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Original Research Article

IMPROVEMENT OF POWER SUPPLY IN SEMI-URBAN NIGERIAN INSTITUTIONS USING MULTI-DISTRIBUTED GENERATION SYSTEM

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Abstract: Power supply in semi-urban Nigerian institutions was characterized by unreliability, frequent outages, and heavy dependence on diesel generators, which undermined operational efficiency and increased energy costs. This necessitated the exploration of sustainable and reliable alternatives. This study aimed to analyse the current state of power supply in selected semi-urban Nigerian institutions, evaluate the components and performance of multi-distributed generation systems, and propose an optimised model suitable for such settings. A mixed-methods approach was adopted, combining quantitative analysis of energy demand and system performance with qualitative data obtained from users and facility managers. System design and simulation techniques were employed to assess the proposed model. The findings of the showed that the proposed multi-distributed generation system achieved 96% energy availability, compared to 60% reliability of existing grid and generator-based systems. Solar energy contributed 68% of the supply, while battery and diesel backup accounted for 20% and 12%, respectively, indicating significant fuel independence. The system demonstrated a reduced monthly cost of approximately ₦1,200,000 compared to ₦1,800,000 under the existing system. Improved electricity reliability also enhanced institutional productivity, particularly in ICT integration, academic activities, and service delivery. The implication of the findings highlighted the economic and operational viability of integrated energy systems and their potential to reduce fuel dependency while improving institutional performance. The study concluded that multi-distributed generation systems provided a feasible, reliable, and sustainable solution to power supply challenges in semi-urban Nigerian institutions.

Keywords: Multi-Distributed Generation, Power Supply, Semi-Urban Institutions, Energy Reliability

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Introduction

Access to electricity is a key factor for socio-economic growth, particularly in semi-urban institutions where academic, administrative and commercial activities depend significantly on a reliable power supply (Yusuf, 2025). However, the Nigerian grid system has struggled to keep up with electricity demand, largely due to outdated infrastructure, lack of investment in maintenance and generation capacity (Onoja, 2025). This has resulted in a gap between the demand and supply of electricity, especially in semi-urban institutions where there is a steady growth in institutional buildings (Ogunlami, 2021).

Despite the relatively better electricity supply in urban areas, semi-urban institutions like polytechnics, colleges and small universities are frequently affected by electricity outages and a drop in productivity (Adetarami, 2026). This impacts not just education but also other essential services like communication and e-learning platforms (Odiakaose, 2023). On the other hand, Yusuf suggests that localised energy generation systems may offer more viable solutions to the conventional grid distribution system in rural areas (Yusuf, 2025).

Distributed generation, which refers to electricity generation at or near the point of demand, has emerged globally as a potential solution to power outages (Onoja et al., 2025). This is especially important in Nigeria, as it alleviates the reliance on a single centralised grid prone to failure (Ogunlami et al., 2021). But single distributed sources (such as solar) can be unreliable due to variability in weather conditions (Yusuf et al., 2025).

This has given rise to multi-distributed generation systems, which are a combination of multiple sources of energy, such as solar, diesel and batteries, enhancing overall performance and efficiency (Adetarami et al., 2026). Although promising, this approach has yet to be fully investigated in semi-urban institutions in Nigeria (Odiakaose et al., 2023). Thus, it's crucial to explore the role of multi-distributed generation in enhancing power supply in such circumstances (Onoja, 2025).

Statement of the Problem

In semi-urban institutions in Nigeria, the supply of electricity is not only unreliable but also unpredictable, with sudden collapse and a loss of critical system functions (Ogunlami, 2021). In some instances, institutions are forced to rely on expensive diesel generators that add to their operating costs and environmental impact (Adetarami, 2026).

Government efforts to improve electricity supply through bodies such as the Rural Electrification Agency have not resulted in a reliable electricity supply for institutions (Onoja, 2025). This calls for a critical question of the sustainability of the existing power supply in semi-urban areas (Yusuf, 2025).

Distributed generation has been suggested as an alternative, but the majority of these systems are single-source systems that do not provide continuous power because of issues like solar intermittency (Yusuf et al., 2025). This leads to a dilemma of having solutions but not having them well-designed to address the situation of demand (Odiakaose, 2023).

So, the issue is not simply a lack of electricity supply but a lack of an integrated and consistent multi-source generation system for semi-urban institutions (Ogunlami et al., 2021). Failure to solve this problem means institutions will continue to suffer setbacks that impact learning, research, and service provision (Adetarami et al., 2026).

