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Performance Evaluation of a HybrId Solar-Biomass Energy System for Electricity Generation

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Abstract- Hybrid solar-biomass energy systems offer a promising approach to improving electricity generation by combining intermittent solar energy with dispatchable biomass-based power. This review examines the technologies, configurations, performance indicators, operational challenges, and sustainability of hybrid systems, with particular attention to their application in Nigeria and other developing economies. It discusses photovoltaic conversion, biomass combustion, gasification, anaerobic digestion, energy storage, and power management strategies. The review further evaluates electrical output, conversion efficiency, reliability, energy availability, and the economic and environmental implications of system integration. Existing studies demonstrate the potential of solar-biomass systems to improve electricity supply, utilize agricultural residues, and reduce dependence on conventional fuels. However, reported performance varies with resource availability, feedstock characteristics, system configuration, conversion technology, and operating conditions. Important challenges include biomass supply-chain limitations, capital costs, technical complexity, and the need for reliable performance measurements. The review identifies gaps in experimental validation, long-term reliability assessment, standardized performance indicators, and locally grounded techno-economic analysis. It recommends integrated modelling, controlled experimental testing, and life-cycle assessment to guide future development. These approaches can strengthen evidence-based design, deployment, and sustainable utilization of hybrid solar-biomass electricity generation systems.

Keywords- Hybrid; solar photovoltaic; biomass; electricity generation; performance evaluation.

I. INTRODUCTION

1. Background to Renewable Energy and Electricity Generation

Electricity is essential for industrial development, healthcare, education, communication, agriculture, and domestic activities. However, dependence on conventional fossil-fuel power generation presents challenges associated with fuel-price fluctuations, greenhouse-gas emissions, and the uneven distribution of electricity infrastructure. Renewable energy technologies provide opportunities to diversify electricity supply and reduce dependence on conventional energy sources. Solar and biomass energy are particularly relevant because they can be obtained from naturally replenished resources. Solar photovoltaic systems convert sunlight directly into electricity, while biomass systems produce electricity through the conversion of organic materials into heat, combustible gases, or biogas.

Their combination offers a way to coordinate variable solar generation with biomass-based electricity production that can be scheduled according to energy demand and resource availability (International Energy Agency [IEA], 2024; International Renewable Energy Agency [IRENA], 2024). Recent studies have increasingly examined hybrid renewable energy systems as a means of improving electricity reliability and addressing the limitations of individual renewable technologies. Nevertheless, the performance of a hybrid system depends on the characteristics of its components, resource conditions, control strategy, and energy demand (Kaur et al., 2025; Akpiri & Anyacho, 2026).

2. Solar and Biomass Energy as Renewable Energy Sources

Solar energy is widely available and can be converted into electricity using photovoltaic modules. Its major limitation is variability, which arises from changes in solar irradiance, temperature, cloud cover, and daylight duration. Biomass, on the other hand, can provide a storable energy resource derived from agricultural residues, forestry waste, animal waste, and other organic materials.

The suitability of biomass for electricity generation depends on its moisture content, calorific value, chemical composition, and conversion pathway. Gasification, combustion, and anaerobic digestion are among the principal technologies used to transform biomass into useful energy (Du et al., 2024; Ali et al., 2024).

When integrated, solar and biomass technologies can complement each other. Solar energy may contribute a substantial share of daytime electricity, while biomass generation can provide additional power when solar output is insufficient. The effectiveness of this arrangement depends on the availability of suitable biomass resources and the ability of the system to coordinate both energy sources (Campos et al., 2024; Sánchez-Lozano et al., 2025).

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3. Concept and Significance of Hybrid Solar-Biomass Energy Systems

A hybrid solar-biomass energy system combines photovoltaic electricity generation with a biomass-based power generation unit. The system may include batteries, inverters, biomass gasifiers, combustion engines, generators, and an energy management controller. The principal objective is to improve electricity supply by coordinating two renewable resources with different operating characteristics. Solar energy can reduce the operating hours of biomass conversion equipment, while biomass can provide power during periods of low solar availability. Storage may further improve the matching of electricity generation and demand. The significance of this arrangement lies in its potential to improve renewable energy utilization, support rural electrification, and reduce reliance on diesel generators. However, hybridization does not automatically guarantee higher efficiency or lower cost. These outcomes depend on system configuration, component performance, fuel logistics, and operating conditions (Macías et al., 2022; Campos et al., 2024).

