Techno-Economic and Environmental Assessment of a Solar–Biomass Hybrid Renewable Energy System for Sustainable Electrification in Omoku, Nigeria

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https://doi.org/10.56201/ijemt.vol.12.no10.2026.pg168.179

Abstract
Reliable and affordable electricity remains a major development requirement in many communities in Nigeria, where dependence on diesel generation increases operating costs and local air pollution. This study evaluates the technical, economic, environmental and potential socio-economic performance of a solar photovoltaic (PV)–biomass hybrid renewable energy system (HRES) designed for Omoku Town, Rivers State. The work adapts resource estimates and simulation results reported in the source dissertation, using HOMER Pro as the principal system-configuration and techno-economic assessment tool and MATLAB as a supporting modelling and analysis environment. The dissertation reports average global horizontal irradiance of 4.77 kWh/m²/day and an estimated annual biomass residue resource of 27,500 tonnes, including cassava peels, palm-kernel shells, sawdust and other agricultural residues. The selected configuration comprises 40 MW of solar PV, a 25 MW biomass plant, 100 MWh of battery storage and 10 MW of grid backup. Reported annual generation is 157,760 MWh, with solar PV contributing 63,600 MWh (40.1%), biomass 74,460 MWh (47.2%) and grid supply 19,700 MWh (12.7%), producing a renewable fraction of 87.3%. The study reports a net present cost (NPC) of ₦780 million and levelized cost of energy (LCOE) of ₦92.5/kWh for the hybrid option, compared with ₦1.22 billion and ₦165/kWh for a diesel-only comparator. Estimated annual emissions reductions relative to diesel are 80.3% for CO_2, 82.1% for CH_4, 86.7% for SO_x, 79.2% for NO and 81.3% for $PM_{2.5}$. Potential social benefits reported include a reduction in household electricity cost, increased employment and wider electricity access. The findings suggest that a solar–biomass configuration may provide a promising pathway for cleaner and more resilient electricity supply in Omoku. However, inconsistencies in some reported resource and cost figures, together with the simulation-based nature of the assessment, mean that the results should be independently reconciled and validated before investment decisions.

Keywords: *Hybrid renewable energy system; Solar photovoltaic; biomass; HOMER Pro; techno-economic analysis; Omoku; Nigeria; emissions reduction*

1. Introduction

1.1 Background

Electricity is a foundational input to household welfare, health services, education, commerce and industrial production. Where electricity supply is unreliable or costly, households and businesses often turn to small diesel or petrol generators. Such arrangements can impose high fuel and maintenance costs, expose users to price volatility and produce local air pollutants and greenhouse-gas emissions. These challenges have strengthened interest in renewable energy systems that can improve energy security while limiting environmental burdens (IEA, 2024; IPCC, 2023; REN21, 2024, as cited in the source dissertation).

Solar photovoltaic technology converts incident solar radiation directly into electricity and has become an important option for distributed generation. Its principal limitation is temporal variability: output changes with solar irradiance, cloud cover, temperature and the day–night cycle. Storage and complementary generation can help reduce the mismatch between PV output and demand. Biomass can play this complementary role because suitable organic residues can be stored and converted into dispatchable energy, provided that feedstock supply, moisture content, conversion efficiency and emissions control are properly managed (Khan et al., 2023; Olatomiwa et al., 2022).

Hybrid renewable energy systems combine two or more energy resources and associated technologies to exploit their complementary operating characteristics. A hybrid system may integrate solar PV, biomass conversion, batteries, power converters and grid or generator backup. System design requires a balance among resource availability, load profiles, reliability, capital investment, replacement schedules and operating costs. Simulation tools such as HOMER Pro can compare alternative system sizes and dispatch arrangements under specified technical and economic assumptions (Singh & Baredar, 2020; Kumar et al., 2021).