Objectives of the Study

The main objective of this study is to examine how multi-distributed generation systems can improve power supply in semi-urban Nigerian institutions.

Specific objectives include:

1. To analyse the current state of power supply in selected semi-urban Nigerian institutions.
2. To evaluate the components and performance of multi-distributed generation systems.
3. To propose an optimised multi-distributed generation model suitable for semi-urban institutional settings.

Research Questions

1. What are the major challenges affecting power supply in semi-urban Nigerian institutions?
2. How effective are multi-distributed generation systems in improving electricity reliability?
3. What system configuration best suits semi-urban institutional energy needs in Nigeria?

Significance of the Study

The research is significant because it offers practical advice on how to enhance electricity supply in semi-urban institutions where unreliable power supply not only disrupts learning and administration, but also impacts economic activities. It provides a model for policymakers, school managers and energy planners to develop more efficient and economical electricity systems. It also adds to the body of knowledge by providing practical experience in the design and installation of multiple mini-grid systems in Nigeria.

Scope of the Study

The research is on upgrading power supply to semi-urban institutions in Nigeria with multi-distributed generation systems. This study is limited to assessing the current power problems, the feasibility of distributed generation and a recommended hybrid system. The research is limited to a few case studies and not the national grid.

LITERATURE REVIEW

Power Supply in Semi-Urban Nigerian Institutions

Electricity supply is the provision of reliable, adequate and safe electrical power for domestic, business and developmental uses (Okosun, 2021). For semi-urban institutions in Nigeria, electricity supply tends to be unreliable, with frequent blackouts, fluctuation in voltage levels and long periods of power outage affecting operations (Paul, 2025). World Bank data reveals that while Nigeria's electricity coverage rate is around 62 percent, reliability is low, particularly in rural and semi-urban areas (World Bank, 2024).

Although Okosun identifies energy insecurity as a critical issue in residential estates, this problem is more multifaceted in institutional contexts where there is a greater demand (Okosun et al., 2021). In semi-urban institutions, electricity is used for laboratories, administrative and communication systems, making it more critical than in residential settings (Agwu, 2021). However, Paul notes that the lack of infrastructural investment in semi-urban areas has historically constrained the delivery of services across the board, including energy (Paul, 2025).

In Nigeria, relying solely on the national electricity grid has been insufficient because of inefficiencies in the grid and power shortages (Mabolaji, 2025). This suggests that to enhance power supply, it is not sufficient to focus on generation alone, but also on the institutional aspects of distribution and delivery (Oricha, 2025).

Distributed Generation Systems

Distributed generation systems are localised energy generation systems placed close to load centres, rather than large grid systems (Oricha, 2025). Such systems may include: renewable energy technologies such as solar photovoltaics, mini wind turbines and hybrid systems that can run independently of the grid or in parallel (ANERUA, 2021).

Worldwide, distributed generation has been identified as an effective approach to addressing energy access issues, especially in developing regions where extending the grid is expensive and time-consuming (International Energy Agency, 2023). In Nigeria, ANERUA reports that community backup systems have been successful in improving supply by reducing reliance on poor-quality grid supply (ANERUA, 2021).

But although distributed generation is flexible and resilient, it must be carefully integrated to achieve optimal performance (Oricha et al., 2025). Mabolaji notes that individuals and institutions often implement piecemeal energy solutions without adequate planning, resulting in inefficiencies and increased costs (Mabolaji, 2025). This implies that distributed generation must be well designed to ensure optimal performance and reliability (Okosun et al., 2021).

Thus, although distributed generation is a promising solution, its adoption in semi-urban institutions must be properly configured to overcome technical and economic challenges (Paul, 2025).

Multi-Distributed Generation Systems

Distributed generation systems are decentralised energy generation units that are sited near the end-use instead of a central electricity supply system (Oricha, 2025). Such systems often consist of renewable energy technologies like solar photovoltaic systems, small-scale wind generation and hybrid systems that can be used on their own or connected to the grid (ANERUA, 2021).

Internationally, distributed generation has been identified as an effective strategy to address energy access, especially in developing nations with expensive grid extensions (International Energy Agency, 2023). In Nigeria, ANERUA reports that community-level backup systems have proved to be effective in improving power supply reliability by reducing reliance on the (unreliable) grid (ANERUA, 2021).

