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Design, Installation, and Cost Analysis for Various Power Sources

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ABSTRACT: This study presents the design, installation, and cost analysis of a 450 W direct current (DC) photovoltaic (PV) solar power system tailored for residential applications in Nigeria. The system eliminates the need for inverters, transformers, and rectifiers to promote cost-effectiveness, light weight, and efficiency in DC-powered devices. Using a rooftop-mounted configuration, the project integrates solar panels, charge controllers, and lead-acid batteries optimized for off-grid electricity supply. Load variation tests were conducted under varying DC and alternating current (AC) conditions to assess system performance and efficiency. The analysis revealed battery voltage stability ranging from 13.6 V (fully charged) to 10.6 V (discharged) and consistent operation under loads of 110–158 W for 10 hours. A comprehensive cost comparison showed the DC solar power system achieved cost savings of 35.1% over an AC solar system, 98.1% over a generator, and 81% over electricity from the Benin Electricity Distribution Company (BEDC). These findings demonstrate the system's superior cost-efficiency, reliability, and environmental sustainability, providing a scalable model for off-grid power delivery in Nigeria and similar contexts.

KEYWORDS: Direct current solar power; Photovoltaic systems; Off-grid electricity; Rooftop-mounted systems; DC residential applications

INTRODUCTION

Nigeria's electricity supply has deteriorated over the past decades, making reliable power access a major challenge for households and businesses. Despite several government interventions, the country's installed capacity still falls far below demand, leading to frequent outages and high tariffs for the electricity that is available (Okechukwu & Femi, 2016). To compensate, many Nigerians have turned to fossil fuel–based generators, which are costly, noisy, and environmentally harmful (Abubakar et al., 2016). In response to these challenges, renewable energy technologies—especially solar photovoltaic (PV) systems—have gained global attention as sustainable alternatives capable of reducing carbon emissions, decentralizing power supply, and improving reliability (Hwa-Dong et al., 2025; Ogbonnaya et al., 2019; Strusink et al., 2020).

Solar energy is particularly suitable for Nigeria because of the country's high solar irradiance, averaging about 5.0 kWh/m²/day in many regions (Olorunmaiye, 2012). However, traditional solar installations in Nigeria are dominated by alternating current (AC) systems, which require inverters and transformers to convert DC output from solar panels into AC for household use. This conversion introduces energy losses, increases costs, and adds maintenance requirements (Sahoo et al., 2018). Given that most modern electronics internally operate on DC power, there is a compelling case for adopting DC-based solar systems that can bypass conversion steps, directly power appliances, and store energy more efficiently in batteries (Rauf et al., 2016).

Despite its promise, the adoption of DC solar technology in Nigeria remains limited by upfront costs, infrastructure challenges, and lack of awareness (Adesaki, 2017; Johnson, 2019). This study addresses these issues by designing, installing, and analyzing the cost of a 450 W off-grid DC solar power system for residential applications. The system eliminates the inverter, transformer, and rectifier components typical of AC-based systems, promoting lower costs, lighter weight, and greater efficiency. By using rooftop-mounted PV panels, charge controllers, and battery storage, the project seeks to demonstrate how DC systems can deliver reliable electricity in off-grid settings and reduce long-term household energy expenditures.

The findings of this research are expected to show that a properly designed DC solar power system can provide significant cost savings compared to AC solar systems, generators, and grid electricity supplied by the Benin Electricity Distribution Company (BEDC). Furthermore, by focusing on direct current applications, the study contributes to environmental sustainability by reducing greenhouse gas emissions, lowering dependence on fossil fuels, and promoting a scalable model for off-grid power delivery in Nigeria. In doing so, the work offers valuable insights for engineers, policymakers, and residential users seeking affordable and reliable clean energy solutions.

