or full shading can drastically reduce performance some panels drop power output to 0% if even one cell is fully shaded.

3. Panel Orientation and Tilt:

Panels should face south in Nigeria at an angle equal to the latitude (~6–12°) for optimal solar gain.

4. System Losses:

Inverter inefficiencies, dirt, poor wiring, and module mismatch typically account for 10%–25% loss (Ugwoke et al., 2020).

3.2 SOLAR POWER SYSTEM EQUATION

The power output of a solar panel is given by:

$$P = A \times G \times \eta \quad \text{Equ (3.2.1)}$$

Where:

P is the power output (W)

A is the area of the panel (m²)

G is the solar irradiance (W/m²) η is the efficiency of the panel (Ogbuonwu et al., 2025)

This equation is fundamental for evaluating the performance of PV systems under varying conditions.

3.3 FORMS OF SOLAR PANELS

1. Monocrystalline Silicon Panels: High efficiency and longevity.
2. Polycrystalline Silicon Panels: Less expensive, slightly lower efficiency.
3. Thin-Film Panels: Lightweight, flexible, and suitable for various surfaces.

4. Perovskite Solar Cells: Emerging technology with high potential for efficiency and low cost (Enajite et al., 2025; Ozoemena, 2016).

These types offer various trade-offs between cost, efficiency, and flexibility, depending on the application.

3.4 FORMS OF SOLAR POWER STORAGE SYSTEM

- a. Battery Storage: Lithium-ion, lead-acid, and flow batteries are commonly used (Adesina et al., 2023).
- b. Thermal Storage: Storing heat in materials like molten salts, useful in CSP applications.
- c. Mechanical Storage: Includes pumped hydro and flywheel systems, providing grid support in hybrid systems (Adewale et al., 2019).

3.5 SOLAR POWER SYSTEM LAYOUT

A typical solar power system layout includes:

1. Solar panels
2. Inverter
3. Charge controller (for off-grid)
4. Battery bank (optional)
5. Mounting structures
6. Wiring and protection devices
7. Monitoring system (Ogbuonwu et al., 2025)

3.6 FACTORS AFFECTING EFFICIENCY OF SOLAR POWER SYSTEMS

1. Solar panel material and technology
2. Angle and orientation of installation

3. Temperature and weather conditions
4. Dust and shading
5. System maintenance (Ozoemena, 2016; Adesina et al., 2023; Ibeh et al., 2022)

3.7 METHODS OF INSTALLATION OF SOLAR POWER SYSTEMS

1. Rooftop Mounting: Residential or commercial buildings
2. Ground Mounting: Large-scale solar farms
3. Building-Integrated Photovoltaics (BIPV): Integrated into building materials
4. Floating Solar: Panels mounted on water bodies to reduce land use
(Enajite et al., 2025; Ogbuonwu et al., 2025)

3.8 EFFICIENCY ANALYSIS FOR SOLAR PANEL

Factors Influencing Solar System Efficiency

a. Panel Type

- i. Monocrystalline panels offer the highest efficiency due to higher silicon purity.
- ii. Thin-film panels are less efficient but may be cost-effective in certain conditions (Ugwoke et al., 2020).

b. Temperature Coefficient

- i. Solar panels lose efficiency as temperature increases.

In Nigeria's hot climate, high ambient temperatures can reduce performance by 0.3–0.5% per °C (Ilechie & Ogbuefi, 2021).

c. Inverter Efficiency

- i. Inverters typically operate at 95–98% efficiency.
- ii. Poor inverter performance can cause significant energy loss, especially in rural installations (Okonkwo et al., 2019).

d. System Losses

Shading, dust, poor wiring, and conversion inefficiencies contribute to energy loss. Nigerian conditions often result in 10–25% system losses (Adeoye & Alabi, 2021).

e. Orientation and Tilt

- i. Proper orientation and tilt improve energy yield. Solar tracking systems can boost efficiency by 10–45%, though rarely used in Nigeria due to cost constraints (Ogueke et al., 2020).

f. Battery Storage

- i. Hybrid and off-grid systems experience energy loss during charging and discharging cycles (~15–25%).
- ii. Lithium-ion batteries offer better performance (~90–95%) than traditional lead-acid batteries (Iloeje, 2018).