The Niger Delta has both solar resources and organic residues generated by agricultural activities, palm processing, sawmilling and municipal activity. Omoku, in Rivers State, is therefore a useful location for examining whether a solar–biomass hybrid can provide a more reliable and sustainable electricity option. The source dissertation identifies solar radiation, palm-kernel shells, cassava residues, sawdust and other agricultural wastes as relevant local resources. Harnessing these resources may create value from waste streams while reducing dependence on diesel-based generation.

1.2 Problem statement

The central problem addressed by the source study is the need for an electricity supply that is reliable, affordable and environmentally preferable to conventional diesel generation in Omoku Town. Standalone PV can be constrained by nighttime and cloudy-period supply, while biomass-only systems depend on secure feedstock logistics and stable conversion performance. Diesel systems are dispatchable but expose consumers to fuel-price changes and produce emissions. The research problem is consequently not simply whether renewable resources exist, but whether a technically coherent hybrid configuration can combine these resources at a cost and performance level suitable for community-scale electrification.

1.3 Aim and objectives

The aim is to assess the techno-economic, environmental and potential socio-economic performance of a solar–biomass HRES for sustainable electrification in Omoku Town. The

objectives are to: (i) characterize the solar and biomass resources reported for the study area; (ii) describe the proposed hybrid configuration and its annual energy contribution; (iii) compare the reported economic performance with a diesel-only system; and (iv) examine the reported environmental and socio-economic implications.

1.4 Contribution and significance

The manuscript consolidates the source dissertation's system configuration and reported performance indicators into a journal-style article. Its practical contribution is a place-specific assessment that links resource estimates to system sizing, costs and environmental indicators. The study may inform preliminary planning by energy developers, local authorities and community stakeholders. Its results should nevertheless be treated as model-based estimates rather than measured outcomes from an operating plant.

1.5 Research scope

The analysis focuses on Omoku Town and the solar PV–biomass–battery configuration described in the source dissertation. A diesel-only system is retained as the comparator. The manuscript does not introduce new field observations or independently rerun the HOMER Pro model; it synthesizes the dissertation's reported inputs and outputs. Where the dissertation contains conflicting estimates, these are flagged rather than silently harmonized.

2. Materials and Methods

2.1 Study area

The study area is Omoku Town in Ogba/Egbema/Ndoni Local Government Area of Rivers State, southern Nigeria. The source dissertation locates the study approximately at latitude 5.34° N and longitude 6.65° E. The local context is characterized in the source as having solar availability throughout the year and organic residues associated with agriculture, palm processing and sawmilling. Seasonal rainfall and cloud cover are relevant to PV output, while biomass use depends on the quantity, quality, collection radius and continuity of feedstock supply.

2.2 Data and system inputs

The dissertation describes an engineering and simulation-based approach using solar-resource data, biomass-residue estimates and an electricity load profile. Solar data were described as monthly irradiance observations or resource estimates for 2024, with resource characterization associated with NASA-SSE and tropical-region assumptions. Biomass estimates were compiled from residue categories including palm-related residues, cassava waste, sawdust/wood residues, municipal organic waste and other agricultural residues. The study also specifies an average load of 18 MW and daily consumption of 432 MWh/day in its resource-parameter table. These values are reproduced as reported and should be checked against the final load profile used in the optimization.

Parameter	Reported value	Role in assessment
Average global horizontal irradiance	4.77 kWh/m²/day (abstract/conclusion); 4.5 kWh/m²/day in one results table	Solar resource input

Clearness index	0.49	Solar-resource characterization
Annual biomass residues	27,500 tonnes/year (abstract/conclusion); 15,000 tonnes/year in one results table	Feedstock availability
Estimated biomass energy output	28,380 MWh/year	Indicative resource potential
Average load	18 MW	Load assumption in results table
Daily electricity demand	432 MWh/day	Calculated from 18 MW average load
Project lifetime	25 years	Economic analysis assumption
Real discount rate	8%	Economic analysis assumption
PV derating factor	80%	PV performance assumption
Biomass gasifier efficiency	25%	Conversion assumption

The source contains inconsistent biomass and irradiance figures: the abstract and conclusion report 4.77 kWh/m²/day and 27,500 tonnes/year, while a resource table reports 4.5 kWh/m²/day and 15,000 tonnes/year. The principal results presented here use the abstract/conclusion values because they are repeated in the stated optimal configuration narrative, but the difference is a material limitation requiring reconciliation from the original resource files and model inputs.

