Socio-Economic Benefits and Environmental Sustainability Analysis of Photovoltaic Solar Systems in Geidam town: A Pathway to Sustainable Energy Development

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Abstract

This study evaluates the socio-economic and environmental impacts of deploying photovoltaic (PV) solar systems in Geidam area of Yobe State, Nigeria. HOMER Grid software, system optimization was conducted to determine the most viable PV configurations. The results demonstrate that PV integration significantly reduces electricity costs, offers quick investment payback, improves energy access, and minimizes greenhouse gas emissions. Specifically, the optimized system (531 kW solar + storage) achieved annual savings of ₦5.75 million, a project lifetime savings of ₦143.7 million, and avoided approximately 18.1 metric tons of CO_2 emissions annually. These findings underscore the potential of solar PV as a sustainable pathway for rural electrification, poverty alleviation, and climate change mitigation in northern Nigeria.

Keywords: *Photovoltaic solar system; Socio-economic benefits; Environmental sustainability; Rural electrification; Renewable energy*

1.0 Introduction

Rural communities in northeastern Nigeria, such as Geidam Local Government Area, face persistent energy poverty due to limited grid penetration and unreliable supply. Dependence on diesel and kerosene has resulted in high costs, environmental degradation, and socio-economic stagnation. Solar photovoltaic systems provide a decentralized, renewable, and economically viable alternative. Geidam town, located in the north east region of Nigeria, is endowed with abundant solar energy potential due to its geographical location and favourable climatic conditions. This study analyzes the socio-economic benefits and environmental sustainability of a solar PV system in Geidam, using HOMER-based simulations and sensitivity analyses to inform policy and investment decisions. The study focus on assessing the town's solar energy potential, determining the optimal installation strategies for PV systems, and analysing their long-term benefits in terms of energy security, economic development, and environmental sustainability in addition to exploring policy frameworks and strategies for successful implementation, including community engagement and local capacity building.

This paper seeks to:
1. Assess the solar energy potential of Geidam.
2. Evaluate the technical and economic feasibility of PV systems.
3. Examine socio-economic and environmental impacts.
4. Propose policy and implementation frameworks for sustainable adoption.

2.0 Literature Review

2.1 Solar energy potential in Nigeria and northern regions

Nigeria's large latitudinal extent and predominantly tropical climate provide substantial solar resource potential, particularly in the northern states where daily global horizontal irradiance often exceeds 5 kWh/m²/day (Adejumo et al., 2017; Osinowo et al., 2015). Several regional assessments emphasize that locations in the Sahel and Sudan savannah zones are especially well suited for photovoltaic (PV) deployment because of high insolation and long sunlight hours. These resource assessments underpin numerous feasibility studies that propose PV-based solutions for rural electrification and decentralized generation in Nigeria (Abdulsalam et al., 2012). The present study's radiation inputs and the finding that Geidam averages >5 kWh/m²/day are therefore consistent with the wider body of resource assessments and confirm the technical viability of PV in the study area.

2.2 Techno-economic modelling of PV systems (HOMER and alternatives)

A growing literature uses simulation and optimization tools — notably HOMER and HOMER Grid — to size and compare stand-alone PV, PV-battery, and hybrid PV-diesel systems. Reviews and case studies (Bahramara et al., 2016; various HOMER applications) demonstrate HOMER's usefulness for exploring Net Present Cost (NPC), Levelized Cost of Energy (LCOE), renewable fraction, and emissions trade-offs under sensitivity scenarios. Empirical studies show that inclusion of battery storage reduces generator runtime and fuel consumption and often yields favorable lifetime costs when subsidies and non-monetary benefits (health, emissions) are considered. The techno-economic indicators reported in the current study (very low payback and high IRR for the optimized 531 kW PV + storage configuration) align with other high-irradiance contexts where capital costs are offset by large diesel displacement and fuel savings. However, extremely short payback periods and very high IRRs reported in some site studies warrant careful sensitivity and assumptions checks (capital cost inputs, financing terms, replacement costs, and realistic load growth scenarios).