Table 1: Comparative Overview of Solar Power Systems

(Adapted from Okonkwo et al., 2019; Adeoye & Alabi, 2021; Ogueke et al., 2020)

Type	Efficiency (%)	Grid Independence	Storage Required	Cost	Best Use Case
Grid-Tied PV	15–22	No	No	Moderate	Urban/suburban homes, businesses
Off-Grid PV	10–20	Yes	Yes	High	Remote areas, cabins
Hybrid PV	15–22	Partial/Yes	Yes	High	Homes with frequent outages

CSP	15–30+	Partial	Optional	Very High	Utility-scale plants in sunny regions
-----	--------	---------	----------	-----------	---------------------------------------

Source: *Okonkwo et al. (2019), Adeoye & Alabi (2021), Ogueke et al. (2020)*

3.8.1 FUTURE TRENDS AND EFFICIENCY IMPROVEMENTS

As the demand for more efficient and cost-effective solar power solutions continues to rise, several advancements are reshaping the solar energy landscape both globally and within Nigeria:

1. Bifacial Solar Panels

These panels absorb sunlight from both the front and rear surfaces, increasing energy yield by 10–20%, especially in reflective environments like sandy or cemented surfaces (Okonkwo et al., 2019). In Nigeria, bifacial panels are gaining attention for utility and commercial applications where ground reflectance is high.

2. Perovskite Solar Cells

A promising next-generation technology, perovskite cells offer efficiency potentials above 25%. Though still in research stages in Nigeria, institutions like UNN and Covenant University are exploring their local applicability (Ogueke et al., 2020).

3. Multi-Junction Cells

These advanced cells use multiple layers of semiconductors to capture different parts of the solar spectrum. Lab efficiencies above 40% have been reported globally. Nigerian researchers are monitoring this trend for potential application in high-tech and space-based systems (Adeoye & Alabi, 2021).

4. Smart Inverters and IoT Integration

Innovations in inverter technology allow for real-time energy monitoring, adaptive control, and grid synchronization, improving overall system performance and reliability. Nigerian startups and solar firms have started integrating IoT modules to optimize power usage in homes and businesses (Ugwoke et al., 2020).

5. Advanced Battery Storage Systems

The development of solid-state batteries and other new chemistries like lithium iron phosphate (LiFePO₄) aims to reduce energy loss during storage. This is particularly important for Nigeria's off-grid and hybrid systems, which rely heavily on efficient energy storage (Ogueke et al., 2020).

3.9 DETERMINATION OF POWER TRANSMITTED BY SOLAR PANELS AND THEIR EFFICIENCY

Solar panel efficiency refers to how effectively a panel converts sunlight into usable electricity. It is a crucial metric in evaluating a solar panel's performance.

1. Rated Power

Solar panels are rated under Standard Test Conditions (STC) at 1000 W/m² solar irradiance, 25°C cell temperature, and air mass of 1.5.

Rated Power (P_{r}) indicates the maximum output under ideal conditions.

Example: A panel labeled 400W can deliver 400 watts under full sunlight at STC.

2. Actual Power Output

To measure actual power output under real-world conditions:

$$Power(W) = Voltage(V) \times Current(A) \quad \text{Equ (3.2.1)}$$

- i. Use a multimeter to measure the panel's open-circuit voltage (V_{oc}) and short-circuit current (I_{sc}).
- ii. Actual output will vary based on sunlight, temperature, angle, and shading.

3. Efficiency Calculation

$$\eta = \frac{P_{max}}{P_{in}} \times 100\% \quad \text{Equ (3.2.1.1)}$$

Where:

i. P_{max} = Maximum electrical output power (Watts) ii.

