International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 10 Issue: 10 | Oct - 2026 SJIF Rating: 8.659 ISSN: 2582-3930

Techno-Economic Evaluation of Renewable and Hybrid Microgrid Configurations Using HOMER Pro

Haindavi Siddabathula[1], K. Vaisakh[2]
[1]student, Department of Electrical Eng, College of Eng., Andhra University
[2]Professor, Department of Electrical Eng, College of Eng., Andhra University

Abstract - **The integration of renewable energy sources into microgrids requires careful selection of generation, storage, and energy-management configurations because renewable intermittency, component costs, load demand, and grid interaction directly influence the economic performance of the system. The current paper includes a techno-economic analysis of ten microgrid options in Visakhapatnam, India, using HOMER Pro software. The software was used to evaluate microgrid systems that include photovoltaics, wind turbines, biomass, batteries, diesel generators, the grid, and hydrogen storage. The analysis was conducted using the same location-specific data on wind, solar energy, and load. The analysis results in systems' initial costs, annual costs, net present costs (NPC), cost of energy (COE), and renewable fraction. According to the results, there is a significant variation in the results in terms of costs, with the highest total NPC in the option reaching $1.42 million to $27.06 million and the lowest – $0.0987/kWh to $1.7700/kWh. The option that includes photovoltaics, batteries, and the grid had the lowest COE of $1.42 million), while the hydrogen-integrated PV-wind-grid-battery system yields the lowest COE ($0.0987/kWh and the lowest NPC of $1.604 million. Thus, it was found that increasing the share of renewables or using complex storage is not necessarily beneficial in terms of economic indicators. Instead, a combination of factors should be considered when choosing a microgrid option, including the share of renewables in the system, initial investment, operational costs, and the degree of dependence on the grid.**

Keywords— Microgrid, HOMER Pro, photovoltaic, wind energy, biomass, battery energy storage, hydrogen storage, net present cost, cost of energy, techno-economic analysis.

I. INTRODUCTION

The increasing penetration of renewable energy technologies has created new opportunities for decentralized electricity generation and flexible microgrid operation [11]. Photovoltaic (PV) and wind energy systems can reduce dependence on conventional generation and contribute to the diversification of electricity supply [14]. However, the intermittent nature of renewable resources creates challenges related to generation availability, storage requirements, system sizing, and economic operation [18]. Consequently, the selection of an appropriate microgrid configuration requires simultaneous consideration of technical characteristics, resource availability, load demand, and lifecycle economics [24].

A microgrid may contain one or more renewable energy sources together with batteries, conventional generators, grid interconnection, and other energy-storage technologies [11]. The resulting system configuration strongly affects both investment and operating expenditure. A configuration with a high renewable fraction may require substantial initial investment, whereas a grid-supported configuration may have lower capital expenditure but greater dependence on electricity purchases [25]. Similarly, the introduction of hydrogen production and storage can provide an additional energy-storage pathway but also introduces additional components and associated capital costs [29].

HOMER Pro is widely used for the design and techno-economic evaluation of hybrid renewable energy systems [24]. The software permits different generation and storage technologies to be combined and evaluates candidate systems using economic and technical parameters [26]. Previous studies have applied HOMER-based analysis to grid-connected hybrid systems [7], rural electrification [28], institutional loads [2], residential applications, and renewable-storage systems [21]. The existing literature demonstrates the usefulness of techno-economic optimization for identifying suitable combinations of renewable generation, storage, conventional generation, and grid interaction [8].

However, many studies concentrate on a particular hybrid configuration or compare a relatively limited number of alternatives [27]. A direct comparison of substantially different architectures under a common

site, load, and economic framework can provide additional insight into the effect of system configuration on lifecycle cost [25]. In particular, comparing single-source systems, hybrid renewable systems, conventional-generator-supported systems, grid-connected systems, high-wind systems, and hydrogen-integrated systems provides a broader view of the economic trade-offs involved in microgrid planning [19].

The present study therefore investigates ten alternative microgrid configurations using HOMER Pro for Visakhapatnam, India. Visakhapatnam is a coastal location with exploitable solar and wind resources, making it suitable for investigating renewable-based microgrid configurations. Solar radiation, wind speed, and temperature data are incorporated into the model, while a scaled electrical load is used consistently for the comparative assessment [20, 25]. The configurations are evaluated using initial capital cost, annual operating cost, NPC, COE, and renewable fraction [9].

The main purpose of the study is not to propose a new optimization algorithm but to provide a systematic comparative evaluation of different microgrid architectures using a common HOMER Pro framework [26]. The comparison helps identify how different combinations of renewable sources, storage technologies, conventional generation, grid supply, and hydrogen storage affect the economic performance of the system [29].

A. Research Gap

Previous HOMER-based studies have demonstrated the feasibility of individual renewable and hybrid configurations [28]. However, the economic characteristics of different architectures can vary significantly even when the systems are designed for the same electrical demand [25]. Direct comparison becomes particularly important when configurations contain substantially different combinations of renewable sources, conventional generation, storage technologies, and grid interaction [17].

The present study addresses this gap by evaluating ten distinct configurations under a common case-study framework. The configurations include single-renewable-source systems, renewable hybrids, biomass-based generation [3], diesel-supported systems [20], grid-connected systems [7], high-wind systems [21], and hydrogen-integrated storage [29]. This provides a broader comparison of the economic consequences of changing system architecture.