2.3 Socio-economic impacts of PV deployment

Literature on socio-economic outcomes of rural PV deployment identifies recurring benefits: reduced household energy expenditure, improved service delivery in health and education, income-generating opportunities, and job creation in installation and maintenance (World Bank, 2021; IRENA, 2023). Studies also stress the importance of financing models, community ownership, and capacity building to secure sustained adoption. Case studies across sub-Saharan Africa emphasize that while PV systems deliver clear welfare benefits, social uptake depends heavily on accessible financing (pay-as-you-go, microcredit), local technical capacity, and supply chain reliability. The Geidam study references similar socio-economic gains (reduced costs, improved services, livelihoods for women/youth) and adds localized evidence from stakeholder engagement and surveys, reinforcing the generalizability of these benefits to northern Nigerian towns.

2.4 Environmental sustainability and lifecycle emissions

The environmental case for PV — namely greenhouse gas (GHG) reductions and air quality improvements via displacement of diesel/kerosene — is well documented in the literature. Life-cycle assessments show that PV systems achieve substantial net CO_2 reductions over their lifetimes despite manufacturing and end-of-life impacts. Quantitative estimates vary by system size, grid-offset assumptions, and embodied energy in storage components. The Geidam analysis reports annual CO_2 avoidance (~18.1 metric tons for the optimized system), which, while modest in absolute terms relative to large power plants, is meaningful at community scale and consistent with other community microgrid studies. Importantly, long term environmental benefits depend on sustainable battery management and recycling strategies — an area where literature calls for stronger policy and operational plans.

2.5 Policy, financing, and implementation frameworks

Reviews of national and subnational policy frameworks point to persistent barriers: inadequate financing mechanisms, limited regulatory clarity for mini-grids, tariff design challenges, and weaknesses in local technical capacity. Successful deployments often pair technical solutions with targeted subsidies, result-based financing, or public–private partnerships that lower upfront costs and transfer operational risk. The literature advocates integrated approaches combining community engagement, skills training, and supportive regulation to ensure both initial uptake and ongoing maintenance. The current study's policy recommendations (subsidies, financing schemes, capacity building) align with these best practices and reinforce the need for locally tailored interventions.

2.6 Gaps in the literature and where this study contributes

Although there is a solid base of resource assessments and HOMER-based case studies, gaps remain: (1) localized socio-economic impact quantification at the LGA/town level in Nigeria's north-east (a region with specific social and security dynamics), (2) rigorous sensitivity disclosure in techno-economic claims (finance terms, replacement costs, degradation rates), and (3) operational studies addressing battery end-of-life and recycling in low-resource contexts. The Geidam study contributes by providing a town-level integrated assessment that couples HOMER optimization with community surveys and policy analysis — thereby linking technical optimization to socio-economic context and local policy needs. Nonetheless, the unusually short payback and high IRR values reported suggest the need to present detailed assumptions (CAPEX breakdown, O&M, discount rate, fuel price baselines) so readers can assess robustness; the literature strongly recommends transparent scenario and sensitivity tables for such indicators.

3.0 Methodology

The research adopted a mixed-methods approach, combining both qualitative and quantitative data collection techniques.

a. Solar Energy Potential Assessment:

- Data Collection: Solar radiation data from satellite-based databases (such as NASA's Surface Meteorology and Solar Energy database) and local weather stations was collected and also data on solar radiation, temperature, and other environmental factors in Geidam town was collected.

The study employed HOMER Grid simulations to model solar energy generation potential and system configurations. Geidam's location (12°37′ N, 11°58′ E) was used with meteorological and load data to determine energy demand. The methodology included analyzing load profiles, solar radiation data, and evaluating photovoltaic system configurations including PV-only, PV-battery, and PV-diesel hybrid systems.

