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Techno-Economic Optimisation of a Grid-Connected Solar PV–Biomass Hybrid Microgrid Using HOMER Pro: A Case Study of GNDEC Ludhiana

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Abstract: This paper presents the design, simulation, and comparative optimisation of a grid-connected hybrid microgrid for Guru Nanak Dev Engineering College (GNDEC), Ludhiana, using HOMER Pro. The study evaluates solar photovoltaic (PV), biomass generation, battery storage, converter, and utility-grid combinations against a conventional grid-only configuration. The campus annual electrical demand is 3,219,990 kWh/year, with an average daily demand of 8,822 kWh/day and a maximum recorded peak of 773 kW. Six system cases and a grid-only base configuration were simulated over 8760 hours using technical, economic, renewable-energy, and environmental indicators. The comparative results identify the PV–biomass–grid configuration (Case 2) as the best overall option, with a Net Present Cost (NPC) of ₹156.95 million, Levelized Cost of Energy (LCOE) of ₹2.97/kWh, renewable fraction of 79.6%, grid dependency of 18.3%, and annual CO_2 emissions of 75,268 kg/year. Case 1, which adds battery storage, gives an NPC of about ₹156 million, LCOE of ₹2.98/kWh, renewable fraction of 79.4%, and emissions of 81,855 kg/year. Compared with the grid-only base, the selected configuration substantially reduces lifecycle cost, electricity cost, grid dependence, and emissions while maintaining zero unmet load and zero capacity shortage.

***Index Terms* -** Hybrid microgrid, Solar PV, Biomass; HOMER Pro, Techno-economic optimization.

I. Introduction

1.1 Background

The electricity requirement of institutions has increased with the expansion of buildings, laboratories, workshops, hostels, administration, computing facilities, and other electrical services. The thesis identifies continued dependence on conventional electricity supply with resource depletion, environmental degradation, rising energy costs, and carbon emissions as major concerns. Renewable sources offer an alternative, but individual renewable technologies have operational limitations. Solar PV is clean and available during daylight, yet its output varies with solar radiation and weather. Biomass, in contrast, is dispatchable and can provide electricity when solar production is inadequate. Their complementary operation therefore provides a basis for a more dependable hybrid supply.

The selected application is Guru Nanak Dev Engineering College (GNDEC), Ludhiana, Punjab. The study uses a grid-connected microgrid containing solar PV, biomass generation, battery storage, power conversion, and the utility grid. The site is reported at 30°51.5' N latitude and 75°51.7' E longitude. The campus annual electrical load is 3,219,990 kWh/year, equivalent to an average daily load of 8,822 kWh/day, with a peak demand of 769 kW in the electrical-load characteristics table. The monthly peak analysis further records a maximum of 773 kW in August. The solar resource assessment indicates adequate solar radiation throughout the year, while the study identifies agricultural residues as a biomass resource available in Punjab. Within this framework, the study is significant because it does not treat renewable generation as an isolated source. Instead, it examines the interaction between renewable production, storage, grid exchange, and the actual institutional load. The comparative approach also makes it possible to identify whether battery storage is economically justified when biomass is already available as a dispatchable source. The final decision is therefore based on measured simulation outcomes rather than an assumption that the most technologically complex system must be the best system.

1.2 Research Problem

The central research problem is the selection and sizing of renewable and supporting components so that the campus load can be supplied reliably at minimum lifecycle cost and with lower environmental impact. A hybrid microgrid contains interacting design variables: renewable capacities, storage, converter capacity, utility-grid exchange, resource availability, and load variation. Oversizing can increase capital expenditure, while undersizing can increase grid purchases or compromise the intended renewable contribution. Solar variability creates another challenge because high daytime generation does not necessarily coincide with demand. Biomass can compensate for low-solar periods, while batteries can shift surplus renewable energy to later periods.

The thesis also identifies a gap in applying site-specific optimisation to a grid-connected PV–biomass system while considering technical, economic, and environmental indicators together. Earlier configurations reviewed in the thesis frequently considered different resource combinations, stand-alone operation, limited storage treatment, or restricted load types. The present study therefore focuses on a common GNDEC load profile and compares multiple configurations under the same HOMER Pro simulation framework.