B. Problem Statement

The selection of a suitable microgrid configuration involves a trade-off between capital investment, annual operating expenditure, renewable contribution, and lifecycle energy cost [21]. A configuration with a larger renewable fraction may not necessarily have the lowest NPC, while a system with low initial investment may have higher long-term grid or fuel expenditure [25]. Therefore, evaluating only one economic indicator may provide an incomplete representation of system performance [26].

This study addresses the problem by comparing ten alternative microgrid configurations using multiple economic indicators rather than relying on a single metric [25].

II. SYSTEM DESCRIPTION AND INPUT DATA

A. Study Area

The selected study location is Visakhapatnam, Andhra Pradesh, India, approximately at 17.68°N latitude and 83.21°E longitude as shown in fig 1. The coastal location provides suitable conditions for investigating both solar and wind-based generation. The resource data used in the study include solar radiation, wind speed, and temperature data corresponding to the study location.



The renewable resource characteristics are particularly important because they determine the expected availability of PV and wind generation throughout the year. Solar radiation is represented using global horizontal irradiance (GHI), while wind speed is incorporated into the wind turbine model. Temperature data are considered because PV output and other system characteristics can be affected by environmental conditions.

Fig 1 Geographical Location of Visakhapatnam, India.

B. Solar Resource

The annual average solar radiation considered in the model is approximately 5.07 kWh/m²/day. The available data indicate seasonal variation in solar radiation, with higher values occurring during the pre-monsoon period. The reported monthly values include approximately 4.89 kWh/m²/day in January, 6.36

kWh/m²/day in March, 6.69 kWh/m²/day in April, and approximately 4.19–4.20 kWh/m²/day during July and August which is shown in below figure 2.

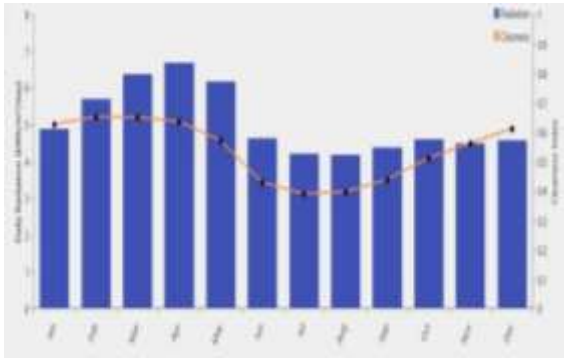


Fig 2 Solar GHI of the location.

C. Wind Resource

The annual mean wind speed used in the study is approximately 5.12 m/s. The wind resource shows significant seasonal variation, with higher wind speeds during the southwest monsoon period. The reported values include approximately 3.61 m/s in January, 3.73 m/s in February, 6.59 m/s in June, 6.77 m/s in July, 6.24 m/s in August, and 4.74 m/s in September as shown in figure 3.

A hub height of approximately 17 m is considered for the wind turbine model. The seasonal variation in wind speed is incorporated directly into the HOMER Pro simulation to determine the expected annual contribution of the wind turbine.

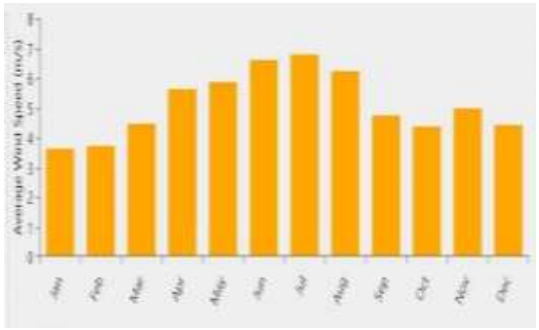


Fig 3 Wind Speed Resources from the NASA

D. Temperature

Temperature is incorporated into the model to represent the environmental conditions of the selected site. The reported average temperatures include approximately 22.93 °C in January, 30.75 °C in May, 29.31 °C in June, and 22.46 °C in December. The highest temperatures occur during the pre-monsoon period, while lower temperatures occur during winter. The temperature resources from NASA are take as below shown in figure 4.

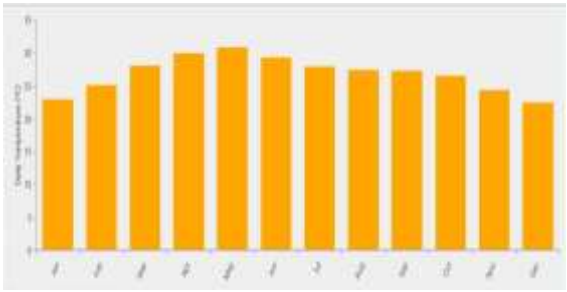


Fig 4 Ambient Temperature Resource from NASA

E. Electrical Load

The electrical demand represents a mixed community load incorporating domestic and rural-industrial activities. The industrial component represents applications such as small manufacturing, cold storage, milk processing, and cottage industries.

The original load profile used in the model has an average daily energy demand of approximately 4,754 kWh/day, corresponding to an average power of approximately 198.08 kW and a peak demand of approximately 504.26 kW as shown in figure 5. A scaled load is subsequently used for the comparative simulations, with an average daily demand of approximately 2,947 kWh/day, an average power demand of approximately 122.79 kW, and a peak demand of approximately 312.59 kW. The load factor is approximately 0.39.

The same scaled demand is maintained for the comparative cases so that differences in economic performance arise primarily from the selected system architecture rather than from changes in electrical demand.