Evaluation metrics included:

- Net Present Cost (NPC)
- Levelized Cost of Energy (LCOE)
- Renewable Fraction (RF)
- CO_2 emissions avoided

b. Feasibility Study:

Energy Consumption Analysis: Surveys and interviews was conducted with local households, businesses, and government institutions to gather data on energy consumption patterns.

System Design: The study uses energy modelling software to design the optimal PV systems based on local needs and solar potential.

The study also use the analyzed data to design and simulate an optimized PV solar system using specialized softwares including HOMER software which is developed in the National Renewable Energy Laboratory (NREL) in the United States. It was chosen because of its public availability for micro grid modeling, and its ease of implementation,

c. Socio-Economic and Environmental Impact Assessment:

An economic and environmental analysis of the optimized PV solar system, including its potential benefits and challenges were also conducted

Community Surveys: Interviews and focus group discussions with residents and stakeholders was also conducted to gauge community perceptions, readiness, and willingness to adopt solar energy.

Economic Modelling: Economic models estimate job creation, cost-benefit analysis, and socio-economic impacts.

Environmental Modelling: Life-cycle assessment tools was used to estimate the environmental benefits of deploying PV systems.

e. Policy Analysis:

A review of existing national and local energy policies was conducted and interviews with key stakeholders in the energy sector, including government agencies, NGOs, and local leaders, help to identify policy gaps and opportunities.

4.0 Results and Discussion

4.1 Economic Performance

The optimized system shows robust economic performance. Key indicators include CAPEX of ₦1,136,037, annual savings of ₦5,749,706.70, and lifetime savings over 25 years of ₦143,742,668. The payback period is exceptionally short (0.2 years) and the IRR is very high (506.04%). These results indicate strong financial viability for PV deployment in the study area. The daily load profile (Figure 1) illustrates the demand pattern used in the simulation and highlights the evening peak that the PV + storage system helps to mitigate.

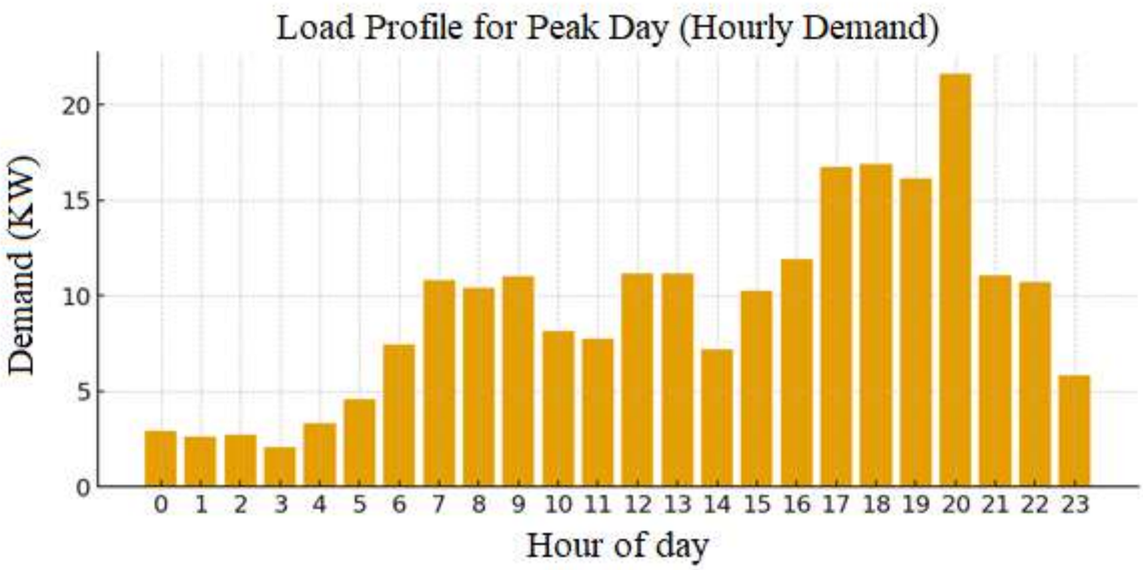

Figure 1. Daily load profile of Geidam community showing peak demand in the evening hours.