2.3 Hybrid system configuration

HOMER Pro was used in the dissertation to evaluate component combinations and identify an optimal configuration. The reported search ranges included 0–50 MW for PV, 0–30 MW for the biomass generator and 0–120 MWh for battery storage, with a 10 MW grid backup and a bidirectional converter. The selected system comprised 40 MW solar PV, 25 MW biomass generation, 100 MWh battery storage and 10 MW grid backup. The system was intended to use solar generation when available, biomass as a dispatchable renewable source, batteries to smooth short-term mismatch and grid supply as backup.

The manuscript treats the configuration as the source's reported optimization result, not as an independently verified global optimum. A reproducible optimization would require the original hourly load profile, time series of irradiance, biomass fuel properties and prices, component capital and replacement costs, fuel and grid tariffs, operating constraints, dispatch strategy and model version.

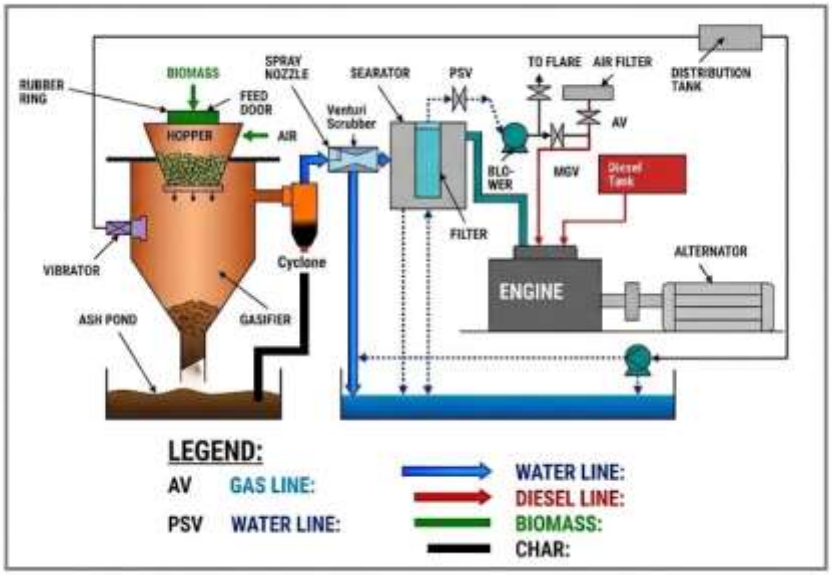


Figure 2.1: Typical Biomass Gasifier-based Power Generation System
Source: Diyoke *et al*. (2014)

2.4 Energy performance indicators

Annual generation and component contribution were assessed from the reported HOMER Pro outputs. The contribution of each component was interpreted as its annual energy divided by total annual supply. Renewable fraction was treated as the reported share of electricity supplied by renewable technologies. Battery storage is a flexibility asset and was not assigned a separate annual generation contribution in the source results.

The source reports total annual generation of 157,760 MWh, made up of 63,600 MWh from PV, 74,460 MWh from biomass and 19,700 MWh from grid backup. The component values sum to the reported total. The corresponding shares are approximately 40.3%, 47.2% and 12.5% when recalculated directly; the dissertation reports 40.1%, 47.2% and 12.7%. The paper retains the source-reported shares in narrative and flags the small arithmetic difference.