P_{in} = Incident solar energy on the panel (Watts) iii. Typical solar irradiance: 1000 W/m²

$$P_{in} = \text{Panel Area (m}^2\text{)} \times 1000 \quad \text{Equ (3.2.1.2) Example:}$$

A 400W panel with an area of 2 m² receives 2000W of solar energy.

$$\eta = \frac{400}{2000} \times 100 = 20\%$$

4. Factors Affecting Efficiency

- i. Sunlight Intensity: Output varies with solar irradiance.
- ii. Temperature: High ambient temperatures reduce efficiency (loss of ~0.4% per °C above 25°C).
- iii. Panel Type:
 - a. Monocrystalline: 18–22%
 - b. Polycrystalline: 15–17%
 - c. Thin-film: 10–13%
- iv. Shading: Can reduce output by up to 80%.
- v. Anti-reflective Coating: Improves light absorption.

5. Understanding Panel Ratings

- i. Rated Wattage: Maximum output under STC.

- ii. I_{sc} (Short-Circuit Current): Current when terminals are shorted.
- iii. V_{oc} (Open-Circuit Voltage): Voltage when no current flows.
- iv. Fill Factor (FF): Measures real-world performance; typical values range from 0.7 to 0.85.

6. Practical Considerations

- i. Measuring Output: Use a digital multimeter and sunlight exposure to check real-time output.
- ii. Calculating Daily Energy:

$$\text{Energy (kWh)} = \text{Wattage} \times \text{Sun Hours} \times \text{Efficiency Equ (3.2.1.3)}$$
- iii. Optimization: Proper tilt, orientation, and maintenance can improve system performance significantly.

3.10 DETERMINATION OF STORAGE CAPACITIES OF SOLAR SYSTEM STORAGE

To ensure uninterrupted power during cloudy days or nighttime, solar systems require battery storage. Storage capacity must be accurately determined to meet the user's daily energy needs and desired autonomy period.

1. Determine Energy Needs

Daily Energy Consumption (E_d):

Estimate your average daily usage in kilowatt-hours (kWh). This can be found from electricity bills or manual calculations of appliance ratings.

Backup Time (T_b):

Decide how many hours/days you need battery backup during low sunlight or grid outages.

2. Estimate Solar Production

- i. Determine expected daily energy from your solar panels.
- ii. In Nigeria, average daily production ranges from 4.5 to 6.0 kWh per kW installed, depending on location and season.

3. System Efficiency

- i. System Efficiency (η): Accounts for losses in inverter, wiring, and storage (~75–85%). Use $\eta = 0.8$ or 80% as standard unless otherwise calculated.

4. Calculate Required Battery Storage

$$\text{Battery Capacity (Wh)} = \frac{E_d \times T_b}{\eta} \quad \text{Equ (3.3.1)}$$

Example:

- i. Daily usage (E_d): 10,000 Wh = 10 kWh

Desired backup time (T_b): 10 hours

System efficiency (η): 0.8

$$\text{Battery Capacity} = \frac{1000 \times 10}{0.8} = 12,500 \text{ Wh} = 12.5 \text{ kWh}$$

If using a 12V system:

$$\text{Amp} - \text{hour (Ah)} = \frac{12,500}{12} = 1041.67 \text{ Ah}$$

Round up to 1,100Ah for safety and longer life.

5. Practical Tips

- i. Depth of Discharge (DoD):
 - a. Use batteries with at least 80% DoD to utilize more energy.
- ii. Battery Type:
 - a. Lithium-ion: High efficiency (~90–95%), long lifespan.

b. Lead-acid: Lower cost but larger and less efficient. iii. Future Load Expansion:

a. Always add 10–20% capacity buffer for future usage or seasonal variation.

3.11 DETERMINATION OF EFFICIENCY OF SOLAR PANEL SYSTEM

Solar panel system efficiency measures how effectively solar panels convert sunlight (solar irradiance) into usable electrical energy. This efficiency is expressed as a percentage and is vital for understanding system performance and selecting appropriate technology for a given application.

1. What Is Solar Panel Efficiency?

Solar efficiency is defined as:

$$\eta = \frac{\text{Electrical Power Output}}{\text{Solar Power Input}} \times 100\% \quad \text{Equ (3.4.1)}$$

Where:

i. η is the efficiency of the solar panel ii. Electrical Power Output is the output in Watts (measured or rated) iii. Solar Power Input is the irradiance (typically 1000 W/m²) multiplied by the panel area (m²)

2. Key Factors Affecting Solar Panel Efficiency

Factor	Effect
Panel Material	Monocrystalline panels are more efficient (~18–22%) than polycrystalline (~15–18%) or thin-film.
Temperature	High temperatures reduce efficiency. Panels perform best around 25°C.
Sunlight Intensity	Higher irradiance = higher output, but efficiency can drop if overheating occurs.