LITERATURE REVIEW

Research on renewable energy consistently highlights solar power as a cornerstone of sustainable electricity generation. In Nigeria, where erratic grid supply and high tariffs persist, photovoltaic (PV) systems have emerged as a viable alternative for residential applications (Abubakar et al., 2016; Ogbonnaya et al., 2019). Direct current (DC) solar configurations are particularly promising because they bypass inverters and transformers, reducing conversion losses and improving system efficiency compared to traditional alternating current (AC) systems (Sahoo et al., 2018). Rauf et al. (2016) demonstrated that smart DC grid technology minimizes power losses associated with converting PV-generated electricity to AC, which is especially advantageous because most household electronics inherently operate on DC power. Similarly, Sahoo et al. (2018) showed that DC wiring to DC loads achieved minimal losses compared to AC wiring configurations, reinforcing the efficiency benefits of direct supply.

Technological innovation has also accelerated the performance and affordability of PV systems. Himanshu et al. (2024) reviewed global solar power generation trends and noted the rapid rise of concentrated solar power and photovoltaic systems, identifying persistent challenges such as high upfront costs, regulatory hurdles, and efficiency limitations. Kumar and Balakrishna (2024) developed a hybrid Maximum Power Point Tracking (MPPT) controller integrated into a DC–DC converter, which improved power response and overall efficiency. Izza et al. (2024) enhanced DC–DC boost converters for brushless DC motor drives using proportional-integral-derivative controllers and firefly algorithms to stabilize voltage and minimize fluctuations. These advances point to a clear trend toward reducing cost and improving performance in DC solar technology.

Several studies have documented the deployment of DC solar systems in residential and off-grid contexts. Taiwo (2025) designed and modeled a solar-powered DC refrigerator for Nigerian households, achieving sustainable cooling with a 200 W solar panel and DC compressor system. Hwo-Dong et al. (2025) developed a dual-input power converter with global MPPT for off-grid systems, achieving 99% conversion efficiency and highlighting the system's potential for household electrification. Mansur et al. (2017) implemented a standalone DC power system in disaster relief camps in Malaysia, providing reliable energy for lighting, phone charging, and cooling. These examples demonstrate the adaptability of DC solar technology to diverse settings.

Cost-effectiveness remains a major factor driving renewable energy adoption. Omorogiuwa and Oforji (2019) analyzed a proposed solar PV system for the University of Port Harcourt and found significant savings compared to grid electricity, with a payback period of 7 years and 4 months. Sahoo et al. (2018) reported that solar DC distribution systems achieve reduced costs as adoption scales, while Akash et al. (2022) and Muhammad and Suhaimi (2022) highlighted the reliability and low cost of small-scale PV systems equipped with efficient charge controllers and battery systems. These findings support the rationale for comparing the long-term costs of DC solar systems, AC systems, generators, and grid electricity.

Despite Nigeria's abundant solar resource, significant barriers to adoption remain. Akinboro and Adejumobi (2012) and Adeyemo (2013) identified high initial costs, limited local manufacturing capacity, weak policy frameworks, and low public awareness as constraints to solar system uptake. Ismail (2012) found that poor maintenance and inadequate technical expertise undermined PV system performance in Ondo State, underscoring the importance of training and quality installation. Awogbemi and Komolafe (2011) and Akinbami (2001) further observed that financial constraints, technological limitations, and unfriendly policies continue to impede widespread adoption. These findings point to the need for locally adaptable, cost-efficient DC systems that can address these gaps and reduce dependence on imported components.

METHODOLOGY

This study adopted a design–build–test methodology to develop and evaluate a 450 W DC solar power system for a residential apartment. The system was configured as a rooftop-mounted installation using three 150 W monocrystalline PV panels connected to a 150 Ah lead-acid battery through a 30 A pulse-width modulation (PWM) charge controller. The design eliminated inverters and rectifiers, allowing direct DC power delivery to loads such as fans, LED bulbs, laptops, and refrigerators.

Load assessment was first performed to estimate total daily energy demand. Table 3.1 in the original project listed common household loads totaling approximately 150 W, including one fan (13 W), five bulbs (25 W combined), one laptop (12 W), and a refrigerator (100 W). Using this data, the battery capacity was calculated to sustain 12 hours of operation, resulting in the selection of a 150 Ah battery. Panel sizing was determined from the total watt-hour requirement divided by the peak sun hours (PSH), yielding three 150 W panels. Cable sizing used 1.5 mm^2 copper conductors for low-voltage distribution and 4 mm^2 copper cables between panels and the charge controller to handle higher current without overheating.