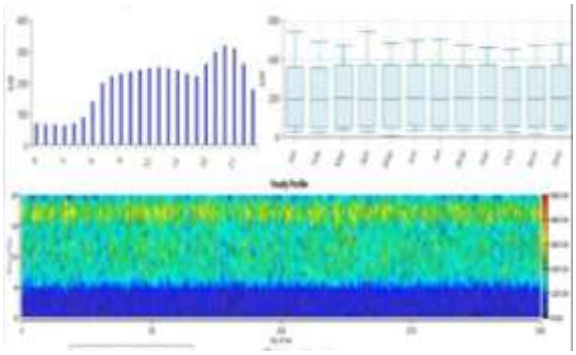


Fig 5 Electrical Load Profile of the System

F. Component Models and Economic Parameters

The principal components considered in the HOMER Pro model are PV modules, wind turbines, biomass generation, diesel generation, battery storage, a bidirectional converter, grid connection, electrolyzer, hydrogen storage tank, and hydrogen-fueled generation.

TABLE I PRINCIPAL COMPONENT PARAMETERS USED IN THE HOMER PRO MODEL

Component / Category	Parameter	Value
Generic Bio-Generator	Capacity in kw Sizing Range in kw Capital in $ Replacement in $ O&M in $ Min Load Ratio in % Lifetime in hrs	500 kW (default) Sizing: 0–250 kW $3,000 $1,250 $0.10 50% 20,000 hrs
Grid	Power Price in $/kwh Sellback Price in $/kwh	$0.100 / kWh $0.050 / kWh
Wind Turbine (Generic3kW)	Capacity in kw Hub Height in m Lifetime in yrs Capital in $ Replacement in $ O&M in $	3 kW 17 m 20 yrs $18,000 $18,000 $180
Electrical Load	Baseline (Avg, Peak, Load Factor) Scaled (Avg, Peak, Load Factor)	4,754 kWh/day, 504.26 kW peak, 0.39 LF 2,947 kWh/day, 312.59 kW peak, 0.39 LF
Random Variability	Day-to-Day in % Timestep in %	10% 20%
Converter	Converter (Cap, Capital, Repl, O&M) Inverter (Lifetime, Efficiency) Rectifier (Rel. Cap, Efficiency)	630 kW, $300, $300, $0 15 yrs, 95% 100%, 95%
PV (Flat Plate)	Capacity in Kwh Derating Factor Lifetime in yrs Capital in $ Replacement in $ O&M in $ Sizing in kw	25 kW 85% 25 yrs $3,000 $3,000 $10 0 – 25 kW
Battery	Voltage in v Nominal Capacity kwh Roundtrip Eff. In % Max Charge Current String Size SOC (Initial / Min) Capital in $ Replacement in $ O&M in $ Lifetime in yrs Throughput in kwh	12 V 12.8 kWh 97% 970 A 1 100%, 30% $745 $745 $74 15 yrs 13,707.10 kWh
Deferred Load	Scaled Annual Avg Storage Cap in kwh Peak Load in kw	500 kWh/day 1,500 kWh 75 kW
Diesel Generator	Capacity in kw Fuel Price in $/L Lifetime in yrs Capital in $ Replacement in $ O&M in $ Min Load Ratio in %	500 kW $1/L 15,000 hrs $15,000 $15,000 $5 25%
Electrolyzer	Capacity in kw Search Size Range Capital in $ Replacement in $ O&M in $ Lifetime in yrs Efficiency in % Min Load in %	150 kW 0–100 kW $1,000 $800 $20 15 yrs 75% 10%
Generator (Stored H_2)	Capacity in kw Default Capacity in kw Capital in $ Replacement in $ O&M in $ Lifetime in yrs Min Load in % CHP Heat Recovery	900 kW 250 kW $2,000 $1,500 $0.020 40,000 hrs 0% 60%
Hydrogen Tank	Size in kg Size Range in kg Capital in $ Replacement in $ O&M in $ Lifetime in yrs Relative to Tank Size	100 kg 0 to 100 kg $500 $400 $10 25 yrs 50%

III. HOMER PRO-BASED METHODOLOGY

A. System Modeling

The proposed microgrid configurations are developed in HOMER Pro by defining the electrical load, renewable resources, component characteristics, economic assumptions, and system constraints. The model permits the generation and storage components to interact through the AC/DC system architecture.

B. Optimization and Economic Evaluation

HOMER Pro evaluates the lifecycle economic performance of the candidate systems using the total net present cost as a principal economic indicator. NPC represents the present value of the system's total costs over the project lifetime, including capital, replacement, operation and maintenance, fuel, and grid-related costs. The general expression for NPC can be represented as

$$NPC = \frac{C_{ann,total}}{CRF(i,N)}$$

where $C_{ann,total}$ is the total annualized cost, i is the real interest rate, N is the project lifetime, and CRF is the capital recovery factor.

The capital recovery factor is given by

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1}$$

The levelized cost of energy is evaluated as

$$COE = \frac{C_{ann,total}}{E_{served}}$$

where E_{served}represents the annual electrical energy supplied to the load.

The renewable fraction is used to indicate the contribution of renewable sources to the electrical supply and is expressed as the fraction of total electrical energy supplied by renewable technologies.

The present study therefore evaluates each configuration using five principal indicators:

- Initial capital cost
- Annual operating cost
- Total net present cost
- Levelized cost of energy and
- Renewable fraction.

These indicators are considered together because no single metric completely describes the performance of a microgrid.

IV. MICROGRID CONFIGURATIONS

Ten configurations are investigated in the study.