2.5 Economic assessment

Economic performance was assessed using net present cost (NPC), levelized cost of energy (LCOE), capital cost, annual operating cost, internal rate of return (IRR) and payback period. The comparison is between the solar–biomass hybrid system and a diesel-only alternative. NPC represents discounted life-cycle costs over the modelled project horizon, while LCOE expresses average cost per unit of electricity delivered. IRR and payback are investment indicators whose interpretation depends on the cash-flow assumptions, tariff revenue, replacement schedules and financing structure. The dissertation reports an NPC of ₦780 million for the hybrid system compared with ₦1.22 billion for diesel, and LCOE values of ₦92.5/kWh and ₦165/kWh, respectively. It also reports a hybrid capital cost of ₦520 million, annual operating cost of ₦6.5 million, IRR of 13.6% and payback of 6.8 years. A separate appendix passage reports $180 million NPC and $0.087/kWh LCOE for the same system; these values are materially inconsistent with the naira-denominated results and are not combined with them. They should be resolved before publication or project appraisal.

2.6 Environmental and social indicators

The environmental comparison uses the dissertation's reported annual emissions for CO_2, CH_4, SO_x, NO_x and $PM_{2.5}$ under diesel and hybrid scenarios. Percentage reductions were reported by the source and are reproduced as estimates. The assessment does not establish whether all life-cycle emissions, biomass regrowth, feedstock transport, land-use change or methane leakage were included; therefore, the results should be interpreted as modelled operational comparisons unless the underlying emissions boundary confirms otherwise.

Socio-economic indicators include household electricity cost, employment and population electricity access. The dissertation reports household cost falling from ₦250/kWh to ₦120/kWh, employment increasing from 40 to 260 jobs and access rising from 45% to 85%. These figures are treated as projected impacts reported by the source, rather than verified post-implementation outcomes. The dissertation also reports 86% support for implementation in its conclusion; the sampling frame, sample size and survey instrument should be consulted before interpreting this as representative community acceptance.

2.7 Analytical procedure

The analytical sequence was: (1) characterize the local solar and biomass resources; (2) specify load and component parameters; (3) compare candidate component combinations in HOMER Pro; (4) extract annual generation, renewable fraction and economic indicators; (5) compare reported emissions with the diesel baseline; and (6) interpret potential social implications. MATLAB was described as a supporting environment for data preprocessing, modelling, parameter estimation, sensitivity analysis and validation. Because raw data and simulation files were not supplied with the dissertation text, this manuscript does not claim to have independently reproduced the simulations.

2.8 Methodological limitations

The design is simulation-based and depends on secondary resource estimates and assumed parameters. The source itself notes limited local data and the absence of long-term operation of a full-scale installation. The manuscript additionally identifies internal inconsistencies in reported resource and cost values. These limitations restrict causal claims and make independent model verification, uncertainty analysis and field validation necessary next steps.

3. Results

3.1 Renewable resource profile

The study reported mean solar irradiance of 4.77 kWh/m²/day and a clearness index of 0.49. The described monthly pattern indicates relatively higher irradiance in February, March and December and lower levels during June, July and August, associated with rainy-season cloud cover. This seasonal pattern supports the rationale for combining PV with a dispatchable resource, since biomass can contribute when PV output falls. However, the source's results table lists average solar radiation of 4.5 kWh/m²/day, and the precise monthly values should be verified against the original resource dataset. Annual biomass residues are estimated at 27,500 tonnes in the abstract and conclusion, with an estimated energy output of 28,380 MWh/year. Residues include cassava peels, palm-kernel shells, sawdust and other agricultural wastes. A separate table lists a total of 15,000 tonnes/year, showing a discrepancy that directly affects fuel availability, plant capacity factor and cost. The feedstock assessment suggests potential for local resource recovery, but a

bankable design would need a seasonal supply inventory, moisture and heating-value tests, competing-use assessment and collection logistics.