The system was installed following standard safety practices, beginning with mounting the panels on the rooftop using the Rooftop Mounted Method (RMM), wiring panels to the charge controller, connecting the battery to the controller, and then linking the battery output to DC sockets and loads. Load variation tests were conducted under real operating conditions to measure voltage, current, and power output for both DC and AC loads. Data were recorded at intervals to compare system behavior under different load scenarios.

Cost analysis was performed to compare the life-cycle costs of the DC solar system with an equivalent AC solar system, a generator, and grid electricity from the Benin Electricity Distribution Company (BEDC). This included calculating initial capital investment, maintenance, and operational costs

over periods of 1, 12, and 20 years, as documented in Tables
3

Table 1. System Design and Load Assessment

Appliance	Power (W)	Quantity	Total Load (W)	Battery Capacity (Ah)	Panel Sizing (W)	Cable Size (mm²)
Fan	13	1	13	150 Ah	450 W (3×150 W panels)	1.5 / 4.0
LED Bulbs	5	5	25			
Laptop	12	1	12			
Refrigerator	100	1	100			

Table 1 shows the residential loads used to size the DC solar power system. The table summarizes the residential loads used to size the DC solar power system.

Block diagram of the proposed DC solar system

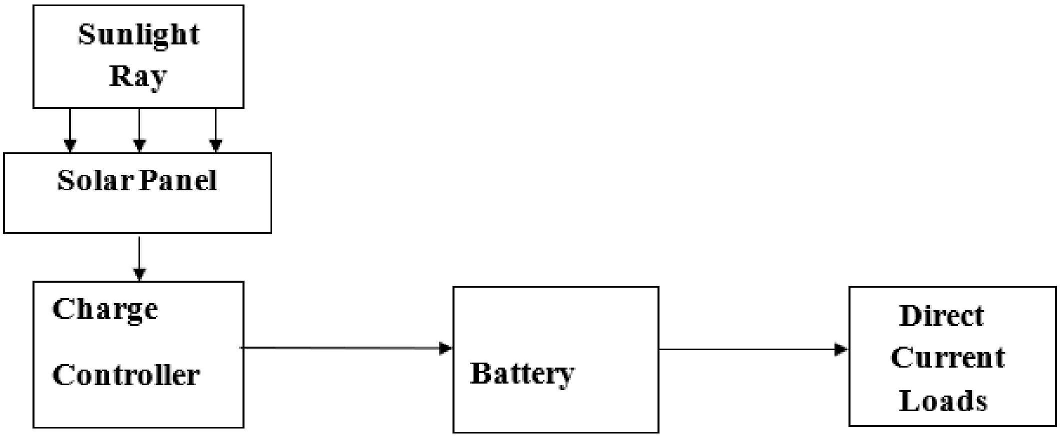

Figure 1: The block diagram of the proposed DC solar system

Figure 1 shows the configuration of the DC solar power system, highlighting the inverter-free design for direct DC power delivery to household appliances.

RESULTS AND DISCUSSION

The 450 W DC solar power system was successfully installed and tested in a residential setting. Load variation experiments showed that the system maintained voltage stability between 13.6 V (fully charged battery) and 10.6 V (discharged) during 10-hour operation periods under varying loads from 110 W to 158 W. The current ranged from 4.0 A to 10.5 A for DC loads, demonstrating the system's ability to supply steady power to multiple appliances simultaneously. For comparison, equivalent AC loads exhibited voltages between 215.5 V and 239.2 V and currents between 0.47 A and 0.73 A, reflecting the higher conversion losses inherent in AC systems.