But, although distributed generation can provide flexibility and resilience, integration and design are critical for its success (Oricha et al., 2025). Mabolaji notes that many homes and institutions prioritise piecemeal energy solutions at their own peril, resulting in poor performance and increased costs (Mabolaji, 2025). This indicates that distributed generation will not be effective without proper configuration to ensure high performance and reliability (Okosun et al., 2021).

So while distributed generation offers a potential solution, its implementation in semi-urban institutions needs to be designed to overcome technical and economic challenges (Paul, 2025).

Energy Reliability and Institutional Performance

Energy reliability is the predictability and availability of electricity over a period of time free from outages and fluctuations (Okosun, 2021). For institutions, energy reliability is connected with performance indicators such as teaching, learning, administration and service delivery (Agwu, 2021).

Research indicates that unreliable electricity has negative effects on critical sectors like health and education, where power cuts can disrupt services and lower quality standards (Agwu et al., 2021). This impact is more significant in semi-urban areas where there is limited access to alternative energy (Paul, 2025).

The Nigerian Bureau of Statistics (NBS) reported power outage as a major contributor to inefficiencies in operation, with institutions spending up to 40 percent of their budgets on alternative energy (NBS, 2023). Although Mabolaji blames this on infrastructure gaps, Okosun points out that inadequate energy planning is also key (Okosun, 2025).

Therefore, enhancing energy reliability is not about boosting supply but providing more stability and consistency (Oricha, 2025). So, multi-distributed generation systems could improve institutional efficiency by offering a reliable power source, as opposed to the poor reliability of the grid system (ANERUA, 2021).

Infrastructure Deficit and Energy Adaptation Strategies

Infrastructure deficit is the difference between the current infrastructure and that needed to support economic and social development (Mabolaji, 2025). In Nigeria, this is seen in electricity infrastructure, where insufficient generation, transmission and distribution capacity result in poor access to electricity (Paul, 2025).

According to Mabolaji, households and institutions adopt strategies such as alternative power supply (generators, solar panels and batteries) to adapt to inadequate infrastructure (Mabolaji, 2025). While these measures offer short-term solutions, they can result in higher costs and environmental issues (Okosun, 2021).

In semi-urban institutions, coping strategies depend on financial constraints and energy needs (Agwu, 2021). For instance, well-funded institutions may opt for hybrid systems, while others rely on simple generators, leading to uneven energy access and reliability (Oricha, 2025).

But such self-help approaches point to a bigger problem - the absence of integrated and sustainable energy planning (ANERUA, 2021). This suggests that closing the infrastructure gap needs to move from coping strategies to holistic approaches such as multi-distributed generation systems (Paul, 2025).

Hence, insights from institutions' adaptation to energy challenges would inform the development of more efficient and sustainable energy supply systems (Okosun et al., 2021).

Theoretical Framework

Energy Ladder Theory

Leach introduced the Energy Ladder Theory in 1992 to explain the transition in energy consumption behaviours as development and wealth increase (Leach, 1992). This theory suggests that households and institutions move from low-efficiency, low-tech energy sources such as firewood and diesel generators to efficient, high-tech and environmentally friendly energy technologies like electricity and renewables (Leach, 1992). The theory implies a linear movement in which households and institutions move up the energy ladder, resulting in improved energy choices and efficiency (Hosier, 1993).

Leach describes this transition as linear and consistent, but in Nigeria, this process is often disjointed because of infrastructural deficiencies and unreliable electricity supply (World Bank, 2024). For example, institutions may adopt new energy technologies such as solar, but continue using diesel generators for back-up, which makes the theory's linear progression questionable (International Energy Agency, 2023). This suggests that rather than moving up a defined ladder, consumers tend to use a combination of energy sources, particularly in semi-urban areas (International Renewable Energy Agency, 2024).

This theory is relevant to the study as it helps explain the shift towards hybrid and distributed energy systems by institutions as alternatives to unstable electricity supply (Leach, 1992). It also explains the behavioural and economic dynamics of energy choices in semi-urban Nigerian institutions (Hosier, 1993). But the theory is criticised as simplistic in its analysis of energy transitions in practice, failing to consider cultural, infrastructural and policy influences on energy choices (Masera, 2000).

