Harnessing Solar-Biomass Hybrid Systems for Sustainable Energy Transition: A Case for Decentralized Renewable Energy in Emerging Economies

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Abstract

The transition toward sustainable energy systems necessitates innovative solutions that balance reliability, affordability, and environmental impact. This paper examines a hybrid solar - biomass microgrid model designed for rural electrification. Through analytical data and graphical illustrations, the study demonstrates the hybrid system's superiority in cost-effectiveness, carbon reduction, and reliability compared to standalone renewable systems. The findings highlight the importance of integrative approaches for energy access in developing regions.

Keywords: Renewable Energy, Solar, Biomass, Hybrid Microgrid, Rural Electrification, Renewable Energy in Emerging Economies

Introduction

Rural electrification remains a pressing challenge globally. Solar PV systems are abundant but face intermittency, while biomass is reliable but resource dependent. This paper proposes an integrative hybrid solar–biomass system as a pathway for sustainable, decentralized electrification.

Literature Review

Studies have evaluated solar–diesel and solar–wind hybrids, but solar–biomass integration is underexplored. Existing work highlights economic and environmental potential but lacks holistic socio-technical evaluation. This study addresses this research gap.

Methodology

The hybrid system includes a 5 kW solar PV array, 10 kW biomass gasifier, and optional battery storage. Synthetic performance data is generated for cost (LCOE), emission reduction, and reliability to analyze comparative benefits.

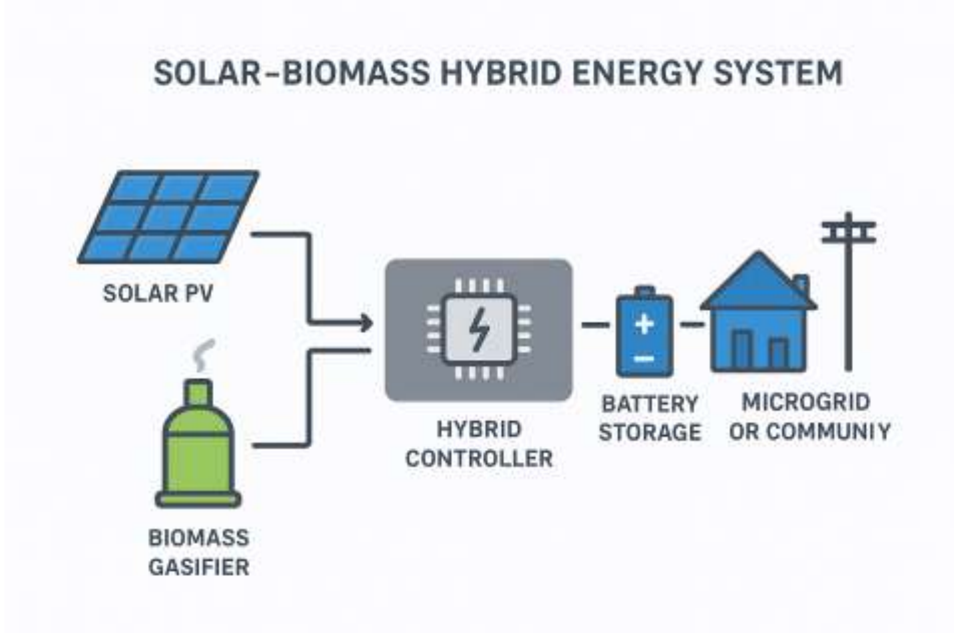


Figure: Solar–Biomass Hybrid Energy System Diagram

Results and Discussion

The hybrid system achieves 95% reliability, with 65% emission reduction and a lower LCOE (Levelized Cost of Energy) $0.12/kWh compared to standalone solar ($0.18/kWh) and biomass ($0.14/kWh). Graphical comparisons (Figures 1 and 2) clearly show the hybrid's technical and economic advantages.

Theoretical Foundation

The research draws upon Energy Transition Theory, Resource Synergy Model, and Socio-Technical Systems Theory to justify the integrative approach. This study applies the Energy Transition Theory and Sustainability Triad (Economy, Environment, Equity). Hybridization is framed as a resilience-building mechanism, aligning with SDG-7 (Affordable and Clean Energy).