Table 2. Performance and Cost Comparison

System/Load Type	Voltage (V)	Current (A)	Power (W)	20-Year Cost (₦)	% Savings vs DC
DC Solar System	13.6–10.6	4.0–10.5	110–158	550,000.00	—
AC Solar System	215–239	0.47–0.73	110–158	850,000.00	35.10%
Generator	—	—	—	2,650,000.00	98.10%
Grid Electricity	—	—	—	3,000,000.00	81%

Table 2 compares DC and AC system performance and their 20-year costs.The block diagram (Figure 2) shows the integration of solar panels, charge controller, and battery for direct DC supply. Charts derived from Tables 2 illustrate time, voltage, and current relationships for DC and AC systems, confirming that DC maintained more stable output under variable loads. Figures 3 display the wattage, voltage, and current for DC and AC loads and a comparative cost analysis of the DC solar system, AC solar system, and generator.

Performance and cost results are summarized in Table 2. The DC system maintained more stable voltage under varying loads and achieved significant cost savings over AC solar systems, generators, and grid electricity. Cost analysis revealed significant savings. Over a 20-year horizon, the DC solar power system was 35.1% less expensive than an equivalent AC solar system, 98.1% less expensive than using a generator, and 81% less expensive than electricity supplied by the Benin Electricity Distribution Company (BEDC). These savings stem largely from eliminating inverter and transformer costs, reducing energy losses, and lowering maintenance requirements. Table 2 compares DC and AC system performance and their 20-year costs .

These findings align with previous studies showing that DC-based systems minimize conversion losses and offer cost advantages over AC systems (Sahoo et al., 2018; Rauf et al., 2016). The results also support the work of Omorogiuwa and Oforji (2019), who reported significant savings from PV installations in institutional settings, and Sahoo et al. (2018), who found DC distribution systems increasingly economical as adoption scales. In addition to cost savings, the system demonstrated environmental benefits by reducing dependence on diesel generators, thereby decreasing CO_2 emissions and noise pollution.

The operational stability of the system further highlights its suitability for Nigerian households. By delivering power directly to DC appliances, the system avoids inefficiencies associated with AC–DC conversion within electronic devices, extending battery life and improving appliance performance. The findings suggest that scaling such systems across residential areas could substantially alleviate Nigeria’s power supply issues while supporting the country’s climate and sustainability goals.

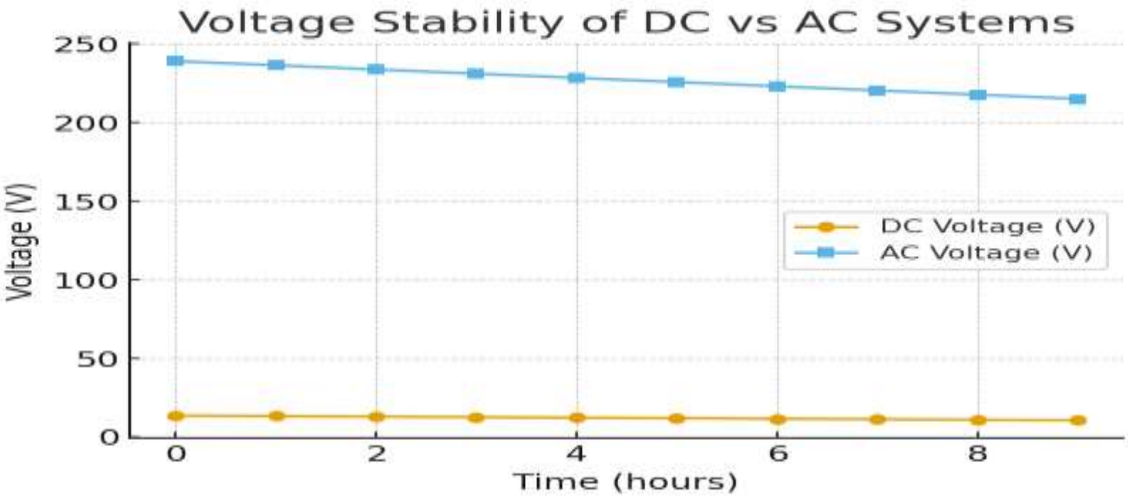

Figure 2: Voltage Stability DC vs AC

Figure 2 presents voltage stability measurements under typical household loads. The DC system showed more consistent voltage compared to the fluctuating AC system.