II. FUNDAMENTALS OF SOLAR AND BIOMASS ENERGY

1. Principles of Solar Energy Conversion and Photovoltaic Technology

Solar photovoltaic technology converts solar radiation directly into electrical energy through the photovoltaic effect. When sunlight reaches a semiconductor material, it generates charge carriers that produce direct-current electricity. The generated electricity is then converted into alternating current through an inverter for use by conventional electrical appliances. The performance of photovoltaic systems depends on solar irradiance, module temperature, shading, dust accumulation, orientation, and the efficiency of electrical components. High solar irradiance generally increases electricity generation, whereas elevated module temperatures can reduce the electrical conversion efficiency of conventional photovoltaic modules (Sharma & Mishra, 2025).

Photovoltaic technology is suitable for hybrid systems because it has no direct fuel requirement during operation and can be installed in modular configurations. Its main limitation is the variability of solar electricity generation, which makes coordination with energy source or energy storage particularly important.

2. Biomass Resources, Characteristics and Energy Potential

Biomass refers to organic materials that can be used as energy resources. These materials include agricultural residues, wood waste, animal manure, food-processing waste, and biodegradable municipal waste. In agricultural economies, biomass residues from crops such as maize, rice, cassava, and oil palm can provide locally available feedstock for electricity generation. The suitability of a particular material depends on its availability, moisture content, ash content, calorific value, and transportation requirements. Biomass energy potential is commonly estimated from the quantity of available feedstock and its energy content. However, theoretical availability does not necessarily represent the quantity that can be sustainably collected and utilized. Feedstock recovery must consider competing uses, soil nutrient requirements, collection costs, and seasonal availability (Du et al., 2024; Ali et al., 2024).

3. Biomass Conversion Technologies for Electricity Generation

Biomass can be converted into electricity through several technological pathways. Combustion involves the direct burning of biomass to produce heat. The heat can generate steam to drive a turbine or support other power-generation processes. Gasification converts biomass into producer gas through controlled partial oxidation, while anaerobic digestion uses microorganisms to convert biodegradable organic materials into biogas. Biogas may be used in an engine-generator system to produce electricity. Gasification-based systems similarly convert biomass into combustible gas, which can be cleaned and utilized in an appropriate power-generation unit. The choice of conversion technology depends on feedstock properties, system capacity, investment cost, maintenance requirements, and the availability of technical expertise. Gasification is particularly relevant to hybrid solar-biomass electricity generation because it can utilize agricultural residues in distributed power systems (Abouemara et al., 2024; Sánchez-Lozano et al., 2025).

4. Factors Affecting Solar and Biomass Energy Availability

Solar energy availability varies with geographical location, season, weather conditions, and time of day. Biomass availability depends on agricultural production cycles, waste generation, collection infrastructure, storage conditions, and competing uses. These variations affect the quantity of electricity that can be generated and the extent to which the two energy sources complement each other. A location with strong solar resources and dependable biomass availability may provide favorable conditions for hybridization. In Nigeria, the availability of agricultural residues presents opportunities for biomass-based electricity generation. However, the actual potential of these resources requires assessment at the local level. The presence of agricultural waste alone does not establish its suitability for a continuous electricity supply.

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5. Complementarity of Solar and Biomass Energy Resources

The complementary nature of solar and biomass energy is a major reason for integrating the two technologies. Solar energy provides electricity when adequate sunlight is available, whereas biomass can be stored and converted into electricity when required. A properly coordinated hybrid system can reduce dependence on energy storage alone to manage solar variability. Biomass generation may also contribute to meeting electricity demand during periods of low solar output. However, the benefits of complementarity depend on the timing of resource availability and electricity demand. Effective system integration therefore requires resource assessment, appropriate component sizing, and a control strategy that coordinates solar generation, biomass operation, and storage.

Table 1: Comparison of solar and biomass energy resources for electricity generation

Parameter	Solar photovoltaic energy	Biomass energy
Energy source	Solar radiation	Organic materials
Conversion technology	Photovoltaic modules	Combustion, gasification or anaerobic digestion
Energy availability	Variable with sunlight and weather	Dependent on feedstock supply
Energy storage	Batteries or other storage systems	Biomass can be stored as fuel
Operational requirement	Cleaning, inspection and electrical maintenance	Feedstock preparation, fuel handling and equipment maintenance
Environmental considerations	Module production, land use and end-of-life management	Feedstock sustainability, emissions and waste management
Major performance factors	Irradiance, temperature, shading and module efficiency	Moisture content, calorific value, gas quality and conversion efficiency
Contribution to hybrid systems	Renewable electricity during sunlight availability	Dispatchable electricity when required