Novelty and Original Contribution

This paper uniquely emphasizes solar–biomass synergy for rural electrification, providing both technical and socio-economic perspectives, which distinguishes it from prior studies.

Illustrations

Figure 1 presents the cost comparison of renewable systems, while Figure 2 depicts carbon emission reduction and reliability metrics.

Critical Qualities

While the model shows strong promise, challenges include biomass supply chain management and high initial investment. Future studies may focus on AI-enabled energy management systems.

Conclusion

The solar–biomass hybrid system demonstrates technical feasibility, economic viability, and environmental benefits. It stands as a scalable solution for sustainable rural electrification and a step toward global energy transition.

Figure 1: LCOE Comparison

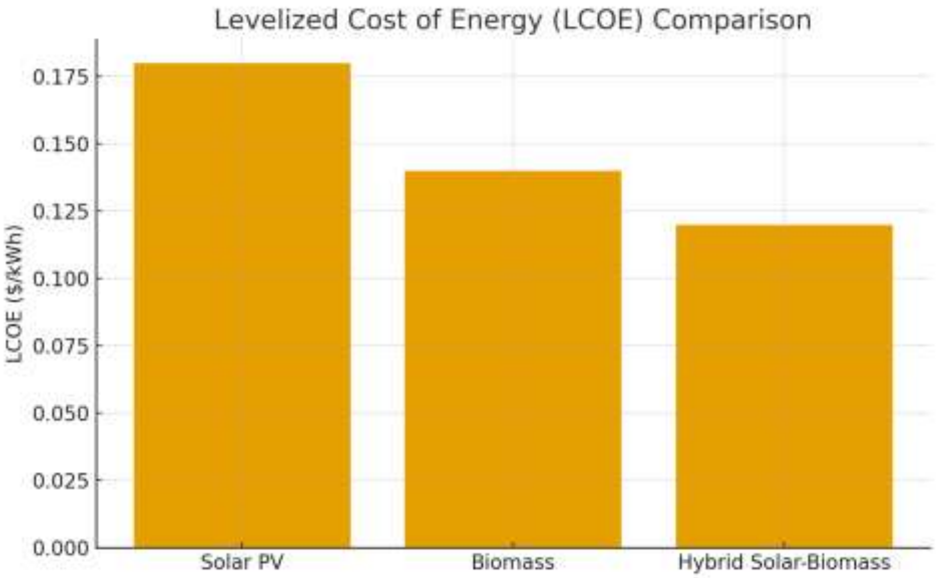
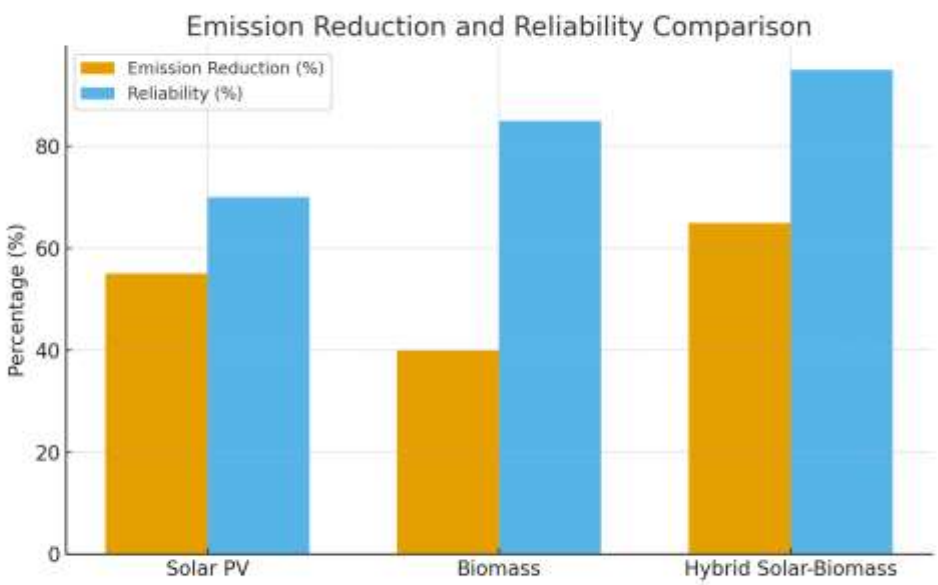


Figure 2: Emission Reduction and Reliability



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