3.2 Optimal configuration and generation mix

Component	Installed capacity	Annual generation (MWh)	Reported share
Solar PV	40 MW	63,600	40.1%
Biomass plant	25 MW	74,460	47.2%
Battery storage	100 MWh	Not reported as generation	Storage asset
Grid backup	10 MW	19,700	12.7%
Total	—	157,760	100%

The reported configuration combines 40 MW of PV, 25 MW of biomass generation, 100 MWh of battery storage and 10 MW of grid backup. Annual electricity supply is reported as 157,760 MWh. Biomass provides the largest single contribution at 74,460 MWh/year, followed by solar PV at 63,600 MWh/year. Grid backup contributes 19,700 MWh/year. The reported renewable fraction is 87.3%, consistent with the combined stated shares of PV and biomass (40.1% + 47.2%). The system architecture therefore relies on biomass for dispatchable renewable output and PV for substantial daytime generation, while storage and grid backup support balancing and reliability.

3.3 Economic results

Indicator	Solar–biomass HRES	Diesel-only comparator
Net present cost	₦780 million	₦1.22 billion
Initial capital cost	₦520 million	₦300 million
Annual operating cost	₦6.5 million/year	₦15.8 million/year
Levelized cost of energy	₦92.5/kWh	₦165/kWh
Payback period	6.8 years	Not reported
Internal rate of return	13.6%	Not reported
Renewable fraction	87.3%	0%

On the naira-denominated comparison, the hybrid system has a reported NPC ₦440 million lower than the diesel system, equivalent to a reduction of approximately 36.1% relative to the diesel NPC. The LCOE is reported to decline from ₦165/kWh to ₦92.5/kWh, a reduction of approximately 43.9%. Although the hybrid configuration requires higher initial capital investment (₦520 million versus ₦300 million), its reported annual operating cost is lower (₦6.5 million versus ₦15.8 million). The source reports an IRR of 13.6% and payback period of 6.8 years for the hybrid case. The economic interpretation is conditional on the cost basis and model assumptions. The appendix's alternative report of $180 million NPC and $0.087/kWh LCOE is not compatible with the naira-denominated comparison and could reflect a unit, scale or transcription error. A final journal submission should include a single reconciled economic table and a transparent statement of currency, exchange rate, project scale, discount rate and tariff assumptions.

3.4 Environmental results

Pollutant	Diesel system (tonnes/year)	HRES (tonnes/year)	Reported reduction
CO_2	145,000	28,500	80.3%
CH_4	390	70	82.1%
SO_x	980	130	86.7%
NO_x	1,250	260	79.2%
$PM_{2.5}$	480	90	81.3%

The reported comparison indicates substantial reductions in all five emissions categories. CO_2 emissions fall from 145,000 to 28,500 tonnes/year, an estimated 80.3% reduction. The source reports reductions of 82.1% for CH_4, 86.7% for SO_x, 79.2% for NO_x and 81.3% for $PM_{2.5}$. The largest stated proportional reduction is for SO_x. These results indicate potential local air-quality and climate benefits relative to the diesel baseline, but the environmental boundary and calculation method need to be documented to establish whether the figures include biomass combustion emissions and upstream impacts.

The dissertation also reports improvement in an Environmental Performance Index, including a 139% improvement in air quality and an 80% improvement in resource-utilization efficiency. Because the index definition, normalization method and baseline are not fully reproduced in the available results, these values are retained as source-reported indicators and should not be interpreted as universally standardized EPI scores.

3.5 Socio-economic indicators

Indicator	Baseline reported	HRES scenario reported	Change
Household electricity cost	₦250/kWh	₦120/kWh	52% reduction reported
Local employment	40 jobs	260 jobs	550% increase reported
Population electricity access	45%	85%	40 percentage-point increase
Community support	Not specified	86% in favour	Source-reported survey result

The dissertation projects a reduction in average household electricity cost from ₦250/kWh to ₦120/kWh and an increase in employment from 40 to 260 jobs. It also reports electricity access increasing from 45% to 85% of the population. These outcomes would be meaningful if realized, particularly through jobs in feedstock collection, plant operation, maintenance, distribution and administration. Nevertheless, they remain projections or reported estimates rather than observed impacts from an operating plant. The 86% community-support figure suggests social acceptance in the source's account, but interpretation requires details of sample size, sampling procedure, question wording and respondent characteristics.