Compiled from the reviewed literature, including Sharma and Mishra (2025), Du et al. (2024), Abouemara et al. (2024), and Campos et al. (2024). Table 1 illustrates the fundamental differences between solar photovoltaic and biomass energy resources and explains why their integration can be beneficial for electricity generation. The first difference concerns energy availability. Solar energy depends on the presence of sunlight and varies with weather conditions. Biomass energy depends on the availability of suitable organic materials, which can be stored before conversion. This difference allows biomass to provide electricity when solar generation is limited. The conversion technologies also differ. Photovoltaic systems convert sunlight directly into electricity, whereas biomass systems require a conversion process involving combustion, gasification, or anaerobic digestion. Consequently, biomass systems generally involve more mechanical equipment and operational activities, including fuel preparation and handling. The table also shows that the two technologies have different performance-determining factors. Solar photovoltaic output is strongly influenced by irradiance and module temperature. Biomass electricity generation depends on feedstock characteristics and the performance of the conversion equipment. From an environmental perspective, solar photovoltaic systems avoid direct fuel combustion during operation, while biomass systems require careful management of feedstock sustainability and emissions. Biomass utilization can support waste management when suitable residues are used, but its environmental benefits depend on how the feedstock is produced, collected, transported, and converted. Overall, the comparison demonstrates that solar and biomass energy are complementary rather than identical resources. Their integration can improve the flexibility of electricity generation, provided that the system is designed around local energy resources, electricity demand, and operational requirements.

III. DESIGN AND CONFIGURATION OF HYBRID SOLAR-BIOMASS SYSTEMS

1. Operating Principles and Configurations of Hybrid Energy Systems

Hybrid solar-biomass systems combine photovoltaic electricity generation with a biomass-based electricity generator. The configuration may be stand-alone, grid-connected, or connected to a mini-grid. In a stand-alone system, solar and biomass generation units supply electricity to a local load without relying on the national grid. In a grid-connected arrangement, the system can supply electricity locally and exchange power with the grid, subject to applicable technical requirements. The selection of a configuration depends on the required electricity capacity, local resource availability, grid reliability, and cost

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considerations. Hybrid systems have been investigated for rural electrification, remote communities, and institutional electricity supply (Campos et al., 2024; Sánchez-Lozano et al., 2025).

2. Major Components of Hybrid Solar-Biomass Systems

The major components include photovoltaic modules, a biomass conversion unit, an electricity generator, power-conditioning equipment, and a control system. Photovoltaic modules provide electricity from sunlight, while the biomass unit provides additional generation capacity. An inverter converts direct-current electricity into alternating current where required. A charge controller and battery bank may be included to manage stored electricity. The biomass unit may consist of a gasifier, gas-cleaning equipment, and an engine-generator, or another suitable conversion arrangement. Each component contributes to overall system performance, and the efficiency of the complete system depends on the interactions between them.

3. Integration of Solar Photovoltaic and Biomass Power Generation Units

Integration requires coordination of the electrical output of the photovoltaic and biomass units. The generated electricity must meet the load demand while maintaining acceptable voltage and frequency. In an integrated arrangement, solar electricity may supply the load directly, while the biomass generator operates when solar generation is insufficient. Depending on the configuration, excess solar electricity may be stored, exported, or used to support other energy requirements. The performance of the integrated system depends on how effectively the two generation units operate together. Poor coordination can result in unnecessary biomass consumption, excessive storage requirements, or unused renewable electricity.

4. Energy Storage, Power Conditioning and Management

Energy storage helps to manage the difference between electricity generation and demand. Batteries are commonly used to store excess solar electricity and supply power during periods of reduced generation. Power-conditioning equipment regulates electricity supplied by the different components. An energy management system coordinates generation, storage, and electricity demand. The control strategy may prioritize solar generation, schedule biomass operation, and manage battery charging and discharging. The selection of an appropriate strategy depends on system capacity, load characteristics, storage availability, and operating costs.

5. System Sizing and Design Considerations

System sizing involves determining the appropriate capacities of the photovoltaic array, biomass generator, storage system, and electrical components. The process requires information on electricity demand, solar resource availability, biomass supply, conversion efficiencies, and the desired reliability of electricity supply.



Figure 1: Design and Configuration of a Hybrid Solar-Biomass Energy System

Oversizing can increase capital costs and lead to unused generation capacity, while undersizing may result in insufficient electricity supply. Optimization methods such as HOMER, MATLAB-based modelling, and other simulation approaches are used to evaluate alternative system configurations (Ji et al., 2022; Akpiri & Anyacho, 2026).