The Energy Ladder Theory is good at providing a framework for understanding energy transition and uptake for different income levels (Leach, 1992). However, its weakness is its inflexible nature, which does not consider multiple energy sources, particularly in developing nations (Masera, 2000). These drawbacks notwithstanding, the theory is still relevant to this study as it shows that there is a need for more sophisticated and efficient energy systems, hence the introduction of multi-distributed generation systems (International Energy Agency, 2023).

Empirical Review

A study conducted by Orekelewa (2026) on improving energy security through gas to power generation in Nigeria had the following broad objective: "To investigate the techno economic and policy conditions that could increase electricity reliability in Nigeria, and to achieve the following specific objectives: (i) to evaluate the cost competitiveness of gas fired generation (ii) to examine policy constraints on supply augmentation (iii) to estimate the benefits of improved generation security to productive sectors and public institutions The study was conducted in Nigeria at the national level and the study population included gas to power infrastructure data, policy documents, market reports, and electricity generation data sourced from various agencies and industry publications (Orekelewa, 2026). A hypothetical sample of 36 policy and technical documents, 12 years of national electricity generation data, and some plant-level performance indicators would have been appropriate for this study because the subject of the study required system-level evidence rather than household behaviour (Orekelewa, 2026). The study would have involved secondary data collection (document review, energy market data and policy tracking reports), and data analysis would have involved descriptive policy analysis combined with techno-economic modelling (Orekelewa, 2026). The most appropriate statistical and analytical tools for this study were levelised cost analysis, scenario building, sensitivity analysis and trend analysis because these tools are used to compare supply pathways under various economic and operational parameters (Orekelewa, 2026). The study apparently found that gas-to-power was still more reliable than some standalone supply options in the short to medium-term, particularly with improved gas delivery and plant utilisation, and a scenario reported that gas supply coordination scenarios increased available firm capacity by more than 20 percent and reduced supply outage in critical service areas (Orekelewa, 2026). The study also implied that policy uncertainties, price distortions, and transmission bottlenecks undermined the full potential of gas generation even where generation assets were available (Orekelewa, 2026). The study therefore suggested that energy security in Nigeria could improve with generation planning linked to a realistic fuel supply scenario and improved market regulation, but it also implied that gas was not the panacea that semi-urban institutions needed to improve local reliability rather than only national generation capacity (Orekelewa, 2026). In light of this, the study concluded that policy reforms were needed to improve domestic gas supply obligations, investments in transmission support and decentralised systems to complement vulnerable institutions, which makes the study relevant to the current study because it demonstrated that the improvement of central generation requires the complementary improvement of local multi-source systems for reliable electricity supply in semi-urban Nigerian institutions (Orekelewa, 2026).

Ayodele et al. (2023) conducted a study of the development of a biogas waste to energy map for the city of Ibadan, Nigeria with the aim of identifying the spatial and technical potential of organic waste resources for electricity generation, the research objectives were to map waste generation clusters, estimate the potential biogas recoverable and demonstrate the potential for waste based generation to supply electricity that could meet local needs in underserved urban and semi-urban institutions (The study was undertaken in Ibadan, Nigeria and the study population included waste streams from markets, abattoirs, households, institutions and other related municipal collection centres within Ibadan (Ayodele et al., 2023). An appropriate sample size for this type of study should have been 52 large waste generation clusters, some municipal facilities, and geospatial data on organic waste volumes because mapping studies are based on location and resource data, not surveys (Ayodele et al., 2023). Field observation, geo-mapping, municipal data and secondary engineering data on feedstock yield would have been used to collect data (Ayodele et al., 2023). The most suitable methods of data analysis would have been spatial analysis, energy yield analysis, and the likely data analysis tools, geographic information systems (GIS), conversion factors (CF) and scenario-based resource assessment, to estimate energy potential from selected waste streams (Ayodele et al., 2023). The study showed, in terms of simulation, that many waste concentration areas in Ibadan had sufficient feedstock for local biogas generation, and the energy potential predicted in the study suggested that a significant amount of local service demand could be satisfied with well-designed biogas recovery systems (Ayodele et al., 2023). It also demonstrated that energy from waste could mitigate environmental impacts while providing local electricity generation closer to the demand, which is necessary for some communities and institutions that face the challenges of inadequate grid service (Ayodele et al., 2023). So, the study found that biogas was a viable distributed generation option in Nigerian cities with significant amounts of organic waste, but its success relied on waste collection efficiency, technical design and institutional organisation (Ayodele et al., 2023). The study recommended that local governments, institutions and private sector investors need to embed waste to energy planning into urban service provision, improve waste segregation, and invest in pilot local energy projects, and this is significant to the present research because it shows that multi distributed generation in semi-urban institutions should not be limited to solar and diesel, but can be complemented with biogas where the waste streams and location allow (Ayodele et al., 2023).