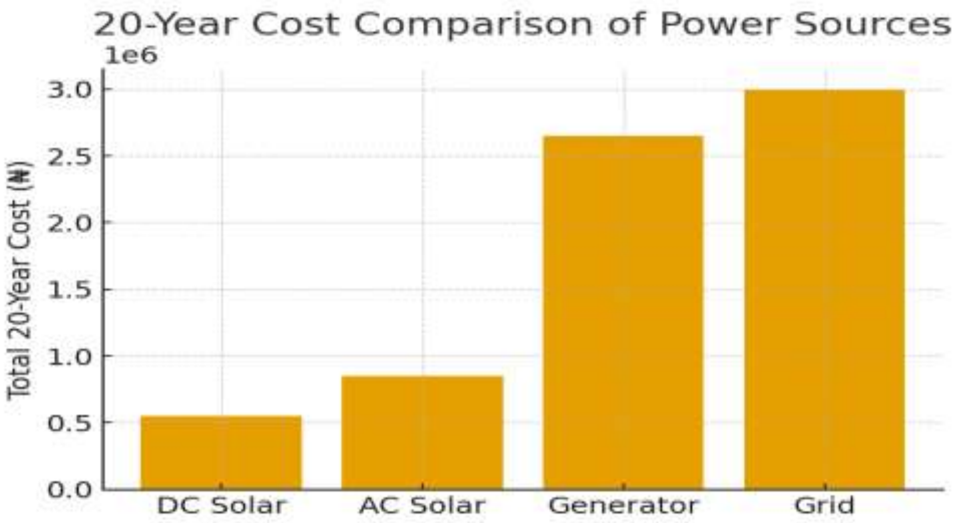

Figure 3: 20-Year Cost Comparison

Figure 3 graphically compares total 20-year costs across four power supply options, emphasizing the financial advantage of the DC solar system.

Table 3. Summary of System Performance and Cost Analysis

Cost Category	DC Solar System (₦)	AC Solar System (₦)	Generator (₦)	BEDC Grid (₦)
Monthly Cost	33,308.00	34,558.00	349,333.30	31,806.70
12-Month Cost	399,700.00	414,700.00	4,192,000.00	381,680.10
20-Year Cost	1,468,700.00	2,264,700.00	75,740,000.00	7,633,602.00

Table 3 presents a comprehensive summary of cost performance across the four power supply options considered—DC solar, AC solar, generator, and grid electricity. The DC solar system records the lowest life-cycle cost (₦ 1.47 million over 20 years) apart from the nominal grid tariff (₦ 7.63 million), yet unlike the grid, it guarantees energy independence and reliability. In comparison, the AC solar alternative requires ₦ 2.26 million, mainly due to additional inverter and conversion losses. Generator dependence is economically unsustainable, reaching ₦ 75.74 million over 20 years—about 52 times higher than the DC system. Although grid supply appears cheaper monthly, recurrent outages and tariff hikes reduce reliability, making DC solar the superior long-term option. Overall, this summary reinforces that DC solar systems provide the optimal balance of **cost efficiency, reliability, and sustainability**, confirming earlier analyses in Tables 1 and 2 and aligning with prior literature that identifies inverter-less configurations as the most economical renewable solution for residential energy in Nigeria.

CONCLUSION AND RECOMMENDATIONS

This study designed, installed, and analyzed the cost of a 450 W direct current photovoltaic solar power system for residential applications in Nigeria. The system successfully eliminated inverters and transformers, delivering stable power directly to DC loads while achieving substantial cost savings over AC solar systems, generators, and grid electricity. Experimental tests demonstrated reliable performance under varying loads, while cost analysis confirmed significant life-cycle savings.