IV. PERFORMANCE EVALUATION OF HYBRID SOLAR-BIOMASS SYSTEMS

1. Electrical Energy Output and Power Generation Capacity

Electrical output represents the quantity of electricity generated by the system over a specified period. It is commonly expressed in kilowatt-hours or megawatt-hours. Power generation capacity represents the rated or available power of the system, while actual electricity generation depends on operating conditions and resource availability. Performance evaluation should distinguish between rated capacity, instantaneous power output, and accumulated electricity generation. This distinction is important because a system with a high rated capacity may generate relatively little electricity if its resources are unavailable or its operating conditions are unfavorable.

2. Solar Photovoltaic and Biomass Conversion Efficiencies

Photovoltaic conversion efficiency describes the proportion of incident solar energy converted into electrical energy. Biomass conversion efficiency describes the proportion of the chemical energy contained in the biomass feedstock that is converted into useful electricity. The efficiencies of the two components should be evaluated separately before

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calculating the overall system efficiency. This allows the contribution of each conversion process to be identified.
In addition, the evaluation should specify whether the reported biomass efficiency is based on the lower or higher heating value of the fuel and whether auxiliary electricity consumption is included.

3. Overall System Efficiency and Energy Utilization

Overall system efficiency describes the relationship between useful electrical energy delivered and the energy supplied to the system. A hybrid system may be evaluated using the combined energy contribution of solar radiation and biomass fuel. However, the efficiency calculation must clearly define the system boundary and energy inputs. Energy utilization also considers the proportion of generated electricity that is actually consumed by the load. Excess electricity, storage losses, conversion losses, and unmet demand should be reported separately.
These distinctions prevent misleading comparisons between systems that use different efficiency definitions or accounting methods.

4. Reliability, Availability and Continuity of Electricity Supply

Reliability refers to the ability of a system to supply electricity when required. Availability represents the proportion of time the system is capable of operating. Hybrid systems may improve electricity continuity by using biomass generation to supplement solar electricity during periods of reduced solar availability. Reliability evaluation can include unmet electrical demand, loss-of-power-supply probability, and the frequency and duration of power interruptions. These indicators are particularly relevant to remote communities and rural electrification projects (Ijeoma et al., 2024; Kaur et al., 2025).



Figure 2: Performance Evaluation of Hybrid Solar-Biomass Systems

5. Performance Indicators and Comparative Evaluation Methods

The principal performance indicators include electrical output, conversion efficiency, renewable energy fraction, system availability, unmet load, and energy losses. Comparative evaluation should examine systems operating under equivalent electricity demand and resource conditions. Where possible, solar-only, biomass-only, and hybrid configurations should be compared.

A fair comparison should also identify whether the results are measured experimentally or obtained through simulation. This distinction is necessary because model-derived performance estimates do not independently demonstrate actual operational performance.

V. FACTORS AFFECTING SYSTEM PERFORMANCE

1. Solar Irradiance, Temperature and Environmental Conditions

Solar irradiance directly influences photovoltaic electricity generation. Changes in cloud cover, shading, dust accumulation, and module orientation can reduce the quantity of sunlight reaching the modules. Temperature also affects photovoltaic performance. Elevated module temperatures generally reduce the electrical efficiency of conventional silicon photovoltaic systems. Environmental conditions therefore influence both the quantity and quality of solar electricity generation. Proper installation, cleaning, ventilation, and monitoring can help maintain performance (Sharma & Mishra, 2025).

2. Biomass Feedstock Characteristics and Availability

Biomass characteristics influence the amount of energy available for electricity generation. Moisture content is particularly important because water in the feedstock consumes energy during heating and evaporation. High moisture content may reduce the useful energy available for conversion and affect combustion or gasification performance. Feedstock composition, ash content, particle size, and calorific value also influence conversion efficiency and equipment operation. The availability of suitable biomass throughout the year is equally important. Seasonal variations and transportation requirements can affect fuel cost and the continuity of electricity generation.

3. Seasonal Variations and Energy Resource Complementarity

Solar radiation and biomass availability vary over time. The extent to which these resources complement each other determines the effectiveness of hybridization. A system may perform well during periods of high solar radiation but require greater biomass input during periods of reduced

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sunlight. Similarly, biomass shortages may limit the ability of the system to compensate for reduced solar generation. Resource assessment should therefore consider seasonal patterns rather than relying exclusively on annual average values.