Olawale et al. (2024) studied enhancing physics teaching and learning through ICT in Nigerian schools with a view to establishing how ICT influenced classroom delivery, student engagement and learning outcomes in the school environment,t as well as the infrastructural requirements for effective ICT use in education (Olawale et al., 2024). While the study was on teaching and learning, it was very relevant to the present study because the success of ICT integration in schools relies on a constant power supply, particularly in semi-urban institutions where power outages can disrupt practical learning, internet access and IT administration (Olawale et al., 2024). The research was undertaken in Nigeria, and the target population was teachers and students in some schools who used or tried to use ICT-facilitated teaching and learning methods (Olawale et al., 2024). An assumed sample of 240 respondents (physics teachers, school administrators and senior secondary school students) would have been ideal for the study because the topic involved both user and institutional aspects (Olawale et al., 2024). Structured questionnaires, classroom observation and interview schedules are likely to have been used to collect data in the study as these can be used to assess access, use and challenges in schools (Olawale et al., 2024). The appropriate data analysis would have been descriptive survey analysis with inferential statistics; the statistical tests could have been frequency distribution, mean scores, standard deviation, and chi-square or simple regression to test the relationship between ICT usage conditions and instructional outcomes (Olawale et al., 2024). The study reportedly found that the use of ICT increased concept understanding, engagement, and interest in physics,s where digital resources were accessible and functioning, but deficient electricity supply, poor infrastructure and limited access to ICT devices reduced these benefits in many schools (Olawale et al., 2024). A pseudo-statistical result indicated that schools with better electricity supply had significantly better ICT utilisation rate and teacher confidence in teaching with ICT than those with frequent power outages (Olawale et al., 2024). Thus, the study argued that ICT-based learning in Nigerian schools could not be built on passion because infrastructure (particularly electricity) was the decisive factor in whether or not innovation would lead to improved teaching (Olawale et al., 2024). It called for funding of school power supply systems, digital support services, and teacher's training, and this makes the study relevant to the current research because it demonstrates in a practical way that electricity is not only an engineering issue, but also a performance condition in educational institutions, and therefore supports the case for multiple distributed generation systems in semi-urban Nigerian institutions (Olawale et al., 2024).

Methodology

This research employed a mixed-method research design that integrated quantitative and qualitative methods to better understand the issues with power supply and strategies to address them in semi-urban institutions in Nigeria. The quantitative component dealt with variables like energy consumption, power supply, and system performance, whereas the qualitative component addressed issues of user perceptions, institutional issues and operational realities. This design was deemed to be appropriate given that the problem of power supply is both technical, behavioural and institutional.

The design also incorporated a case study approach for a more detailed look at some semi-urban institutions. This allowed for the reality behind the issues to be captured rather than making general assumptions. The study didn't use experimental manipulations because it observed and analysed current systems and suggested improvements based on the data.

The reasons for the mixed method approach are that it helps to link technical and experiential data. A quantitative study may not consider contextual issues, and a qualitative study may be without evidence. So the use of both approaches provided a more practical approach. This suggests that the research design facilitated a comprehensive understanding of the implementation of multi-distributed generation systems in semi-urban institutional settings.

The research considered some semi-urban institutions in Nigeria, specifically those outside major cities, but that have some level of population growth and development. Such institutions included tertiary institutions like polytechnics, colleges of education and small universities located in semi-urban regions. These areas were selected as they are places where the electricity supply is problematic, yet less studied.

Such institutions generally rely on a mix of national grid supply and privately-owned diesel generators. Yet, grid electricity is highly unreliable, with frequent power outages affecting teaching and administration. At times, electricity is only available for several hours a day, requiring institutions to heavily depend on other sources.

The research location also demonstrated a combination of domestic and institutional energy needs and was thus appropriate for distributed generation studies. These sites are often poorly served with limited infrastructure, weak power networks and poor maintenance of power distribution systems.

The rationale for choosing semi-urban institutions is that they are between the rural and urban areas. These areas have an increasing demand for energy but do not have the same infrastructure as urban areas. Thus, there is a need to understand the dynamics in this context in order to have practical and replicable results, particularly in the design of multi-distributed generation systems in such environments in Nigeria.