4. Discussion

4.1 Resource complementarity and system reliability

The reported solar resource is sufficient to justify assessing PV as a major contributor to local electricity supply, while the described seasonal decline during the wet months illustrates the

limitations of a PV-only design. Hybridization with biomass can reduce exposure to solar variability because stored feedstock can be converted when PV output is low. This complementarity is consistent with the general rationale for HRES discussed by Sorrenti et al. (2022), Pawar et al. (2024) and Khan et al. (2023), as cited in the dissertation. However, resource complementarity is only realized when biomass supply is dependable, conversion equipment performs reliably and the system controller coordinates generation and storage.

The source reports 27,500 tonnes/year of biomass, but a results table lists 15,000 tonnes/year. This is not a minor reporting difference: it could alter the feasible biomass plant capacity, annual output, fuel costs and renewable fraction. Feedstock assessment should therefore distinguish gross residue generation from technically recoverable and economically collectible residue. Competing uses such as animal feed, soil amendment, domestic fuel and industrial processing should also be considered. Moisture content, ash content and lower heating value should be measured for locally available feedstock mixes.

4.2 Configuration and dispatch implications

The selected 40 MW PV and 25 MW biomass arrangement allocates a substantial share of energy to both renewable technologies. Biomass contributes the largest reported annual share, suggesting that the proposed system is not simply a PV installation with a minor backup generator; it is a hybrid architecture in which dispatchable biomass is central to meeting demand. The 100 MWh battery can support ramp management and short-duration balancing, but storage duration depends on the actual power rating, usable depth of discharge, efficiency and dispatch rules. Since the source does not report the battery power rating or hourly dispatch profile in the summarized results, the battery's contribution to reliability cannot be quantified from capacity alone.

The 10 MW grid connection provides a further reliability resource, but it also means that the reported 87.3% renewable fraction is not equivalent to full energy autonomy. The grid contributes 12.7% of annual supply in the source table. For practical planning, this may be an advantage where grid supply is available and can support the system during prolonged periods of poor solar output or maintenance. Conversely, grid outages may reduce the reliability benefit, so scenario analysis should test grid availability and backup constraints.

4.3 Economic interpretation

The naira-denominated results indicate that the hybrid system can reduce lifecycle cost and cost per kilowatt-hour compared with the diesel-only comparator, despite a higher initial investment. The reported 43.9% reduction in LCOE could improve affordability if savings are passed through to consumers. Lower annual operating cost is plausible where solar generation displaces purchased fuel and where biomass can be sourced at competitive prices. Yet biomass systems still incur costs for collection, transport, preprocessing, storage, ash handling, plant staffing and emissions control. These costs must be represented explicitly to avoid overstating financial attractiveness.

The reported IRR of 13.6% and payback of 6.8 years suggest potential investability under the assumptions used, but investment decisions require a reconciled cash-flow model. The discrepancy between the naira-denominated NPC of ₦780 million and the separate $180 million value is especially important. The latter cannot be treated as a simple currency conversion of the former. The source should be checked for system scale, units, decimal placement and whether the two figures refer to different configurations. Publication-quality reporting should present the currency

and price year, exchange-rate assumption, discount rate, inflation treatment, component replacement schedule, financing structure and sensitivity ranges.

Sensitivity analysis is also important because the system's economics may respond strongly to biomass fuel price, feedstock availability, PV capital cost, battery replacement cost, diesel price, grid tariff, discount rate and capacity factor. A robust follow-up should compare at least low, central and high scenarios and report how frequently the hybrid option remains least-cost. Monte Carlo or robust optimization could further represent uncertainty in resource and cost inputs, as the dissertation's literature review discusses in relation to HRES optimization (Khan et al., 2021; Ali et al., 2022; Hossain et al., 2023).