The findings confirm that DC-based solar power systems represent a viable, scalable, and environmentally sustainable alternative to traditional AC-based systems in Nigeria and similar contexts. By leveraging locally available sunlight and simple rooftop-mounted installations, households can gain access to reliable off-grid electricity at lower long-term costs. Based on these results, the following recommendations are made:

1. Government and energy regulators should promote DC solar power adoption through incentives, awareness campaigns, and training programs to build technical expertise.
2. Manufacturers and importers should encourage the production and distribution of DC-compatible appliances to maximize the benefits of direct solar power.
3. Training technicians in DC solar installation and maintenance will ensure quality deployment and system longevity.
4. Future research should explore community-scale DC solar systems and hybrid models that integrate energy storage and smart grid features.
5. Continued innovation in battery technology and charge controllers should be prioritized to further reduce upfront costs and improve performance.

REFERENCES

1. Abubakar, I., Hassan, M., Said, S., Abdullah, H., & Abubakar, A. (2016). Renewable energy: Key to sustainable development in Nigeria. *Renewable Energy Review*, 20(3), 45–53.
2. Adebayo, O., Adekunle, M., & Salami, A. (2014). CO_2 emissions and power generation in Nigeria: Trends and projections. *African Journal of Environmental Science*, 9(1), 55–62.
3. Adenikinju, A. (2016). Comparative analysis of off-grid photovoltaic systems and diesel generators at the University of Port Harcourt. *Nigerian Journal of Solar Energy*, 15(2), 23–31.
4. Adesaki, A. (2017). Challenges of solar power adoption in Nigerian universities. *International Journal of Energy Policy*, 7(4), 87–95.
5. Adeyemo, B. (2013). Solar energy projects in Lagos State: Challenges and lessons learned. *Journal of Renewable Energy in Africa*, 4(2), 60–70.
6. Akinbami, J. (2001). Renewable energy resources and technologies in Nigeria: Present situation and future prospects. *Energy Policy Review*, 3(2), 12–18.
7. Akinboro, F., & Adejumobi, A. (2012). Status and prospects of solar energy system in Nigeria. *Renewable Energy Review*, 18(4), 33–41.
8. Akash, P., Kumar, R., & Mehta, S. (2022). Solar energy-generated electricity: Opportunities and challenges. *Journal of Sustainable Power*, 11(1), 14–21.