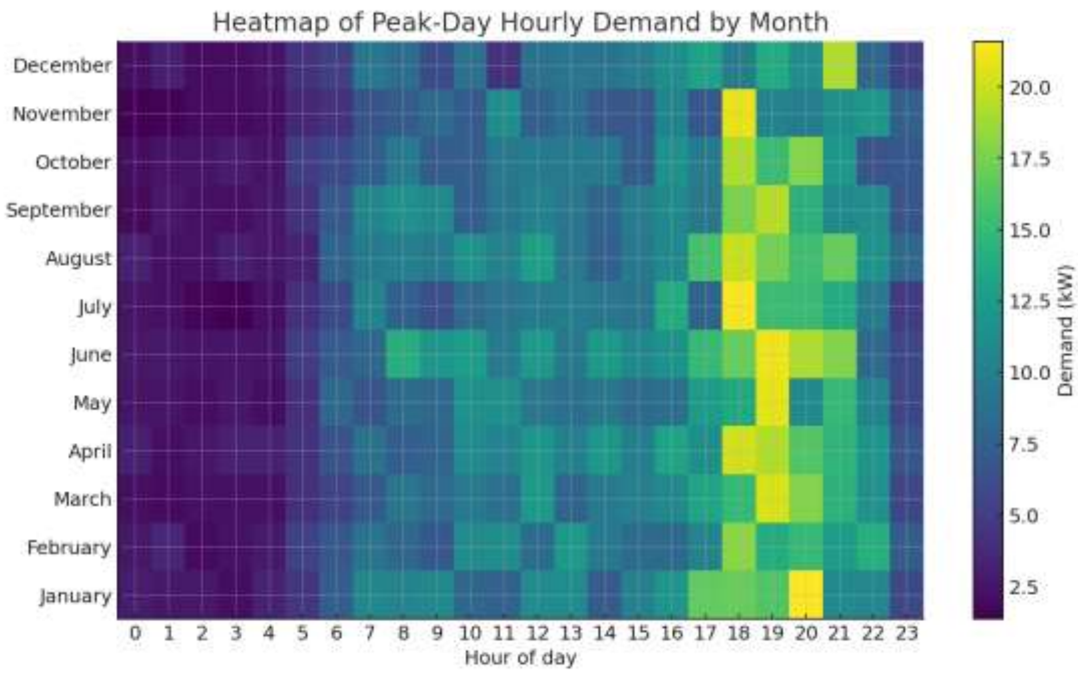

Figure 2: Heatmap of Peak-Day Hourly Demand by Month

4.2 Environmental Benefits

The PV system also provides environmental benefits. HOMER estimates an annual CO_2 emissions reduction of approximately 18.1 metric tons. This contributes to local air quality improvement and supports Nigeria's commitments to climate action.