1.3 Research Objective

The objective is to identify the most suitable configuration for the GNDEC campus by jointly considering technical adequacy, economic performance, renewable-energy penetration, grid dependence, and environmental performance. The optimisation seeks to maintain uninterrupted supply without unmet load or capacity shortage, reduce NPC and LCOE, decrease electricity purchased from the utility, increase renewable contribution, and reduce CO_2 emissions. To meet these objectives, the study models solar PV, biomass, battery storage, converter, and grid components and evaluates alternative combinations. The final selection is based on comparative performance rather than on a single economic indicator. This approach allows the configuration with the most balanced overall performance to be distinguished from alternatives that may be strong in only one dimension.

II. Literature Review

2.1 Solar PV, Biomass and Hybrid Renewable Systems

The literature reviewed in the thesis establishes solar PV as an important renewable electricity technology because of its availability and environmental advantages. Nema et al. reported that PV provides clean and sustainable generation but requires integration with another source or storage because of intermittency. Mekhilef et al. associated PV integration with reduced carbon emissions and operating costs, while Kalogirou emphasised the importance of complementary technologies for overcoming solar variability. These findings support the use of PV as the principal renewable source in the GNDEC model, but not as the only source where continuous supply is required.

Biomass is presented as a controllable renewable source that can provide electricity when intermittent renewable resources are insufficient. McKendry described biomass as a versatile energy resource suitable for integration with intermittent sources, while Demirbas linked biomass utilisation with reduced conventional-fuel dependence. Saidur et al. highlighted the backup capability of biomass generation. The thesis therefore treats biomass as a dispatchable complement to PV, particularly during low-solar and night-time periods.

2.2 HOMER Pro Optimisation and Research Gap

Hybrid renewable systems combine different resources to improve reliability, energy security, renewable penetration, and economic performance. The reviewed studies in the thesis report favourable outcomes from combining complementary renewable resources, including PV and biomass. Bajpai and Dash concluded that hybrid configurations can improve reliability and lower operating costs, while Singh and Baredar reported reliable rural electrification from PV–biomass configurations with reduced emissions and lifecycle costs.

The thesis also identifies HOMER Pro as the principal optimisation tool for comparing alternative configurations. Lambert et al. described HOMER as a tool for comparing system configurations using economic indicators such as NPC and LCOE. Bahramara et al. reported its usefulness for technical and economic assessment, and Olatomiwa et al. associated HOMER-based optimisation with improved renewable utilisation and lower energy costs. The reviewed evidence supports a multi-criteria site-specific evaluation. The research gap identified in the thesis is the need to optimise the interaction of PV, biomass, battery, converter, and grid for the particular GNDEC load while simultaneously considering economic, technical, renewable, and environmental outcomes. Taken together, the reviewed work indicates that PV contributes low-cost daytime generation, biomass supplies controllable support, and hybridisation can reduce the weaknesses of individual technologies. At the same time, the thesis notes that many earlier studies did not provide the same site-specific combination of load, grid connection, biomass, storage, and multi-criteria comparison used here. This establishes the rationale for the present GNDEC assessment.

III. METHODOLOGY

3.1 Study Site and Input Data

The study uses the GNDEC campus as the application site. The location entered into HOMER Pro is Guru Nanak Dev Engineering College, Ludhiana, Punjab, at 30°51.5' N and 75°51.7' E. The electrical demand consists of an AC primary load with annual consumption of 3,219,990 kWh/year and average daily consumption of 8,822 kWh/day. The load profile is represented by 8760 hourly values so that seasonal and operational variations can be included in simulation. The peak-demand table records monthly values ranging from 623 kW in February to 773 kW in August.

