Research Article

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Techno-Economic Investigations of Hybrid Renewable Energy Systems for Andaman & Nicobar Islands

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ABSTRACT

In the industrialized world, the development in energy sector is needed at any point in time. Traditional energy sources such as oil, coal, and natural gases are limited in nature so that the energy requirements have not been fulfilled for a longer time. So, “Renewable energy” plays a pivotal role in addressing energy demand and energy access challenges. This paper presents the issues associated with conventional or non-renewable energy systems. Utilizing a hybrid power system can help people become less dependent on renewable or traditional energy sources. The sensitivity analysis, optimization, cost savings, and decrease in greenhouse gas emissions are covered in this study. The Andaman & Nicobar Islands, India, face unique challenges in electricity generation due to their isolation and dependence on fossil fuels. This study investigates the techno-economic feasibility of hybrid renewable energy systems (HRES) as a sustainable and cost-effective alternative. The tool used for the optimization of power systems in the Andaman and Nicobar Islands is HOMER. The HOMER optimizes the power system combinations and gives results in terms of operating cost, total fuel consumption, return on investment, power generation etc. A comparison between the base model and the proposed model has been performed using HOMER and the result shows that the proposed model is economical and best suited in all respect.

Keywords: HOMER; Optimization; Hybrid renewable energy; Wind energy; Solar energy.

1. INTRODUCTION

For all the social activities, energy is required. It is needed for cooking, heating, drive industries, agriculture, production, transportation etc. At present, most of the energy generated through conventional fossil fuels decrease day by day. Hybrid Renewable energy is very demanding for its low operating cost. A hybrid renewable energy system integrates two or more renewable energy sources, such as Solar, Wind, Hydro and Biomass (Adefarati *et al.* 2017). For an isolated area that relies on expensive diesel generators, hybrid systems can significantly reduce fuel costs and the need for fuel transport, leading to increased energy independence and reduced environmental impact. Energy generation by renewable sources is more reliable and economical as compared to non-renewable energy sources (Mohammad *et al.* 2022).

Due to the substantial variations in wind speed magnitude at high cut-in speed ranging between 3.5m/s and 4.5m/s, windmills suffer a lot. Similarly, solar PV systems cannot deliver power to a steady demand reliably during cloudy days and nights. Therefore, system oversizing is required to achieve sustainability and dependability (Mohammad, 2022). Localized energy sources are necessary in isolated places since they frequently lack connection to a centralized grid. Numerous renewable energy sources, including biomass, wind, and solar, are combined with energy storage in hybrid systems to ensure a steady and predictable power supply, lowering the chance of blackouts. This research paper is based on the studies in Andaman and Nicobar Islands. About 37 of the 571 islands that make up the union territory of Andaman and Nicobar Islands, which is part of India, are inhabited. The area is approximately 8249 km^2. The daily energy usage of the islands is 457983.33 kWh (Beccali *et al.* 2008). The installed power capacity of the islands was around 75 megawatts at the end of the fiscal year 2022. Nearly 53 power plants in 19 inaccessible islands are used to generate electricity, of which 12 are in north and middle Andaman, 16 in south Andaman, and 25 in Nicobar district. About 566 of the approximately 2682 km of low-tension lines and 1133 km of high-tension lines are used for distribution in the islands (Ansari *et al.* 2016). Due to lower industrial power requirements, these islands' annual per capita energy consumption is approximately 385 kWh, compared to the national average of 593 kWh. The main aim of this research work is to develop an ideal hybrid system for an island by reducing fuel consumption, operating and maintenance costs, net present cost, and cost of energy. Additionally, there has been a net reduction in a variety of greenhouse gases, including nitrogen oxide, carbon dioxide, and carbon monoxide (Sharma *et al.* 2023).

2. METHODOLOGY

Resource assessment: Solar insolation and wind speed data are analysed to identify suitable locations for renewable energy integration.

System modelling: Various HRES configurations, including solar PV, wind turbines, and battery storage, are modelled using specialized software.

Techno-economic analysis: Key performance indicators like cost of energy (COE), capacity shortage, and system reliability are evaluated for each configuration.

3. PROFILE OF ANDAMAN AND NICOBAR ISLANDS

The Bay of Bengal is where the Andaman and Nicobar Islands are situated, closer to Southeast Asia, rather than mainland India. Here are some key characteristics of the region:

3.1 Geographical Location

These islands are situated between longitude 92° to 94° East and latitude 60 to 140 North, as shown in Fig. 1. They are a part of India's Union Territory, and their proximity to the equator influences their climate (Jalil *et al*. 2022).