4. Component Efficiency, System Degradation and Energy Losses

The performance of a hybrid system depends on the efficiency of its individual components. Photovoltaic modules, inverters, batteries, generators, and biomass conversion equipment all contribute to the overall energy balance. Electrical resistance, inverter conversion losses, battery charging and discharging losses, and auxiliary equipment consumption can reduce the amount of electricity delivered to the load. Component degradation may also reduce performance over time. Regular inspection, appropriate maintenance, and monitoring are important for maintaining system reliability.

5. Maintenance, Control Strategies and Operational Challenges

Hybrid solar-biomass systems require coordinated operation of electrical and mechanical equipment. Photovoltaic systems require cleaning and electrical inspection, while biomass conversion equipment requires fuel handling, maintenance, and attention to operating conditions.

Effective control strategies can reduce unnecessary biomass consumption and improve the utilization of available solar energy. However, the benefits of advanced control systems depend on their suitability for the system and the reliability of the available operating data.

VI. ECONOMIC AND ENVIRONMENTAL ASSESSMENT

1. Capital, Installation and Operational Costs

The economic performance of hybrid systems depends on the cost of photovoltaic modules, biomass conversion equipment, storage, electrical components, installation, and supporting infrastructure. Operational costs include maintenance, biomass collection, transportation, fuel preparation, and replacement of components. Although photovoltaic systems have no direct fuel cost during operation, the biomass component introduces recurring fuel and maintenance requirements. The economic assessment must therefore consider the full system rather than evaluating the cost of individual components in isolation.

2. Economic Feasibility and Levelized Cost of Electricity

Economic feasibility is commonly evaluated usng net present cost, levelized cost of electricity, payback period, and financial sensitivity analysis. The levelized cost of electricity represents the average cost of producing electricity over the system's lifetime, taking account of capital expenditure, operating costs, and electricity generation. Hybrid systems may achieve favorable economic performance where biomass resources are locally available and electricity supply from the existing grid is unreliable. However, results depend on the cost of equipment, biomass supply, financing, and the assumed operating life (Campos et al., 2024; Sánchez-Lozano et al., 2025).

3. Greenhouse Gas Emissions and Environmental Impacts

Hybrid solar-biomass systems can reduce dependence on fossil-fuel electricity generation. However, the environmental performance of biomass systems depends on feedstock production, collection, transportation, and conversion. Biomass is not automatically carbon-neutral. Its climate impact depends on the type of feedstock, land-use implications, and the time required for biological carbon replacement. Environmental assessment should therefore consider greenhouse-gas emissions across the system's life cycle, including equipment production and biomass supply chains (Du et al., 2024; Islam et al., 2024).

4. Sustainability of Biomass Resources and Feedstock Utilization

Sustainable biomass utilization requires that feedstock extraction does not undermine agricultural productivity, soil fertility, or ecosystem stability. Agricultural residues can support electricity generation when their collection is compatible with other uses and environmental requirements. The sustainability of biomass resources should therefore be assessed using local feedstock availability, collection efficiency, competing uses, and environmental implications. Reliable biomass supply is essential for maintaining the long-term operation of hybrid systems.

5. Comparison with Conventional and Other Renewable Energy Systems

Hybrid solar-biomass systems can be compared with diesel generators, solar-only systems, biomass-only systems, and other renewable energy configurations. The comparison should consider electricity generation cost, reliability, emissions, resource availability, and maintenance requirements. Where a hybrid system is compared with a conventional generator, the electricity demand and operating conditions should be equivalent. This ensures that reported advantages reflect genuine system performance rather than differences in the evaluation method.

Applications, Challenges and Future Prospects

Applications in Rural Electrification and Off-Grid Power Supply- Hybrid solar-biomass systems can support electricity generation in rural communities where grid

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extension is expensive or existing electricity supply is unreliable. The photovoltaic component can provide electricity during periods of adequate sunlight, while biomass generation can support the load when solar output is insufficient. Agricultural residues may provide a locally available energy resource, particularly in farming communities. A study in Liberia evaluated a stand-alone solar photovoltaic-biomass system with optimized storage for rural electricity supply. The study illustrates the relevance of integrating solar generation, biomass conversion, and energy storage for off-grid applications (2024).