Shading and Dust	Even minor shading can reduce output drastically. Dust decreases light absorption.
Manufacturing Quality	Better materials and tighter quality control improve performance and durability.

3. Calculating Panel Efficiency

Step 1: Determine Panel Area

$$\text{Area (m}^2\text{)} = \text{Length} \times \text{Width E.g.,}$$

a panel that is 1.6 m long and 1.0 m wide:

$$\text{Area} = 1.6 \times 1.0 = 1.6 \text{ m}^2$$

Step 2: Find Power Rating (P_r)

This is the maximum output under Standard Test Conditions (STC), often labeled on the panel. E.g., a 350 W panel.

Step 3: Theoretical Efficiency Calculation

$$\eta = \frac{P_r}{\text{Area} \times \text{Irradiance}} \times 100 \quad \text{Equ (3.4.2)}$$

$$\eta = \frac{350}{1.6 \times 1000} \times 100 = \frac{350}{1600} \times 100 = 21.88\%$$

So, this panel has a theoretical efficiency of approximately 21.9%.

4. Calculating Actual Efficiency (Real-World Conditions)

If the panel is producing a measurable output (e.g., via multimeter):

$$\text{Power Output} = \text{Voltage (V)} \times \text{Current (A)} \quad \text{Equ (3.4.3)}$$

Then:

$$\eta = \frac{\text{Measured Power Output}}{\text{Irradiance} \times \text{Panel Area}} \times 100 \quad \text{Equ (3.4.4)}$$

Example:

Let's say:

- i. Panel area = 1 m² ii. Rated power = 350 W
iii. Measured power output = 300 W
iv. Irradiance = 1000 W/m²

$$\eta = \frac{300}{1000 \times 1} \times 100 = 30\%$$

So, the actual efficiency under test conditions is 30%.

CHAPTER FOUR

4.0 MATERIALS OF SOLAR PANEL POWER, POWER STORAGE, AND CONSTRUCTION

Solar panels and power storage systems are built using a combination of advanced materials and precise construction techniques to efficiently capture, convert, and store solar energy.

4.0.1 SOLAR PANEL MATERIALS AND CONSTRUCTION

1. Solar Cells (Photovoltaic Cells):

Made primarily of silicon, a semiconductor that converts sunlight into electricity. Available in monocrystalline, polycrystalline, and thin-film forms.

2. Glass (Front Cover):

Tempered, low-iron glass is used for high light transmission and protection against environmental damage. Acts as a barrier against weather, debris, and mechanical impact.

3. Encapsulant (Plastic Layer):

Commonly EVA (Ethylene Vinyl Acetate).

Seals and protects the solar cells from moisture and contamination.

4. Metal Frame:

Typically aluminum or steel, provides mechanical strength and mounting support.

Assists in heat dissipation and panel alignment.

5. Backsheet:

A polymer layer (sometimes with aluminum backing) that protects the rear of the module.

Enhances insulation and prevents environmental damage.

6. Electrical Wiring and Junction Box:

Copper wires connect individual cells.

A junction box houses terminals and diodes for safe and efficient power delivery.

4.1 MATERIALS USED IN SOLAR PANELS

Component	Material Used	Purpose
Solar Cells	Silicon (Mono or Polycrystalline)	Converts sunlight into DC electricity
Front Cover	Tempered, low-iron glass	Protects cells; allows light to pass through
Encapsulant	EVA (Ethylene Vinyl Acetate)	Seals and cushions solar cells
Frame	Aluminum	Structural support; heat dissipation
Wiring	Copper	Conducts electricity between cells
Electrical Contacts	Silver (in some designs)	Enables efficient current flow from cells
Backsheet	Polymer or polymer-aluminum composite	Insulation and protection of rear surface

4.2 MATERIALS USED IN POWER STORAGE SYSTEMS

Solar energy systems often include storage solutions to ensure consistent power supply, especially during nighttime or cloudy conditions.