TABLE II INVESTIGATED MICROGRID CONFIGURATIONS

Case	Configuration
Case 1	PV + Battery + Grid
Case 2	Wind + Battery + Grid
Case 3	PV + Wind + Battery + Grid
Case 4	Biomass + Battery + Grid
Case 5	PV + Wind + Diesel Generator + Battery
Case 6	PV + Wind + Diesel Generator + defferable load
Case 7	PV + Wind + Grid + Battery +diesel gen+deff. load
Case 8	Wind + PV + Battery
Case 9	Defff load+ Wind + PV + Battery
Case 10	PV + Wind + Grid + Battery + Electrolyzer + H_2 Tank + Stored-H_2 Generator+deff load

The configurations are intentionally varied to examine the economic consequences of changing the generation mix and storage architecture. Cases 1–4 primarily examine individual generation technologies with storage and grid support. Cases 5 and 6 investigate conventional-generator-supported renewable systems. Cases 7–9 investigate increased renewable penetration and alternative renewable sizing. Case 10 introduces hydrogen as an additional storage pathway.

A. System Architecture Descriptions

To illustrate the physical energy conversion and power dispatch pathways, the block schematics of the investigated microgrid topologies are categorized into four primary architectural frameworks:

1. *Grid-Connected Renewable Systems (Cases 1–4 & 7):* These configurations utilize a common hybrid AC/DC bus arrangement. Photovoltaic arrays and battery storage are interfaced via the DC bus, whereas wind turbines, biomass generators, and the utility grid connect directly to the AC bus. The utility grid acts as a secondary buffer, absorbing excess generation or supplying power during deficits.

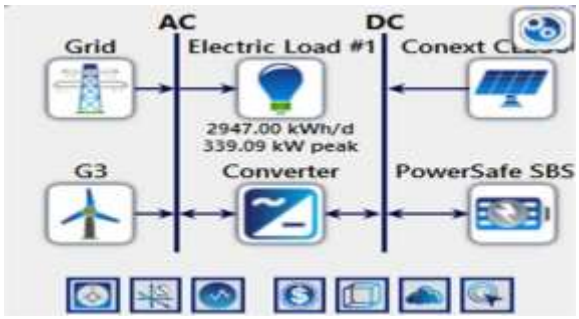


Fig 6 Grid Connected Renewable System Architecture

2. *Standalone Diesel-Hybrid Configurations (Cases 5 & 6):* Designed for off-grid operation, these systems incorporate a diesel generator on the AC bus to maintain system frequency and supply firm capacity when renewable output and battery state-of-charge (SOC) drop below operational thresholds.

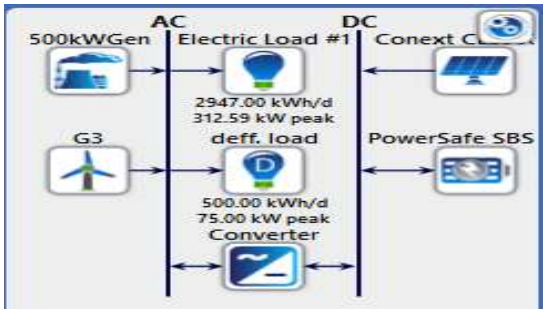


Fig 7 Standalone diesel-hybrid Architecture

3. *High-Penetration Standalone Systems (Cases 8 & 9):* These systems eliminate fossil generation entirely in off-grid mode. To guarantee power reliability, PV array and wind turbine capacities are substantially oversized, paired with large-scale battery banks to absorb intermittent power surges.

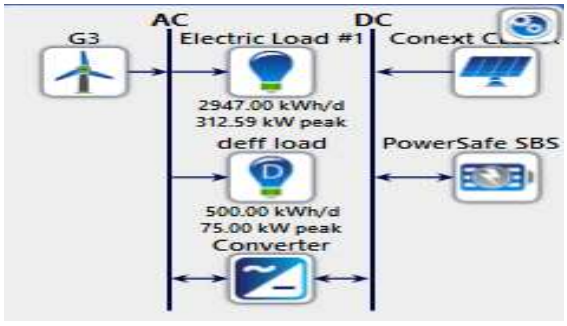


Fig 8 System Architecture of case 8 and case 9

4. *Hydrogen-Integrated Microgrid Architecture (Case 10):* Case 10 incorporates a Power-to-Gas-to-Power (P2G2P) energy storage loop alongside conventional battery storage. When renewable generation exceeds immediate load requirements and battery capacity, the excess AC/DC power energizes a polymer electrolyte membrane (PEM) electrolyzer to produce green hydrogen. The gas is compressed and stored in a high-pressure H_2 tank, which subsequently fuels a hydrogen engine/fuel cell to regenerate electricity during extended renewable deficits, establishing a 100% green microgrid ecosystem.

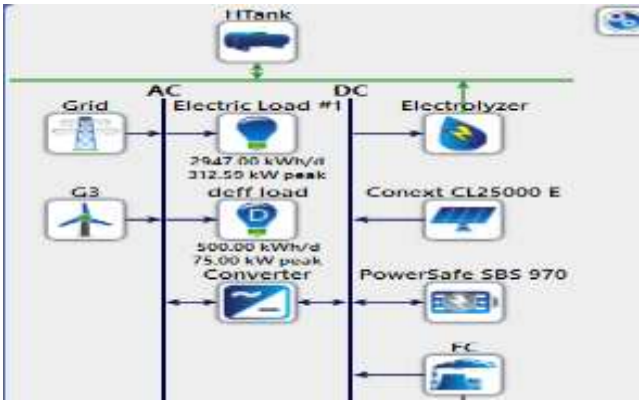


Fig 9 Hydrogen- Integrated Microgrid Architecture of case 10

V. RESULTS AND DISCUSSION

A. Comparative Economic Results

The principal simulation results obtained from the current HOMER Pro model are summarized in Table III.