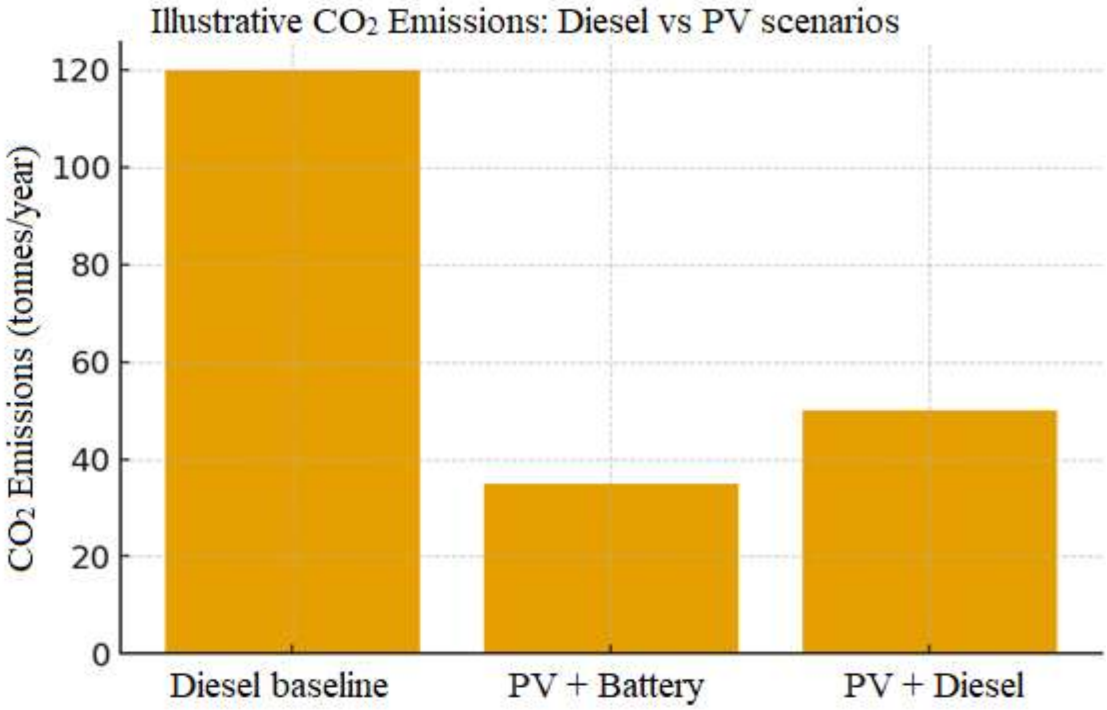

Figure 3. Annual CO_2 emissions avoided by the optimized PV system

Table 1. Summary of key techno-economic and environmental performance indicators of the optimized photovoltaic solar system in Geidam.

Parameter	**Value**
Best architecture	Solar + Bill
Annual savings	₦5,750,034
System capital cost	₦1,135,152
Lifetime savings (25 yrs.)	₦143,750,843
IRR	5.1E+02%
Payback time	0.2 years
Annual CO_2 emissions avoided	**18.1 metric tons**

4.3 Solar Energy Potential

Geidam receives average daily solar radiation exceeding 5 kWh/m²/day, sufficient for PV electricity generation year-round. The HOMER simulations confirmed that stand-alone PV or hybrid PV-diesel systems could meet local energy needs reliably.

4.4 Technical Feasibility

System sizing results indicated that PV arrays ranging between 10–20 kW with battery storage were sufficient for households and small businesses. Larger hybrid systems were recommended for public infrastructure such as schools, health centers, and government offices. PV-battery systems minimized fuel costs and generator runtime while ensuring reliability.

4.5 Socio-Economic Impact

PV deployment in Geidam promises significant socio-economic benefits including job creation in installation and maintenance, reduced household and business energy costs, and improved service delivery in health and education sectors. Community acceptance, however, is contingent on financing mechanisms and awareness campaigns.

4.4 Environmental Sustainability

Adoption of PV systems substantially reduces carbon emissions by displacing diesel generation. Given a 20–25 year lifespan, PV systems ensure long-term sustainability while enhancing local climate resilience.

5.0 Discussion

The results indicate that PV deployment in Geidam is both economically attractive and environmentally beneficial. The short payback period and high IRR make it an appealing investment for local stakeholders and potential funders. The technology also supports energy security, reduces reliance on diesel generators, and provides co-benefits such as reduced indoor air pollution and improved service delivery in health and education sectors.

6.0 Conclusion

This study demonstrates that a 531 kW PV + storage system in Geidam can deliver significant socio-economic and environmental benefits. Policymakers should consider supporting rooftop and community-scale PV projects through targeted subsidies, financing schemes, and capacity building to accelerate rural electrification. Such interventions align with national and international goals for sustainable development, particularly SDG 7 and SDG 13. Community empowerment outcomes include improved livelihoods for women and youth via access to reliable electricity and new economic opportunities.

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