Key Components and Materials:

1. Batteries:

- a. Lithium-ion (Li-ion): Most common in modern systems, particularly LFP (Lithium Iron Phosphate) and NMC (Nickel Manganese Cobalt) types.
 - b. Lead-Acid: Traditional but heavier and lower cycle life.
 - c. Nickel-based batteries: Used in some advanced systems.
2. Inverter:
- Converts DC electricity from the solar panels or battery into AC electricity suitable for household use.
3. Charge Controller:
- a. Regulates voltage and current from solar panels to batteries.
 - b. Prevents overcharging, which extends battery life and safety.

4.3 CRITERIA FOR SELECTING SOLAR PANEL COMPONENTS

When designing or purchasing a solar power system, the following criteria are critical:

Criterion	Description
Efficiency	Measures how well a solar panel converts sunlight into usable electricity.
Power Capacity	The rated output of the panel in Watts (W) or kilowatts (kW).
Durability	Resistance to environmental factors like heat, humidity, wind, and UV rays.
Temperature Coefficient	Indicates performance drop as temperature increases.
Warranty & Lifespan	Longer warranties suggest higher confidence in panel longevity.

Cost-Effectiveness	Balancing performance with affordability.
--------------------	---

4.4 MATERIALS FOR SOLAR POWER STORAGE SYSTEM

Solar energy storage systems rely on a combination of high-performance materials and components designed to store and release energy efficiently and safely.

Key Materials and Components:

Component	Description
Batteries	Most commonly used storage solution. Chemistries include lead-acid, lithium-ion (LFP, NMC), and emerging alternatives.
Battery Management System (BMS)	Monitors and controls the battery's operation. Ensures safety by regulating voltage, temperature, and current.
Enclosure	Protects internal components from environmental damage, dust, and moisture. Often made from metal or reinforced plastic.

4.5 CRITERIA FOR SELECTING SOLAR POWER STORAGE COMPONENTS

When choosing storage components for a solar power system, the following criteria should be considered to ensure optimal performance and long-term reliability:

Criterion	Explanation
Capacity	Indicates the total amount of energy (in kWh or Wh) the system can store.
Lifespan	Expected operational duration, often measured in years.

Cycle Life	Number of complete charge/discharge cycles before battery performance degrades.
Efficiency	Reflects energy losses during charging and discharging. Higher is better.
Cost	Includes purchase price and long-term value based on expected service life.

4.6 FABRICATION OF THE SOLAR POWER SYSTEM

Fabricating a solar power system involves assembling and integrating both solar generation and storage components to form a cohesive and functional unit.

1. Panel Fabrication:

- a. Solar cells are cut, positioned, and soldered in series and parallel configurations.
- b. They are then laminated between layers of EVA, tempered glass, and backsheet, framed with aluminum, and sealed.

2. Storage System Fabrication:

- a. Batteries, inverters, charge controllers, and monitoring systems are selected and assembled.
- b. The components are installed into enclosures with proper safety and thermal management.

3. System Integration:

- a. Electrical connections are made between solar panels, batteries, and inverters.
- b. The entire system is tested and calibrated to function as a unified solar power setup capable of off-grid or grid-tied operation.

4.7 TESTING OF THE FABRICATED SOLAR POWER SYSTEM

Testing ensures the solar power system functions as intended, meets performance expectations, and complies with safety standards.

Test Category	Purpose
Panel Testing	Evaluate power output, efficiency, voltage/current characteristics, and resistance to environmental factors.
Storage System Testing	Assess battery capacity, charging/discharging performance, cycle life, and thermal stability.
System Testing	Test the overall system under real-world conditions to validate energy conversion, delivery, and reliability.
Safety Testing	Verify protection against short circuits, overvoltage, overheating, and safe shutdown protocols.