TABLE III COMPARATIVE PERFORMANCE OF THE TEN CONFIGURATIONS

Case	Initial Capital Cost ($)	Operating Cost ($/yr)	NPC ($)	COE ($/kWh)	Renewable Fraction
1	75,817	104,356	1,420,000	0.1020	3.31%
2	36,746	107,500	1,430,000	0.1030	0.84%
3	93,817	104,247	1,440,000	0.1040	3.73%
4	750,745	102,012	2,070,000	0.1490	0.00078
5	313,245.63	373,344.1	5,139,658	0.3696	68.5%
6	811,265.23	397,708.7	5,952,650	0.3660	76.2%
7	243,834.71	119,672	1,790,897	0.1102	92.4%
8	18,120,864.62	500,897.2	24,596,220	1.7700	62.5%
9	19,664,218.43	572,211.1	27,061,490	1.6600	84.0%
10	25,751.38	122,086.3	1,604,024	0.0987	100%

The results show that the economic performance varies substantially with the selected architecture. The lowest reported NPC occurs for Case 1, whereas Case 10 reports the lowest COE. The results therefore demonstrate that NPC and COE do not necessarily identify the same configuration.

This distinction is important because a configuration may have a relatively low cost of energy while requiring a different capital structure or producing a different lifecycle NPC. Consequently, the evaluation should not be based on a single metric.

B. Initial Capital Cost

The initial capital investment varies considerably between the configurations. Case 2 has a reported initial capital cost of approximately $36,746, which is lower than the capital cost of Case 1. Case 1 requires approximately $75,817, while Case 3 requires approximately $93,817.

The capital cost increases substantially for configurations incorporating larger renewable capacities or conventional generation. Cases 5 and 6 report initial capital costs of approximately $313,245.63 and $811,265.23, respectively as seen table 3. Cases 8 and 9 have particularly high reported capital costs, exceeding $18 million as shown in figure 10.

The difference indicates that increasing renewable capacity does not automatically produce an economically attractive system. Higher installed capacity requires greater investment, and the additional generated energy must justify the corresponding capital expenditure over the project lifetime.

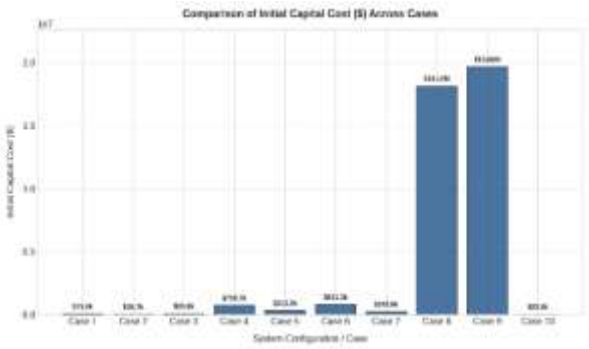


Fig 10 Comparison of Initial Capital Cost ($).

C. Annual Operating Cost

The annual operating cost provides insight into the recurring expenditure associated with operating the microgrid.

Cases 1–4 have reported annual operating costs in the approximate range of $102,012–$107,500/year. Case 4 reports the lowest operating cost among these configurations at approximately $102,012/year.

In contrast, Cases 5 and 6, which include diesel generation, have significantly higher reported operating costs of approximately $373,344.10/year and $397,708.70/year as seen in table 3. The higher operating expenditure is associated with the recurring costs of conventional generation.

Cases 8 and 9 also report high operating costs, approximately $500,897.20/year and $572,211.10/year as shown in figure 11. These results indicate that substantially increasing renewable capacity can produce a significant increase in capital as well as operating expenditure when the selected configuration is not appropriately matched to the load and available renewable resource.

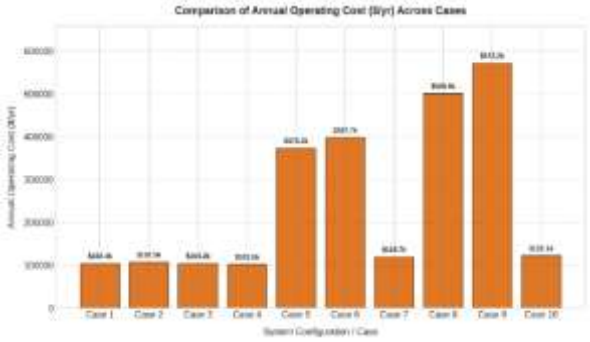


Fig 11 Comparison of Annual Operating Cost ($/yr).

D. Net Present Cost

NPC is a particularly important indicator because it incorporates the economic consequences of the system throughout the project lifetime.

The reported NPC values for Cases 1–4 are relatively close, ranging from approximately $1.42 million to $2.07 million. Case 1 reports the lowest NPC among these four configurations at approximately $1.42 million as compared in table 3.

Case 7 reports an NPC of approximately $1.79 million, despite having a substantially higher renewable contribution than the first few configurations. This illustrates the economic trade-off between increasing renewable penetration and the additional investment required.

Cases 5 and 6 have NPC values of approximately $5.14 million and $5.95 million, respectively. The significantly higher lifecycle costs indicate the economic impact of incorporating diesel generation into the selected architectures under the modeled assumptions.

The high-wind configurations produce the largest reported NPC values. Case 8 reports approximately $24.60 million, while Case 9 reports approximately $27.06 million as observed in figure 12. These results

indicate that simply increasing wind capacity is not sufficient to guarantee economic improvement.