Solar resource information is generated in HOMER Pro from the selected geographical coordinates. The thesis reports adequate solar radiation throughout the year and a PV capacity factor of about 18.97% for the 2022 kW PV configuration. The base PV assessment gives annual generation of 3,360,524 kWh/year. Biomass data are represented by a 500 kW generator with annual production of 834,075 kWh/year, annual biomass consumption of 2,555 tons, 2,407 operating hours/year, and 30.5% electrical efficiency. The proposed battery arrangement is used for storing surplus renewable energy and supplying energy when renewable output is insufficient; the initial storage capacity described for the proposed microgrid is 137 kWh, with 82.3 kWh usable energy.

3.2 System Modelling and Simulation

HOMER Pro is used for system modelling, hourly simulation, optimisation, economic evaluation, and environmental assessment. The study evaluates NPC, LCOE, renewable fraction, grid dependency, CO_2 emissions, energy production, and load adequacy. The model includes PV, biomass generator, battery storage, converter, and utility grid. The operating logic described in the thesis allows PV generation to serve daytime demand, biomass to support periods of insufficient solar generation, batteries to store surplus renewable electricity, and the grid to act as a reserve and energy-exchange source.

Seven configurations are considered in the analysis: the grid-only base configuration and six evaluated cases. Case 1 contains PV, biomass, battery, converter, and grid; Case 2 contains PV, biomass, converter, and grid; Case 3 contains PV, battery, converter, and grid; Case 4 contains PV, converter, and grid; Case 5 contains biogas/biomass generation and grid; and Case 6 is grid-only. Each configuration is separately simulated under the same annual operating horizon. The selection procedure compares the resulting technical, economic, and environmental indicators and ranks the alternatives.

3.3 Evaluation Criteria and Selection

The economic indicators are based on NPC and LCOE. NPC represents the lifecycle cost of the system, while LCOE expresses the cost per unit of annual electrical energy supplied. Renewable fraction is used to quantify renewable contribution, while grid dependency measures the share associated with utility supply. Environmental performance is assessed primarily through annual CO_2 emissions. System adequacy is checked through unmet load and capacity shortage. The thesis reports zero unmet load and zero capacity shortage for all compared configurations, allowing the main distinction between cases to arise from cost, renewable penetration, grid dependence, and emissions. This multi-criteria structure prevents selection based solely on initial cost and provides a consistent basis for identifying the best-performing configuration.

IV. Results and Discussion

4.1 Load and Resource Characterisation

The GNDEC microgrid is modelled around an annual AC primary load of 3,219,990 kWh/year and an average daily demand of 8,822 kWh/day. The monthly peak-demand profile reaches 773 kW in August, while the annual load is represented through 8760 hourly values. The grid-only monthly purchase profile ranges from 228,211 kWh in February to 299,729 kWh in August. The resource model uses the GNDEC coordinates in HOMER Pro and reports adequate solar radiation throughout the year. A 2022 kW PV reference configuration produces 3,360,524 kWh/year with a capacity factor of about 19%. The biomass resource is represented by a 500 kW generator producing about 834,075 kWh/year, operating 2,407 hours/year at 30.5% electrical efficiency and consuming about 2,555 tons/year of biomass. The proposed battery concept stores surplus renewable electricity and has an initial capacity of 137 kWh, of which 82.3 kWh is usable.

4.2 Case 1: PV–Biomass–Battery–Grid

Case 1 is the complete PV–biomass–battery–grid arrangement. HOMER selects 2022 kW PV, a 500 kW biomass generator, 72 battery strings, and an 800 kW converter. Annual generation comprises 3,360,524 kWh PV (65.2%), 834,075 kWh biomass (16.2%), and 961,515 kWh grid purchases (18.6%), for 5,156,114 kWh total generation. Renewable fraction is 79.4%, renewable production is 104% of load, and grid dependency is 18.6%. Grid sales are 832,727 kWh/year. The system has zero unmet load and zero capacity shortage. NPC is about ₹156 million and LCOE is ₹2.98/kWh. Annual CO_2 emissions are 81,855 kg/year. The case therefore combines high renewable penetration with storage-based operating flexibility.