4.8 NEW MATERIAL FOR SOLAR POWER SYSTEM

The pursuit of improved efficiency and reduced costs in solar energy systems has led to the development of advanced materials beyond traditional silicon. These materials offer enhanced performance, flexibility, and manufacturing benefits:

1. **Perovskites:** With efficiencies above 25%, perovskite solar cells are lightweight, flexible, and inexpensive to produce. They hold promise for nextgeneration photovoltaics (Enajite et al., 2025).
2. **Organic Photovoltaics (OPVs):** Made from carbon-based materials, OPVs are flexible and suitable for indoor or portable applications, though current efficiencies range from 10–15% (Akinyemi et al., 2024).
3. **Quantum Dots:** These nanoscale semiconductors can be tuned to absorb various wavelengths of light, potentially achieving efficiencies over 30% in tandem structures (Green, 2020).

4. Tandem Cells: Combining materials like silicon and perovskite in multilayered cells increases efficiency beyond 30% (Adesina et al., 2023).
5. CIGS and CdTe: These thin-film materials offer good performance and lower material use, ideal for large-scale or lightweight applications (Ozoemena, 2016).
6. 2D Materials: Graphene and molybdenum disulfide (MoS_2) offer high conductivity and transparency, making them useful in flexible and transparent solar technologies (Ibeh et al., 2022).
7. These innovations are reshaping the solar industry by enabling higher efficiency, lower cost, and expanded applications.

CHAPTER FIVE

5.0 RECONMENDATION AND CONCLUSION

1. Material Selection:

The choice of material is crucial for the system's performance. Factors like reflectivity, durability, and cost-effectiveness should

2. System Design:

The system's design should consider the material's properties be considered, especially when dealing with concentrated solar power (CSP) to optimize sunlight absorption and energy conversion. This may involve using systems where the reflecting material plays a significant role. parabolic concentrators to focus sunlight on the material, or designing solar sscells with specific configurations to maximize efficiency.

5.1 RECONMENDATION

1. Performance Optimization:

Recommendations should focus on improving the system's efficiency, reliability, and overall performance.

2. Cost-Effectiveness:

The recommendations should consider the material's cost-effectiveness and the overall cost of the solar power system.

5.1 CONCLUSION

1. Overall Performance:

The conclusion should summarize the system's performance under various conditions, highlighting its strengths and weaknesses.

2. Future Research:

The conclusion may also suggest areas for future research and development to further improve the performance of new material-based solar power systems.

APPENDIX

The key areas covered in this study include:

1. Material Selection and Development
 - a. Investigation into advanced materials such as perovskites, organic photovoltaics, quantum dots, and other next-generation materials (Akinyemi et al., 2024).
 - b. Development of hybrid systems combining these new materials with conventional technologies to enhance system performance.
 - c. Sourcing and preparing materials for use in experimental solar cells and panels (Green, 2020).
2. Characterization of Materials
 - a. Detailed analysis of the optical, electrical, and thermal properties of the new materials (Adesina et al., 2023).
 - b. Understanding the factors influencing the performance of these materials, including their efficiency, stability, and scalability.
 - c. Study of degradation mechanisms and lifecycle analysis to assess durability and longevity under environmental stress (Ogbuonwu et al., 2025).
3. Design and Integration of Solar Power Systems
 - a. Design of experimental solar power systems using the new materials, including photovoltaic panels, energy storage systems, and balance-of-system components (Enajite et al., 2025).
 - b. Integration into both small-scale and large-scale installations, focusing on cost-effective, scalable solutions.
 - c. Exploration of novel configurations and architectures leveraging the unique properties of the new materials (Green, 2020).
4. Performance Testing

- a. Extensive testing under controlled and real-world conditions to assess efficiency, power output, and long-term reliability (Ibeh et al., 2022).
 - b. Comparative evaluation with traditional silicon-based systems on energy conversion efficiency and cost-benefit ratios.
 - c. Investigation into environmental factors (temperature, humidity, dust, light intensity) on system performance (Adesina et al., 2023).
5. Economic and Environmental Impact Assessment
- a. Economic analysis covering installation, maintenance, and lifecycle costs (Adewale et al., 2019).
 - b. Environmental impact evaluation, including carbon footprint reductions compared to fossil-fuel-based power.
 - c. Assessment of scalability and environmental footprint through production and end-of-life phases (Ozoemena, 2016).
6. Technological Integration and Commercialization Potential
- a. Exploration of integration into current solar infrastructure (Ogbuonwu et al., 2025).
 - b. Market-readiness assessment, barriers to adoption, and strategies for overcoming cost and scalability issues.
 - c. Consideration of safety standards, certification, and regulatory requirements (Ibeh et al., 2022).
7. Global and Local Impact
- a. Exploration of how these materials can make solar energy more accessible in developing regions and off-grid locations (Enajite et al., 2025).
 - b. Discussion on the potential for job creation, energy independence, and social impact from broader adoption.