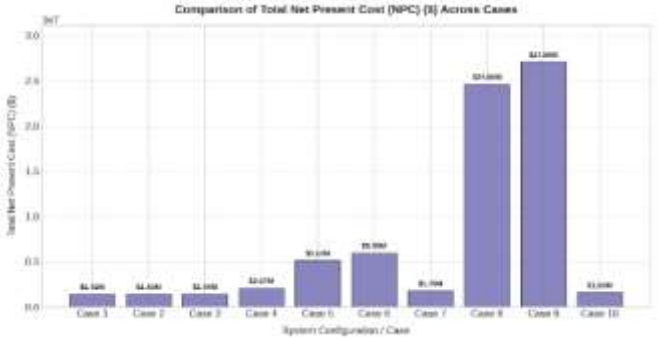


Fig 12 Comparison of Total Net Present Cost ($).

E. Cost of Energy

The reported COE provides a normalized indicator of the economic cost of supplying electrical energy.

The lowest reported COE in the current results is $0.0987/kWh for Case 10, followed by approximately $0.1020/kWh for Case 1 and $0.1030/kWh for Case 2 as observed in table 3.

Cases 5 and 6 report COE values of approximately $0.3696/kWh and $0.3660/kWh, respectively as shown in figure 13. Cases 8 and 9 have much higher reported COE values of $1.7700/kWh and $1.6600/kWh.

The results show that renewable penetration alone cannot be used as an economic indicator. The cost of installed capacity, replacement expenditure, operating expenditure, and the utilization of each component all influence the final COE.

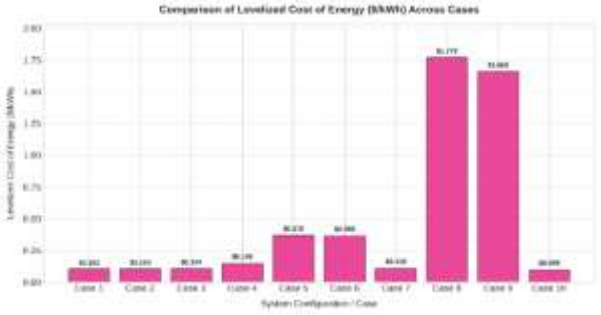


Fig 13 Comparison of Levelized Cost of Energy ($/kwh).

F. Renewable Fraction

Renewable fraction indicates the contribution of renewable sources to the total electricity supplied to the load. The values reported in the current model vary considerably between cases.

Case 7 reports a renewable fraction of approximately 92.4%, while Cases 8 and 9 report approximately 62.5% and 84.0%, respectively. Case 10 is reported as having a renewable fraction of 100% as shown in table 3.

The results indicate that a higher renewable fraction can be achieved by increasing renewable generation capacity and reducing dependence on conventional or grid-based supply. However, Cases 8 and 9 demonstrate that a high renewable contribution can be accompanied by a very large economic cost as shown in the figure 14 below.

Therefore, renewable fraction should be considered together with NPC and COE rather than used independently to determine system suitability.

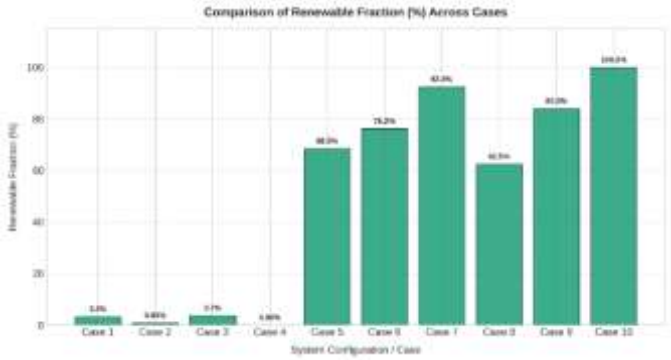


Fig 14 Comparison of Renewable Fraction (%).

G. Effect of Grid Integration

The comparison between grid-connected and non-grid configurations demonstrates the economic importance of utility support.

Grid-connected systems can utilize electricity purchases when local renewable generation and storage are insufficient to meet demand. This can reduce the requirement for large generation capacities and therefore reduce the capital investment required to achieve reliable electricity supply.

The results of Cases 1–4 show relatively low lifecycle costs compared with the diesel-supported and high-wind configurations. This suggests that grid interaction can provide an economically significant source of supply under the assumed grid purchase price of $0.10/kWh.

However, grid-connected systems also depend on the assumed electricity purchase price. Therefore, changes in the utility tariff could alter the relative economic performance of the configurations.

H. Effect of Diesel Generation

Cases 5 and 6 incorporate diesel generation together with renewable sources and battery storage. Their reported NPC and COE values are considerably higher than those of the low-cost grid-connected configurations.

The increase in annual operating cost is particularly significant. Case 5 has an annual operating cost of approximately $373,344.10, while Case 6 has approximately $397,708.70/year. These values are

considerably higher than the operating costs of Cases 1–4.

The result indicates that although diesel generation can provide dispatchable electricity, the recurring cost of fuel and generator operation can significantly affect lifecycle economics. The comparison also demonstrates why the economic evaluation of a microgrid should include both capital and operating expenditure.

I. Effect of Increased Renewable Capacity

Cases 8 and 9 investigate configurations with increased wind capacity together with PV and battery storage. These systems report very high capital costs and high NPC values.

Case 8 has a reported capital cost of approximately $18.12 million and NPC of approximately $24.60 million. Case 9 has a capital cost of approximately $19.66 million and NPC of approximately $27.06 million.

The results demonstrate an important design principle: increasing renewable capacity beyond the level required by the load does not necessarily improve lifecycle economics. The additional generation must be sufficiently utilized to compensate for the increased investment.