4.4 Environmental implications

The source-reported reductions across CO_2, CH_4, SO_x, NO_x and $PM_{2.5}$ indicate a potentially substantial environmental advantage over diesel-only generation. Reducing diesel combustion can reduce local exposure to fine particulate matter and nitrogen and sulfur oxides, while lower fossil carbon emissions can contribute to climate mitigation. Biomass, however, should not automatically be treated as emissions-free. The net benefit depends on feedstock sourcing, regrowth and land-use effects, combustion efficiency, particulate controls, methane leakage where digestion is used, and transport emissions. If biomass is produced from residues that would otherwise be burned or decomposed, the climate and waste-management case may be stronger, but this requires a clear baseline. The reported 80.3% reduction in CO_2 is a model result and should be presented as such until the emission factors, system boundaries and energy-equivalence basis are disclosed. A like-for-like comparison should deliver the same useful electricity and reliability level in both scenarios. If the diesel system and HRES have different unmet-load levels or generation quantities, direct annual emissions comparisons may be misleading. Future analysis should report emissions per delivered kWh alongside annual totals and include lifecycle sensitivity cases.

4.5 Socio-economic implications and implementation

Lower electricity costs and improved access can support productive uses of energy, including refrigeration, food processing, small manufacturing, health services and digital connectivity. The reported increase from 40 to 260 jobs implies that local employment could be a significant co-benefit, although the number should be disaggregated into temporary construction roles, permanent plant jobs and indirect supply-chain employment. Local hiring and training can increase community benefit, but skills development and safety procedures will be needed for biomass handling, electrical work, plant operation and maintenance.

Community acceptance is another important condition for implementation. The source reports that 86% of respondents favoured the proposed project. Such support can improve implementation prospects when community engagement is sustained and transparent. However, the study should make the survey methods available and clarify whether the question concerned general support for renewable energy or acceptance of the specific proposed facility, including its location, land requirements, traffic and emissions. Meaningful engagement should include disclosure of tariffs, complaint mechanisms, local procurement arrangements and benefit-sharing.

4.6 Comparison with the wider literature

The study's overall pattern is consistent with the broader literature summarized in the dissertation: hybridization is commonly used to manage intermittency, simulation tools support system sizing, and lifecycle cost comparisons are necessary when renewable systems have higher upfront investment but lower fuel costs (Zhou et al., 2021; Kumar et al., 2021; Olatomiwa et al., 2022). The Omoku case adds a locally specific resource combination in which solar PV is paired with agricultural and wood residues. Its value lies in linking resource assessment, system configuration and multiple performance dimensions in one planning exercise.

The results should not be generalized uncritically to other Nigerian towns. Solar availability, feedstock density, local demand, grid reliability, transport distances, tariff structures and financing conditions differ substantially across locations. The proposed configuration is best regarded as a preliminary case-study design whose transferability requires local data and recalibration.

5. Conclusion

This study assessed a proposed solar–biomass hybrid renewable energy system for Omoku Town using resource estimates and simulation results reported in the source dissertation. The reported resource profile—average solar irradiance of 4.77 kWh/m²/day and an estimated 27,500 tonnes/year of biomass residues—suggests a potentially useful combination of variable solar generation and dispatchable biomass energy. The reported configuration of 40 MW PV, 25 MW biomass, 100 MWh battery storage and 10 MW grid backup is associated with annual supply of 157,760 MWh and a renewable fraction of 87.3%.

The naira-denominated economic results indicate a lower NPC and LCOE for the hybrid system than for the diesel-only comparator, alongside a reported 13.6% IRR and 6.8-year payback. The source also estimates large reductions in several pollutant emissions and potential benefits in household electricity cost, employment and access. Taken together, these results support further development of solar–biomass hybridization as a promising option for sustainable electrification in Omoku. Nevertheless, the evidence should be treated as preliminary. Conflicting resource figures and incompatible economic estimates must be reconciled, and the emissions and socio-economic calculations require clearer documentation. The study therefore concludes that the concept is promising, but that independent model reproduction, local resource verification, transparent sensitivity analysis and operational validation are essential before the configuration is used as a definitive investment design.

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