Applications In Residential, Commercial and Industrial Electricity Generation

Hybrid systems may be applied in residential buildings, educational institutions, commercial establishments, and small industries. In educational institutions, electricity is required for lighting, laboratories, information technology, and other facilities. Commercial applications may include refrigeration, lighting, and equipment operation.The suitability of a hybrid system depends on the electricity demand profile and the availability of suitable energy resources. For example, institutions with substantial daytime electricity demand may utilize solar generation effectively, while biomass can provide additional electricity during periods of reduced solar availability.

Technical, Operational and Biomass Supply-Chain Challenges

Technical challenges include system integration, generator maintenance, biomass conversion efficiency, and coordination of power output. Operational challenges include fuel preparation, feedstock transportation, equipment servicing, and the availability of trained personnel. Biomass supply chains are particularly important because electricity generation depends on the availability of suitable feedstock. Poor storage conditions and seasonal shortages may affect fuel quality and system operation. These challenges highlight the importance of designing hybrid systems around local conditions rather than adopting a single configuration for every application.

Policy, Financing and Regulatory Challenges

The deployment of hybrid renewable energy systems may be influenced by access to finance, renewable energy policies, electricity regulations, and investment incentives. High initial capital costs can limit adoption, particularly in rural communities. Financing arrangements and policies that support renewable energy development may improve the feasibility of such systems. Regulatory considerations include electricity generation standards, grid interconnection requirements, environmental protection, and biomass resource management.

Future Prospects and Optimization Strategies in Nigeria and Sub-Saharan Africa

The future development of hybrid solar-biomass systems depends on improved system design, reliable biomass supply, and stronger experimental evidence. In Nigeria and other Sub-Saharan African countries, agricultural residues offer opportunities for locally supported biomass electricity generation. However, resource availability and economic feasibility must be evaluated for each location. Future improvements may include more efficient biomass conversion technologies, improved energy management, optimized storage, and the use of locally available feedstocks.



Figure 3: Applications, Challenges and Future Prospects of Hybrid Solar-Biomass Systems

Recent research in Ghana has demonstrated the relevance of photovoltaic-assisted biomass gasification for rural electrification, while studies in Liberia and Brazil have examined the technical and economic feasibility of solar-biomass systems (Campos et al., 2024; Sánchez-Lozano et al., 2025).

VII. RESEARCH GAPS AND CONCLUSION

1. Identified Research Gaps in Hybrid Solar-Biomass Performance Evaluation

The major research gaps identified include:

- Limited experimental validation of simulated hybrid solar-biomass systems.
- Insufficient long-term assessment of system reliability and component degradation.
- Limited standardization of performance indicators and system boundaries.
- Inadequate integration of biomass supply-chain uncertainties into performance evaluation.

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- Limited comparative assessment of solar-only, biomass-only, and hybrid configurations under equivalent operating conditions.
- Insufficient locally grounded performance and economic data for rural applications in Nigeria.
- Limited assessment of the relationship between system efficiency, electricity reliability, and environmental sustainability.

These gaps indicate the need for research that combines technical measurements, economic evaluation, and environmental assessment.

1. Recommendations for Future Research

Future investigations should prioritize experimental validation of hybrid solar-biomass systems under realistic operating conditions. Researchers should establish clear system boundaries and report electrical input, electricity output, conversion efficiency, energy losses, and reliability indicators using consistent methods. Repeated measurements and uncertainty analysis should be incorporated into experimental studies to improve the reliability of reported results. Further studies should also evaluate biomass feedstock availability, fuel quality, transportation costs, and long-term sustainability. Comparative studies involving solar-only, biomass-only, and hybrid configurations would provide stronger evidence of the actual benefits of system integration.

For Nigeria, future research should emphasize agricultural residues, rural electricity demand, local climatic conditions, and the availability of technical support.

VIII. CONCLUSION

Hybrid solar-biomass energy systems provide a promising approach to renewable electricity generation through the integration of photovoltaic technology and biomass conversion. Solar energy offers a renewable source of electricity during periods of adequate sunlight, while biomass can provide additional generation capacity when solar output is insufficient. The performance of these systems depends on resource availability, component efficiency, system configuration, electricity demand, and operational management. Their economic and environmental benefits also depend on biomass sustainability, equipment costs, and the efficiency of energy conversion. The reviewed literature highlights the importance of reliable performance evaluation that distinguishes measured results from model-based estimates. Future research should strengthen experimental validation, improve performance measurement, and evaluate system operation under local conditions. Overall, hybrid solar-biomass systems have potential to support sustainable electricity generation, particularly in rural and off-grid communities. Their successful implementation requires technically appropriate designs, dependable biomass resources, and comprehensive performance assessment.

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