This finding is particularly relevant when designing renewable-dominated microgrids. The objective should not simply be to maximize installed renewable capacity but to determine an economically justified capacity based on the load profile and available resource.

J. Hydrogen-Integrated Configuration

Case 10 incorporates PV, wind, grid supply, battery storage, an electrolyzer, a hydrogen storage tank, and a stored-hydrogen generator.

The hydrogen subsystem provides an additional energy-storage pathway. Renewable electricity can be supplied to the electrolyzer for hydrogen production, while stored hydrogen can subsequently be used for electricity generation through the hydrogen generator.

The reported results for Case 10 are an initial capital cost of approximately $25,751.38, annual operating cost of approximately $122,086.30/year, NPC of approximately $1.604 million, COE of approximately $0.0987/kWh, and renewable fraction of 100%.

Among the ten reported configurations, Case 10 therefore has the lowest reported COE, while its NPC remains higher than the reported NPC of Case 1.

However, the capital cost reported for Case 10 requires careful verification because the configuration contains several additional components, including the electrolyzer, hydrogen tank, and hydrogen generator. The value should be confirmed directly from the HOMER Pro optimization and cost-summary screens before publication.

The hydrogen configuration should therefore be interpreted as an investigation of an additional storage pathway rather than automatically described as the universally optimal system.

VI. OVERALL COMPARATIVE DISCUSSION

The ten configurations demonstrate that microgrid economic performance depends strongly on the relationship between generation capacity, storage, grid interaction, and load demand.

The first four cases have comparatively low NPC values, indicating that systems using moderate renewable capacities together with grid support can achieve relatively low lifecycle costs under the assumed electricity tariff. Case 1 has the lowest reported NPC among the ten configurations, whereas Case 10 has the lowest reported COE.

The comparison also demonstrates that a lower initial capital cost does not necessarily result in the lowest NPC. Case 2 has a lower initial investment than Case 1, but its reported NPC is slightly higher. This occurs because lifecycle economics also include operating, replacement, fuel, and grid-related expenditures.

Similarly, a high renewable fraction does not automatically correspond to low lifecycle cost. Cases 7–9 demonstrate that increasing renewable penetration can result in significantly higher investment requirements. The high-wind configurations are particularly expensive under the present assumptions.

The diesel-supported systems demonstrate the opposite trade-off. Their dispatchable generation capability can support the electrical load, but fuel and operating costs increase the annual expenditure and lifecycle NPC.

The hydrogen-integrated configuration introduces another important trade-off. Hydrogen storage provides an alternative pathway for storing renewable energy, but the electrolyzer, hydrogen tank, and hydrogen generator add additional components to the system. Its economic performance therefore depends strongly on component costs, efficiencies, operating strategy, and hydrogen utilization.

The overall results demonstrate that microgrid planning should be treated as a multi-criteria economic and technical comparison, rather than as a simple search for the highest renewable fraction or the lowest capital cost.

VII. CONCLUSION

This paper presented a comparative techno-economic evaluation of ten renewable and hybrid microgrid configurations for Visakhapatnam, India, using HOMER Pro. The study considered PV, wind, biomass, diesel generation, battery storage, grid interaction, and hydrogen-based energy storage within a common modeling framework. The configurations were evaluated using initial capital cost, annual operating cost, NPC, COE, and renewable fraction.

The results demonstrate significant variation in economic performance between the investigated architectures. The reported NPC values range from approximately $1.42 million to $27.06 million, while the reported COE values range from $0.0987/kWh to $1.7700/kWh. The PV-battery-grid configuration produces the lowest reported NPC among the ten configurations, whereas the hydrogen-integrated configuration reports the lowest COE.

The analysis further demonstrates that increasing renewable capacity does not necessarily improve economic performance. The high-wind configurations have substantially higher capital and lifecycle costs, despite their increased renewable contribution. Similarly, the diesel-supported systems experience higher operating costs because of conventional-generation expenditure. Grid-connected configurations benefit from the ability to obtain electricity from the utility when local renewable generation is insufficient.

The hydrogen-integrated configuration demonstrates the potential of combining renewable generation, battery storage, and hydrogen storage within a single microgrid architecture. Nevertheless, the economic benefit of hydrogen storage depends strongly on the component costs, system sizing, operating strategy, and utilization of the stored hydrogen. Therefore, the hydrogen configuration should be considered as an alternative storage architecture rather than being identified as universally optimal.

Overall, the study demonstrates the usefulness of HOMER Pro for systematic comparative assessment of different microgrid architectures. The results indicate that an economically suitable configuration is obtained not simply by maximizing renewable generation but by balancing renewable contribution, capital investment, operating expenditure, storage requirements, grid dependence, and lifecycle cost.

References

[1] “Techno-economic analysis of solar, wind and biomass hybrid renewable energy systems in Bhorha village, India,” *Energy Reports*, 2024.

[2] “Techno-economic and environmental analysis of grid connected hybrid wind/photovoltaic/biomass system for Marmara University Goztepe campus,” *International Journal of Green Energy*, 2020, doi: 10.1080/15435075.2020.1821691.

[3] “A PV-Biomass off-grid hybrid renewable energy system (HRES) for rural electrification: Design, optimization and techno-economic-environmental analysis,” *Journal of Cleaner Production*, 2022.

[4] “Optimization and sizing of SPV/Wind hybrid renewable energy system: A techno-economic and social perspective,” *Energy*, 2021.