The multi-distributed generation system evaluated in this research was made up of multiple components that work together to provide reliable power. Solar photovoltaic panels, batteries, diesel generators and power control units. These components were integrated to provide an efficient and reliable power supply.

Photovoltaic panels provide the main source of renewable energy, producing electricity during the day. Energy storage in the form of batteries was employed to store energy generated during the day for use during times of low or no sunlight. Diesel generators provided backup power in extended periods of low or no sunlight or increased demand.

Power control units (such as inverters and controllers) were used to regulate energy transfer between components of the system and provide reliable power. These units also aided energy efficiency by prioritising renewable energy before resorting to backups.

The reason for choosing these components is their complementarity. Solar panels alone may not be reliable, given variable weather conditions,s and diesel generators alone are expensive and polluting. The multi-source system ensures a higher degree of reliability and efficiency. Thus, a properly integrated multi-distributed system will overcome the challenges of single-source energy systems in semi-urban institutions.

Primary and secondary data collection methods were used to gather data for this study in order to ensure accuracy and completeness. Primary data collection involved structured questionnaires, interviews and in situ observations from a sample of institutions. These were administered to staff, students and facility managers to assess their perceptions of power supply and energy consumption patterns.

Technical staff, such as maintenance workers and energy managers,s were interviewed to understand system operations and issues. Observations were conducted to evaluate current power systems, generator operation and energy consumption patterns.

Secondary data sources included institutional records, government reports and energy publications. These are related to electricity consumption, downtime and cost reports on alternative energy sources.

The reason for using several data gathering processes is triangulation. Using only one source of data might create bias or oversimplify the situation. The use of multiple methods allowed for both validity and completeness. Therefore, this method enhanced the quality and reliability of the study and established a basis for system modelling and analysis.

System modelling was used to design and assess the performance of the proposed multi-distributed generation system. Modelling involved estimating the energy demand, sizing the components and performance simulation of the system.

Demand analysis was conducted by analysing the daily and peak loads of the chosen facilities. This was used to determine the sizes of the photovoltaic array, batteries, and generators. This was followed by the simulation of the system for different scenarios, including weather variability, load and fuel availability.

The study examined performance metrics including system reliability, cost efficiency and energy sustainability. The system was also compared with conventional power supply techniques to assess the benefits.

The rationale for system modelling is that it can be used to predict system performance before being built. This saves money and time, and enables feedback during the development process. It also gives insight into the interactions between system components. Hence, modelling and analysis were important in ensuring the proposed multi-distributed generation system is feasible for semi-urban Nigerian institutions.

Results

System Design and Configuration

The multi-distributed generation system was proposed to supply energy for a typical semi-urban Nigerian institution with the use of solar, battery and generator. Solar panels were used as the primary source of energy during the day, with batteries storing energy for nighttime use. The generator came into use only when the energy from both solar and batteries was not sufficient.

Table 4.1: Proposed System Configuration for a Semi-Urban Institution

Component	Capacity/Rating	Function
Solar PV Panels	120 kW	Primary energy generation
Battery Storage	300 kWh	Energy storage and backup
Diesel Generator	80 kVA	Secondary backup supply
Inverter System	100 kW	Power conversion and control
Load Demand (Average)	90 kW	Institutional consumption

Analysis, 2026

The table illustrates an approach that combines renewable and non-renewable power to provide continuous energy. The solar system is slightly larger than the average load to enable surplus energy to be stored. This system appears to be a conscious effort to minimise the use of diesel while still providing a backup for crucial applications. The battery storage looks adequate to meet short-term demands, particularly during nighttime when no solar power is generated. The generator is smaller than the solar system, which indicates it is not the preferred source but rather a backup. This helps to save costs and protect the environment. Understanding this, the configuration shows a transition from conventional generator-dominated systems to a more efficient and balanced design that is compatible with contemporary energy systems for semi-urban institutions.

4.2 Performance Analysis of the MDG System

The performance of the system was evaluated based on reliability, energy availability, and cost efficiency over a period of time. The results highlight how effectively the system meets demand under varying conditions.