4.3 Case 2: PV–Biomass–Grid

Case 2 removes the battery while retaining PV, biomass, converter, and grid. Its optimised capacities are 2137 kW PV, 500 kW biomass, and 800 kW converter. PV produces 3,551,463 kWh/year (66.2%), biomass produces 834,025 kWh/year (15.5%), and grid purchases contribute 981,363 kWh/year (18.3%), giving 5,366,851 kWh/year total generation. Renewable production is 107% of load and 81.7% of total generation, while renewable fraction is 79.6%. Grid sales are 862,997 kWh/year. There is zero unmet load and zero capacity shortage. NPC is ₹156.95 million and LCOE is ₹2.97/kWh. CO_2 emissions are only 75,268 kg/year, with CO, SO_2 and NO_x emissions of 5.11, 324 and 162 kg/year. The case gives the lowest LCOE and lowest emissions among the compared configurations.

4.4 Case 3: PV–Battery–Grid

Case 3 combines 2068 kW PV, 201 battery strings, an 800 kW converter and the grid. PV generates 3,436,899 kWh/year, equal to 69.7% of system generation, while grid purchases provide 1,492,995 kWh/year (30.3%). Total generation is 4,929,895 kWh/year, with zero unmet load and capacity shortage. Renewable production is 89.2% of load and renewable contribution to total generation is 69.7%. The battery charges 46,974 kWh/year and discharges 40,903 kWh/year, with 0.625-hour autonomy. NPC is ₹227.3 million, LCOE is ₹4.56/kWh, and CO_2 emissions are 544,118 kg/year.

4.5 Case 4: PV–Grid

Case 4 is the PV–grid configuration without biomass or battery. The optimised design contains 2137 kW PV and an 800 kW converter. PV produces 3,551,463 kWh/year (68.0%) and grid purchases provide 1,671,855 kWh/year (32.0%), giving 5,223,318 kWh/year total generation. Grid sales are 662,284 kWh/year and the system has zero unmet load and capacity shortage. NPC and LCOE are ₹233.07 million and ₹4.64/kWh, respectively. CO_2 emissions are 638,049 kg/year. The absence of storage leaves some solar energy unused during low-load periods.

4.6 Case 5: Biogas/Biomass–Grid and Case 6: Grid-Only

Case 5 uses biogas/biomass generation with the grid. The generator produces 821,250 kWh/year (24.9%), while grid purchases supply 2,478,958 kWh/year (75.1%); total generation is 3,300,208 kWh/year. Renewable contribution is 24.9%, and 80,218 kWh/year is sold to the grid. Feedstock consumption is 2,555 tons/year, with 7 tons/day average requirement and 2.18 kg/kWh specific fuel consumption. NPC is ₹256.74 million and LCOE is ₹6.02/kWh. CO_2 emissions are 1,516,464 kg/year. Case 6, the grid-only reference, supplies the complete 3,219,990 kWh/year load from the utility. It has 100% grid dependency, 0% renewable fraction, NPC of ₹333 million, LCOE of ₹8.00/kWh, operating cost of ₹25.8 million/year, and CO_2 emissions of 2,035,034 kg/year.

Across the cases, all systems record zero unmet load and zero capacity shortage. The combined PV–biomass cases have the highest renewable penetration and the lowest grid dependency, making their balance of technical and economic performance particularly strong.

TABLE 1. COMPARATIVE TECHNO-ECONOMIC AND TECHNICAL RESULTS

Case	Configuration	NPC (₹ million)	LCOE (₹/kWh)	Renewable fraction (%)	Grid dependency (%)
Base	Grid only	333.00	8.00	0.0	100.0
1	PV + Biomass + Battery + Grid	156.00	2.98	79.4	18.6
2	PV + Biomass + Grid	156.95	2.97	79.6	18.3
3	PV + Battery + Grid	227.30	4.56	69.7	30.3
4	PV + Grid	233.07	4.64	68.0	32.0
5	Biogas + Grid	256.74	6.02	24.9	75.1
6	Grid only	333.00	8.00	0.0	100.0

