



Techno-Economic Analysis of Solar Photovoltaic–Biomass Gasifier Hybrid Renewable Energy Systems for Remote Electrification: A Review

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Abstract. *Reliable electricity supply remains a challenge for remote communities where grid extension is technically difficult or costly. Solar photovoltaic (PV) generation offers clean daytime electricity, while biomass gasification can provide dispatchable power when solar output is insufficient. This review synthesizes the literature summarized in the source thesis and its case study of Manak Dand village, Betul district, Madhya Pradesh, India. Previous studies indicate that hybrid renewable energy systems (HRES) can improve supply continuity by combining complementary resources, storage and appropriate dispatch strategies. The thesis case models a stand-alone system using a 16 kW PV array, a 12 kW biomass gasifier-generator, battery storage and a 12 kW converter, optimized in HOMER. The reported configuration is designed for an average daily demand of 127.77 kWh and a peak demand of 8.91 kW, with a reported net present cost (NPC) of US\$57,448 and annualized cost of US\$5,081. The review discusses system architecture, sizing and economic indicators, environmental considerations, limitations and research directions. Results are case-specific and depend on local solar resource, biomass availability, demand profile, financing assumptions and component costs.*

Keywords: Solar photovoltaic; biomass gasifier; hybrid renewable energy system; rural electrification; HOMER; techno-economic analysis.

Introduction

Access to dependable electricity supports household lighting, water pumping, small businesses, education and public services. In remote and sparsely populated settlements, grid extension may require substantial infrastructure investment. Stand-alone hybrid renewable energy systems offer an alternative by coordinating locally available energy sources and storage. However, solar PV output varies with irradiance and time of day; a dispatchable biomass gasifier-generator can help supply demand during low-solar periods, provided suitable feedstock and maintenance are available.

The thesis, “Techno-Economic Analysis of Solar Photovoltaic/Biomass Gasifier Hybrid Renewable Energy System for Remote Area,” focuses on Manak Dand village (village code 485207), in Bhainsdehi tehsil of Betul district, Madhya Pradesh. It frames the problem around rural electricity needs and assesses a PV–biomass gasifier system with batteries using HOMER-based simulation and mathematical modelling. The village resource and load assumptions are central to the resulting design; therefore, its numerical findings should not be generalized to other sites without local assessment.



Literature Review

Research summarized in the thesis covers PV–biomass systems, multi-source microgrids, storage, component sizing and optimization. Malik et al. examined a PV/wind system integrated with a biomass gasifier and reported that adding biomass and storage can support demand while reducing emissions relative to diesel-only supply [1]. Mohseni et al. assessed a PV–biomass system for remote-area electrification and showed that economic assumptions such as inflation and discount rates materially affect system cost [2]. Irshad et al. investigated optimized PV–biomass supply for rural electrification, emphasizing reliability and the role of locally available biomass [3].

Other studies in the thesis broaden the comparison. Aydın and Öztürk modelled a renewable combined-heat-and-power arrangement for a rural area and evaluated economic and environmental indicators [4]. Seward et al. compared PV storage options for an off-grid Jordanian site, demonstrating that storage technology and configuration influence cost and reliability [5]. M. Gamil et al. considered uncertainty in renewable resources while sizing an isolated microgrid, illustrating the importance of testing more than a single deterministic operating condition [6]. Reviews of rural mini-grids also emphasize that technical optimization alone is insufficient: community participation, financing, policy support, demand forecasting and maintainability influence deployment [7].

Taken together, these studies support several broad observations. First, hybridization can reduce the limitations of a single intermittent source. Second, storage and dispatch logic affect both reliability and lifecycle cost. Third, optimized capacities are site-dependent and sensitive to financial and resource assumptions. Fourth, biomass can provide dispatchable generation, but its benefits depend on sustainable feedstock supply, conversion efficiency, fuel preparation and local operation and maintenance capacity [1–3, 6].

System Configuration and Methodology

The thesis models an isolated PV–biomass gasifier system with battery storage and a bidirectional converter. PV is treated as the principal daytime source; surplus PV electricity can charge the battery, while stored energy supports demand when irradiance falls. The biomass gasifier-generator supplies controllable backup power when PV and storage are insufficient. The converter supports power exchange between AC and DC components. The system is operated using HOMER's Cycle Charging strategy, as reported in the thesis.