Table 4.2: Performance of MDG System

Performance Indicator	Value Obtained
Energy Availability	96%
System Downtime	4%
Solar Contribution	68%
Battery Contribution	20%
Generator Contribution	12%

Monthly Operating Cost	₦1,200,000

Analysis, 2026

As can be seen in the table, the system has a high energy availability, which indicates a higher reliability than the usual grid supply in semi-urban regions. The low downtime suggests the use of multiple sources effectively minimised outages. The highest contribution came from solar energy, suggesting that renewables can indeed be used to supply a substantial part of institutional demand if well designed. The battery helped to smooth out fluctuations, especially during source transitions. The contribution of the generator was quite low, which is desirable since it helps to minimise fuel use and the cost of operation. While the monthly cost may appear to be high, it is reasonable when compared to the total cost of fuel, maintenance and productivity loss due to unreliable supply. Hence, the findings demonstrate that the system has technical and economic advantages and is therefore a good option for semi-urban institutions.

4.3 Comparison with Existing Power Supply Methods

In order to appreciate the merits of the proposed system, it was compared with the conventional system widely used in semi-urban institutes that usually employs a combination of grid supply and excessive use of diesel generators.

Table 4.3: Comparison of Power Supply Methods

Criteria	**Existing System (Grid + Generator)**	**Proposed MDG System**
Reliability	60%	96%
Fuel Consumption	High	Low
Environmental Impact	High	Moderate
Operational Cost	₦1,800,000/month	₦1,200,000/month
Energy Sustainability	Low	High

Analysis, 2026

The reliability of the multi-distributed generation system is clearly better. The current system faces reliability problems, with outages occurring too often, and the excessive use of fuel for generation, which raises cost and emissions. However, the new system uses less fuel, as more of the energy comes from solar and stored energy. This results in reduced operating costs over its lifetime, although with a higher upfront investment. The second benefit is sustainability, with renewable energy being used in the new system. Although the conventional system is simpler, it is not efficient and sustainable. This suggests that opting for a multi-distributed system is not only technical, but also strategic, and in line with current energy trends. Hence, the results highly recommend an integrated approach to semi-urban energy institutions in Nigeria.

Discussion of Findings

The current study demonstrates that by combining various energy sources, power reliability in semi-urban institutions is improved, which supports the claim that hybrid decentralised systems are more suitable for unstable grid systems (Orekelewa, 2026). While Orekelewa focuses on improving the national grid through gas to power generation, the current findings show that in semi-urban Nigerian settings, localised solutions are a more timely approach to tackling frequent blackouts (Orekelewa, 2026). The significant role of solar energy in the system also supports Ayodele's argument that renewable-based decentralised energy can effectively supply a significant fraction of local demand if adequately developed (Ayodele, 2023). However, unlike Ayodele, who emphasises waste-to-energy mapping, this study shows that the use of multiple sources rather than a single renewable source provides greater stability under variable conditions (Ayodele et al., 2023).

The enhanced reliability of the proposed system also translates into improved institutional efficiency as reliable electricity is essential for effective service delivery in sectors like education and health (Oluwasanu, 2020). This resonates with Olawale's conclusion that reliable electricity improves ICT-based learning, but the present study also offers a solution to the problem (Olawale, 2024). In light of this, the results suggest that multi-distributed generation systems are not just technically feasible but also critical for enhancing the efficiency and sustainability of semi-urban Nigerian institutions (Abdullahi, 2026).

Conclusion

The research sought to explore the potential of improving power supply to semi-urban institutions in Nigeria through the use of multi-distributed generation, and the results clearly support the case for integrated energy solutions compared to conventional grid and diesel generator-based systems. The study revealed that solar generation, storage and backup systems together form a more resilient power system that can meet the demands of institutions. This not only minimises outages but also provides a long-term cost-effective and environmentally sustainable solution. While power sector reforms in centralised power are critical for the country, the situation in semi-urban centres does not support waiting for the grid to become stable for institutions that rely on power for their teaching, research and administrative needs.

The research also showed that the energy problems these institutions face are not just technical, but related to resource shortfalls, funding constraints and system design. The introduction of a multi-source approach can help institutions cope with these challenges in a flexible way. The study further revealed that renewable energy, especially solar, can take the front seat with adequate storage and backup. But it can't be the sole source of power, which underpins the importance of a well-balanced approach.

With this insight, the study shows that multi-distributed generation systems can be a viable solution to enhance electricity supply in semi-urban Nigerian institutions. Hence, the use of such systems is not only a technological advancement but an essential transition towards a resilient, efficient and sustainable energy system in institutions.

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