TABLE 2. ANNUAL GENERATION AND ENVIRONMENTAL COMPARISON

Case	Renewable generation (%)	Grid contribution (%)	CO_2 (kg/year)	Reduction vs. base (%)
Base	0.0	100.0	2,035,034	0.00
1	81.4	18.6	81,855	95.98
2	81.7	18.3	75,268	96.30
3	69.7	30.3	544,118	73.26
4	68.0	32.0	638,049	68.65
5	24.9	75.1	1,516,464	25.48
6	0.0	100.0	2,035,034	0.00

The numerical comparison shows that the most favourable configuration is not simply the system with the largest renewable output; it is the system that balances cost, reliability, renewable penetration, grid interaction, and emissions. Case 2 achieves the lowest LCOE at ₹2.97/kWh, a renewable fraction of 79.6%, grid dependency of only 18.3%, and the lowest annual CO_2 emissions of 75,268 kg/year. Relative to the grid-only base, its NPC decreases from ₹333 million to ₹156.95 million, while LCOE falls from ₹8.00/kWh to ₹2.97/kWh. CO_2 emissions decrease by 96.30%. Case 1 has almost identical economic and technical performance but adds battery storage; its LCOE is ₹2.98/kWh and emissions are 81,855 kg/year. The storage option provides an additional energy-management function but does not improve the headline economic or environmental indicators enough to displace Case 2.

The PV-only configurations demonstrate that solar generation alone can sharply reduce grid dependence and emissions, but their NPC and LCOE remain higher than those of the PV–biomass cases. Case 5 shows that biomass without PV is less effective economically and technically in this application. Overall, the results support the thesis ranking of Case 2 as best overall and Case 1 as the next-best choice. An important practical observation is that all configurations maintain supply adequacy, so the optimisation is primarily a question of how efficiently that adequacy is achieved. The addition of biomass to PV reduces the need for grid purchases during periods when solar output is unavailable, whereas the battery provides energy shifting but also introduces an additional component. Consequently, Case 2 achieves the best overall ranking despite not containing a battery. Case 1 remains attractive because its storage capability can improve operational flexibility even though its headline metrics are slightly less favourable.

V. CONCLUSION & FUTURE SCOPE.

The study concludes that a grid-connected PV–biomass hybrid microgrid can significantly improve the economic, renewable, and environmental performance of the GNDEC campus. Among the evaluated configurations, **Case 2 (PV–biomass–grid)** was the best overall, with an NPC of ₹156.95 million, LCOE of ₹2.97/kWh, 79.6% renewable fraction, and 96.3% reduction in CO_2 emissions compared with the grid-only system. The results demonstrate that combining solar PV with dispatchable biomass generation can reduce grid dependence while maintaining reliable power supply.

- Integrate additional renewable resources such as wind, mini-hydroelectric generation, and fuel cells to increase diversity of supply and reduce utility-grid dependence.
- Evaluate advanced storage options, including lithium-ion, flow, and hybrid energy-storage systems, to improve renewable-energy utilisation and energy management.
- Develop an intelligent energy-management system using artificial intelligence, machine learning, and IoT for real-time generation control, load scheduling, and demand forecasting.

VI. REFERENCES

1. Bajpai, P., & Dash, V. (2012). Hybrid renewable energy systems for power generation in stand-alone applications: A review.
2. Demirbas, A. (2009). Political, economic and environmental impacts of biofuels: A review.
3. Kavadias, K. A., & Triantafyllou, P. (2021). Hybrid Renewable Energy Systems' Optimisation.
4. Kaabeche, A., Belhamel, M., & Ibtiouen, R. (2011). Sizing optimization of grid-independent hybrid photovoltaic/wind power generation system.
5. Kalogirou, S. A. (2014). Solar Energy Engineering: Processes and Systems.
6. Akella, A. K. (2009). Social, economical and environmental impacts of renewable energy systems.
7. Mekhilef, S., Saidur, R., & Safari, A. (2011). A review on solar energy use in industries.
8. Lund, H. (2007). Renewable energy strategies for sustainable development.