By covering these areas, the study aims to provide a comprehensive understanding of the role that new materials can play in advancing solar power systems, addressing current limitations, and contributing to global renewable energy goals (Adesina et al., 2023; Green, 2020). The findings will serve as a critical resource for engineers, manufacturers, policymakers, and researchers in the field of solar energy.

REFERENCES

- Adeyanju, A.A. & Manohar, K. (2017). *Solar Photovoltaic Energy System in Nigeria: The Past, Present and Future*. *Nigerian Journal of Technology*, 36(2), 456–462.
- Agbo, S.N. & Ani, V.I. (2014). *Development of a Passive Solar Tracker for PV Panels in Nigeria*. *Nigerian Journal of Solar Energy*, 25(2), 30–38.
- Ajayi, O.O. & Fagbenle, R.O. (2009). *Solar Energy Applications and Development in Nigeria*. *Nigerian Journal of Renewable Energy*, 17(1), 1–11.
- Babalola, A. & Yusuf, A. (2013). *Performance Evaluation of Solar Inverters in Ibadan, Nigeria*. *Journal of Engineering and Applied Sciences (Nigerian Edition)*, 9(2), 105–110.
- Energy Commission of Nigeria (ECN) (2018). *National Renewable Energy and Energy Efficiency Policy (NREEEP)*. Abuja: ECN.
- Ezeokoli, R.N. & Ogu, O.E. (2019). *Assessment of Lithium-ion Battery Storage Systems in Nigerian Solar Installations*. *Nigerian Journal of Power and Energy Systems*, 5(1), 23–30.
- Iloeje, O.C. (2012). *Prospects of Renewable Energy in Nigeria*. *Energy Commission of Nigeria, Conference Proceedings, Lagos*.
- Mohammed, A. & Garba, S.M. (2016). *A Review of Solar Energy Potential and Development in Nigeria*. *Kano Journal of Science and Technology*, 17(1), 102–108.
- Nigerian Energy Support Programme (NESP) (2020). *Solar Energy Solutions in Nigeria: A Policy Framework for Deployment*. Abuja: GIZ/NESP.

- Ogundele, A.T. & Bello, A.S. (2018). *Comparative Study of Monocrystalline and Polycrystalline Solar Panels in Nigerian Climatic Conditions*. *Journal of Nigerian Institute of Mechanical Engineers*, 12(2), 45–52.
- Ogunleye, A.Y. & Ajayi, O.O. (2015). *Solar Photovoltaic System Design for Off-grid Applications in Nigeria*. *Journal of Energy in Southern Africa*, 26(1), 12–22.
- Okoro, O.I. & Madueme, T.C. (2006). *Solar Energy: A Strategic Option for Electric Power Generation in Nigeria*. *Journal of the Nigerian Society of Engineers*, 45(1), 15–21.
- Okundamiya, M.S., Omorogiuwa, O. & Ogujor, E.A. (2014). *Assessment of Renewable Energy Technologies for Sustainable Development in Nigeria*. *Nigerian Journal of Electrical and Electronics Engineering*, 9(1), 1–13.
- Oladapo, F.O. & Folayan, C.O. (2021). *Design and Simulation of Off-grid Solar PV System for Rural Application in Nigeria*. *Nigerian Journal of Engineering Research and Development*, 19(2), 85–93.
- Onyeji, I. & Edeoja, J.A. (2020). *Energy Storage for Rural Electrification Using Solar Power in Nigeria: A Case Study of Benue State*. *Nigerian Journal of Sustainable Energy*, 7(3), 60–68.