[5] HOMER Energy, “Deferrable Load,” *HOMER Pro Documentation*. “Techno-

[6] Economic Evaluation of Interconnected Nuclear-Renewable Micro Hybrid Energy Systems with Combined Heat and Power,” *Energies*, 2020.

[7] K. K. Kumar, S. Singh, and S. Kundu, “Modeling and Simulation of Grid-Connected Hybrid Renewable Energy Systems Using HOMER Pro Software,” *Indian Journal of Renewable Energy*, 2025.

[8] “Prefeasibility techno-economic analysis of hybrid renewable energy system,” *Process Integration and Optimization for Sustainability*, 2024.

[9] “Techno-economic assessment of hybrid renewable energy system with multi energy storage system using HOMER,” *Energy*, 2024.

[10] “Techno-economic evaluation of hybrid renewable systems for green hydrogen production and utilization,” *Results in Engineering*, vol. 30, 2026, Art. no. 111080.

[11] S. Upadhyay and M. P. Sharma, "A review on configurations, control strategies and power management of hybrid renewable energy systems," *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 43–51, Oct. 2014.

[12] O. Hafez and K. Bhattacharya, "Optimal planning and design of a renewable energy based supply system for microgrids," *Renewable Energy*, vol. 45, pp. 7–15, Sep. 2012.

[13] P. Lilienthal, "HOMER Pro Microgrid Analysis Tool," *National Renewable Energy Laboratory (NREL)*, Golden, CO, USA, Tech. Rep., 2016.

[14] S. K. Sinha and S. Chandel, "Review of recent trends in optimization techniques for solar photovoltaic–wind based hybrid energy systems," *Renewable and Sustainable Energy Reviews*, vol. 50, pp. 755–769, 2015

[15] A. Chauhan and R. P. Saini, "A review on integrated renewable energy system based power generation for stand-alone applications: Configurations, technical options, and economic assessment," *Renewable and Sustainable Energy Reviews*, vol. 38, pp. 99–116, Oct. 2014.

[16] Y. Sawle, S. C. Gupta, and A. K. Bohre, "PV-wind hybrid system optimization using grid-linked and off-grid configurations for remote area electrification," *Renewable Energy*, vol. 113, pp. 1259–1275, Dec. 2017.

[17] S. M. Dawoud, X. Lin, and M. I. Okba, "Hybrid renewable energy systems optimization in microgrids: A review," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 2039–2052, Feb. 2018.

[18] M. S. Ismail, M. Moghavvemi, and T. M. I. Mahlia, "Energy management strategy in microgrid system with renewable energy resources and energy storage: A review," *IEEE Access*, vol. 7, pp. 159828–159848, 2019.

[19] H. R. Ismail, A. K. Al-Thani, and M. A. Hassan, "Green hydrogen integration in hybrid microgrids for energy storage and curtailment mitigation: A comprehensive review," *International Journal of Hydrogen Energy*, vol. 46, no. 58, pp. 29810–29828, Aug. 2021.

[20] S. A. A. A. Al-Ammar, A. M. A. Al-Muhsen, and A. A. A. Al-Othman, "Optimized dynamic load control and deferrable load management in standalone microgrids," *IEEE Transactions on Smart Grid*, vol. 11, no. 4, pp. 3120–3131, Jul. 2020.

[21] D. B. Nelson, M. H. Nehrir, and C. Wang, "Unit sizing and cost analysis of stand-alone hybrid wind/PV/fuel cell power generation systems," *Renewable Energy*, vol. 31, no. 10, pp. 1641–1656, Aug. 2006.

[22] [R. Atia and N. Yamada, "Sizing and energy management of stand-alone PV-wind-battery systems considering energy curtailment and load shifting," *Energy Conversion and Management*, vol. 121, pp. 42–51, Aug. 2016.

[23] P. Lilienthal, "HOMER: The Hybrid Optimization Model for Multiple Energy Resources," *National Renewable Energy Laboratory (NREL)*, Golden, CO, USA, Tech. Rep. NREL/TP-710-38183, 2017.

[24] T. Lambert, P. Lilienthal, and P. Gilman, "Design and analysis of hybrid microgrid systems using HOMER," in *Integration of Alternative Sources of Energy*, F. A. Farret and M. G. Simões, Eds. Hoboken, NJ, USA: Wiley-IEEE Press, 2006, pp. 379–416.

[25] B. K. Das, M. S. Hassan, M. S. Hossain, and F. S. Rahman, "Techno-economic and environmental assessment of a PV/wind/battery hybrid microgrid using HOMER Pro for off-grid electrification," *Energy*, vol. 227, p. 120535, Jul. 2021.

[26] A. K. Sen, R. Bhattacharya, and S. S. Roy, "Multi-scenario microgrid optimization using Cycle Charging and Load Following dispatch strategies in HOMER Pro," *IEEE Transactions on Industry Applications*, vol. 58, no. 4, pp. 4310–4321, Jul./Aug. 2022.

[27] M. S. Adaramola, "Techno-economic analysis of a solar-wind hybrid energy system for off-grid power supply in rural communities," *Energy Conversion and Management*, vol. 88, pp. 930–938, Dec. 2014.

[28] G. Bekele and G. Tadesse, "Feasibility study of small Hydro-PV-Wind hybrid power system for off-grid rural electrification in Ethiopia," *Applied Energy*, vol. 97, pp. 5–15, Sep. 2012..

[29] M. H. Jahangir and R. Cheraghi, "Techno-economic and environmental assessment of hydrogen storage integrated with renewable microgrids using HOMER Pro," *International Journal of Hydrogen Energy*, vol. 45, no. 23, pp. 12642–12657, Apr. 2020.