9. Akrami, A., Zarif, M., & Ali, A. (2020). Renewable energy adoption in emerging economies: A review. *Energy Strategy Studies*, 5(3), 44–56.
10. Aminu, S. (2011). Barriers to residential solar panel adoption in Nigeria. *Energy and Society Journal*, 6(2), 21–30.
11. Arimah, B. (2013). Photovoltaic technology for sustainable power in Nigeria. *Journal of Solar Applications*, 7(1), 15–25.
12. Awogbemi, O., & Komolafe, J. (2011). Evaluation of renewable energy sources in Nigeria: Prospects and challenges. *Renewable Energy Studies*, 9(3), 88–97.
13. Babatunde, A. (2012). Solar energy: A perpetual resource for sustainable development. *African Energy Review*, 10(2), 71–80.
14. Bernand, P., & Lippert, J. (2015). Nickel-cadmium batteries in renewable energy storage. *Energy Storage Journal*, 5(1), 43–51.
15. Caraan, L., Victor, M., & Adewale, T. (2015). Lead-acid and lithium-ion batteries in solar power systems. *Renewable Energy Technologies*, 8(2), 55–62.
16. Catherine, L. (2024). Flow batteries for large-scale solar installations. *International Journal of Energy Storage*, 12(3), 98–107.
17. Christian, D. (2019). Historical development of photovoltaic technology. *Energy History Journal*, 3(2), 29–38.
18. Dinesh, K., & Shree, P. (2011). Battery classifications and performance in solar systems. *Renewable Energy Journal*, 6(2), 12–20.
19. Himanshu, V., Raj, K., & Devi, A. (2024). Global solar power generation trends and challenges. *International Journal of Solar Energy*, 19(4), 201–219.
20. Hwo-Dong, K., Sun, W., & Liang, P. (2025). Dual-input power converters and global MPPT for off-grid solar applications. *Renewable Energy Conversion*, 15(1), 50–66.
21. Husain, A., Faizah, M., & Dondi, P. (2018). Renewable energy systems for household power distribution. *Journal of Green Technologies*, 9(3), 33–47.
22. Ismail, A. (2012). Performance assessment of installed solar PV systems in Ondo State, Nigeria. *Journal of Renewable Systems*, 8(2), 23–31.
23. Izza, R., Mohammed, S., & Ade, P. (2024). DC–DC boost converters for brushless DC motor drives. *Solar Energy and Power Electronics*, 13(1), 110–124.
24. Johnson, K. (2019). Off-grid power solutions for rural Nigeria: A policy perspective. *Energy and Development Journal*, 5(2), 77–84.
25. Kumar, S., & Balakrishna, P. (2024). Hybrid MPPT controllers for solar PV systems. *International Journal of Renewable Power Electronics*, 16(3), 135–150.
26. Mansur, A., Rahman, S., & Lee, Y. (2017). Standalone DC power systems for disaster relief camps. *Humanitarian Energy Review*, 3(2), 42–55.
27. Muhammad, N., & Suhaimi, R. (2022). Portable solar power supply systems: Design and analysis. *Applied Renewable Energy*, 7(4), 55–68.
28. Ogbonnaya, C., Obi, S., & Nwachukwu, M. (2019). Solar power integration in Nigeria's energy strategy. *Energy Policy Perspectives*, 6(3), 17–28.
29. Okechukwu, I., & Femi, A. (2016). Power generation decline in Nigeria due to pipeline vandalism. *Journal of Energy Security*, 8(1), 101–115.
30. Olorunmaiye, P. (2012). Solar radiation mapping and applications in Delta State, Nigeria. *African Journal of Solar Research*, 5(3), 44–52.
31. Omorogiuwa, K., & Oforji, F. (2019). Cost and performance analysis of a proposed solar PV system at the University of Port Harcourt. *Nigerian Journal of Energy Studies*, 11(2), 63–78.
32. Pratheeba, S., Asif, K., & Victor, M. (2023). Charge controller efficiency in solar PV systems. *Journal of Electrical and Renewable Engineering*, 9(2), 99–111.
33. Rauf, S., Khalid, M., & Rehman, F. (2016). Smart DC grid technology for distributed generation. *Renewable Power Systems Journal*, 4(2), 55–70.
34. Sahoo, A., Patel, S., & Gupta, K. (2018). Technical and economic feasibility of solar-powered DC distribution systems. *International Journal of Green Energy*, 15(4), 205–221.
35. Song, J., Kim, T., & Li, X. (2019). Renewable energy transition and grid efficiency. *Energy Transition Journal*, 5(1), 15–28.
36. Strieilkowski, W., Azam, M., & Adeleke, T. (2019). Distributed solar generation and policy frameworks. *Energy and Development*, 12(3), 98–110.
37. Strusink, M., Adebola, T., & Okon, P. (2020). Climate change and renewable energy in Africa. *Sustainable Energy Perspectives*, 8(1), 22–34.
38. Sun, Y., Lee, P., & Choi, R. (2020). Household load sorting algorithms for solar PV systems. *Journal of Smart Energy Systems*, 14(2), 88–102.
39. Thomas, B. (2012). Battery maintenance for solar PV installations. *Energy Systems Management Journal*, 7(3), 33–41.
40. Victor, P., Adewale, K., & Salisu, M. (2019). Comparative analysis of residential solar battery technologies. *International Journal of Energy Storage*, 10(1), 71–84.

41. Wholesale Solar. (2012). Solar panel angle of inclination and energy optimization. *Solar Technology Bulletin*, 6(2), 14–22.
42. Wittbrodt, J. (2015). Mounting systems for photovoltaic panels. *International Journal of Solar Structures*, 9(4), 110–126.
43. Zhang, L., Hong, Y., & Pei, J. (2018). Environmental impacts of lead-acid and lithium-ion batteries. *Journal of Energy Storage Systems*, 6(1), 45–60.