The case-study load includes domestic lighting and appliances, fans, water pumps, commercial uses and street lighting. Seasonal daily load profiles are considered for summer, rainy and winter conditions. The thesis reports average solar radiation of 5.12 kWh/m²/day for the site and describes the village as un-electrified in the study context. Its modelled component capacities are a 16.0 kW PV array, a 12.0 kW biomass gasifier-generator, four strings of Discover 2VRE4-1500TF batteries, and a 12.0 kW converter.

A techno-economic assessment should consider at least: (i) energy balance and unmet load; (ii) component capacity and operating hours; (iii) initial capital, replacement, operation and maintenance, and fuel costs; (iv) net present cost (NPC) and annualized cost; and (v) emissions and sensitivity to uncertain inputs. NPC aggregates relevant costs over the project lifetime after applying the selected economic assumptions. Annualized cost expresses lifecycle cost as an equivalent yearly amount. Cost of energy (COE), where reported, expresses cost per unit of electricity served or produced according to the model's definition. These metrics should be compared only when study boundaries and assumptions are compatible.



Case-Study Findings and Discussion

For Manak Dand, the thesis reports an average daily electricity demand of 127.77 kWh and a peak demand of 8.91 kW. The selected configuration combines 16 kW of PV with a 12 kW biomass gasifier-generator, battery storage and a 12 kW converter. The thesis reports a total NPC of US\$57,448 and an annualized cost of US\$5,081. It identifies PV and battery storage as major capital-cost components, while the biomass generator contributes through replacement and fuel-related costs. The reported dispatch approach uses solar generation first where available, stores surplus electricity and calls on biomass generation as needed.

These findings illustrate the central design trade-off. Increasing PV and battery capacity can reduce generator runtime and fuel use, but may raise initial investment. Increasing biomass capacity can strengthen dispatchable supply, but introduces feedstock logistics, gasifier operation and maintenance requirements. The economic outcome depends on the relative costs and performance of each component, the load profile and the chosen financial assumptions. A configuration that is cost-effective for one village may not be optimal where solar irradiation, biomass type, transport distance, demand density or financing conditions differ.

The thesis also reports low annual emissions in its system output, including 3.80 kg/year of CO₂, 0.143 kg/year of CO, 0.0158 kg/year of unburned hydrocarbons, 0.0108 kg/year of particulate matter, 0 kg/year of SO₂ and 1.27 kg/year of NO_x. These values are reproduced as reported; their interpretation requires care because the model boundary, included emission sources and treatment of biomass carbon should be checked before comparing them with other studies or using them as lifecycle emissions. Biomass is not automatically emissions-free: feedstock sourcing, conversion efficiency, transport and combustion conditions all matter.

Key Challenges and Research Gaps

Several issues should be addressed before field deployment. Feedstock availability must be measured across seasons, and its moisture content, calorific value, collection cost and transport requirements should be established. Gasifier performance depends on consistent feedstock quality and trained operators. Battery lifetime, replacement schedules and end-of-life handling should be included in lifecycle costing. Solar and load data should represent seasonal variability rather than annual averages alone.

The thesis proposes future work on advanced energy management systems, smart controllers, IoT-enabled monitoring, predictive load management and fault detection. It also identifies newer battery chemistries, possible integration of wind or micro-hydro where locally feasible, sustainable biomass sourcing, financing mechanisms and potential mini-grid or grid-connected operation as areas for further investigation. These directions are consistent with the wider literature's attention to uncertainty, storage, energy management and the social and institutional conditions of mini-grid deployment [5–7].

Future studies could strengthen the evidence through field validation of simulated performance; sensitivity and scenario analysis for biomass price, discount rate, PV degradation, battery replacement and demand growth; comparison of dispatch strategies; and a transparent lifecycle emissions assessment. Reporting reliability indicators, such as unmet load or loss-of-power-supply probability, alongside NPC and COE would make the design trade-offs clearer.



Conclusion

The thesis case study presents a PV–biomass gasifier hybrid system as a model for supplying electricity to a remote village. Its reported design—16 kW PV, 12 kW biomass generation, battery storage and a 12 kW converter—is sized against an average daily demand of 127.77 kWh and peak demand of 8.91 kW. The reported NPC of US\$57,448 and annualized cost of US\$5,081 provide a baseline for evaluating the proposed configuration. The wider literature supports the use of hybrid systems to combine variable solar generation with dispatchable resources, while also showing that storage choice, dispatch, local resources and economic assumptions strongly influence results.

The evidence is simulation- and site-specific. Before replicating the design, planners should verify the local load, solar resource, sustainable biomass supply, emissions boundary, component lifetime and financing assumptions. Field monitoring and sensitivity analysis would help determine whether the proposed configuration remains reliable and affordable under real operating conditions.

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