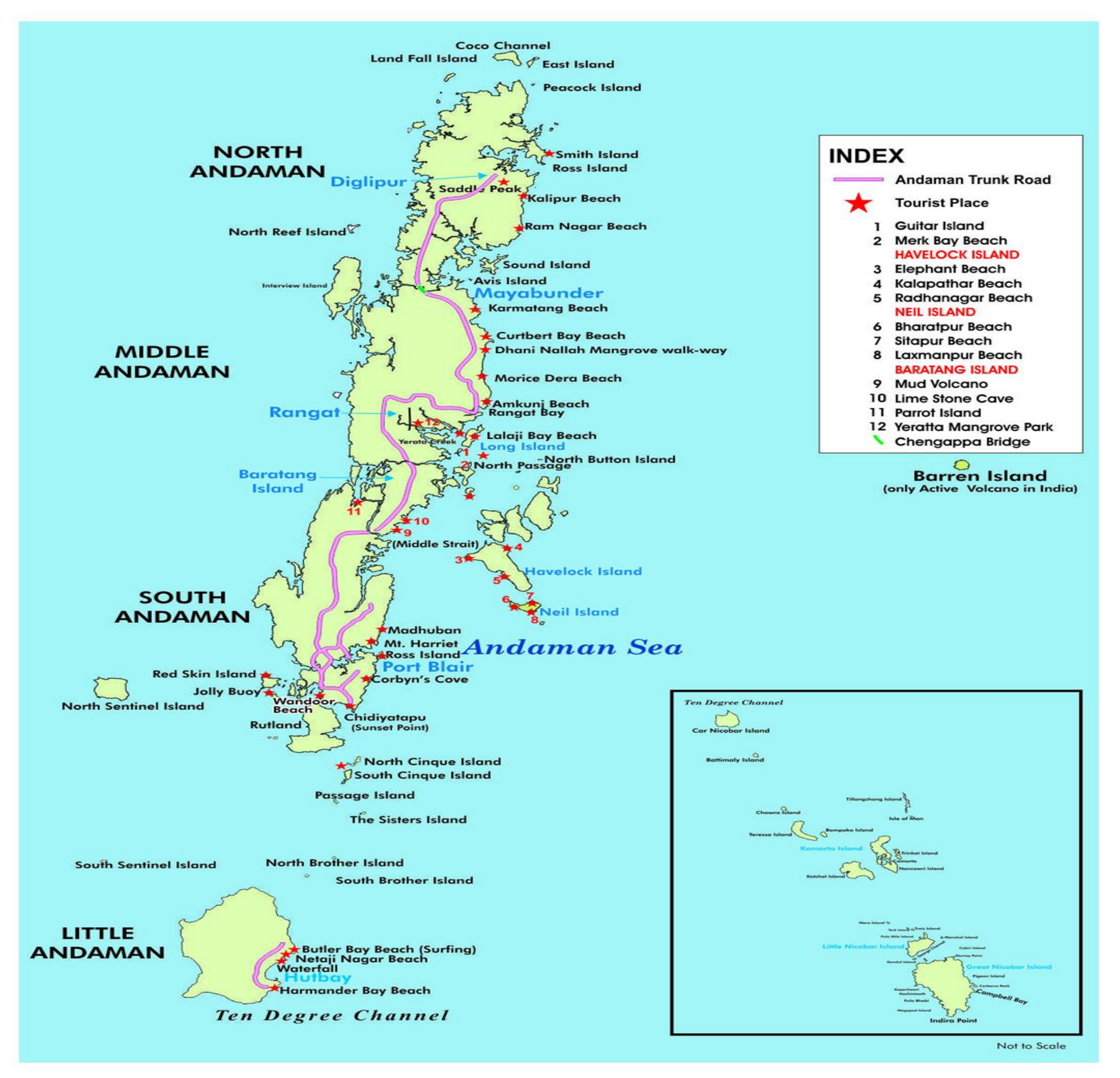


Fig. 1: Andaman and Nicobar Island

3.2 Topography

The islands vary in topography, with some being hilly and forested while others are flatter. The highest point on the Andaman and Nicobar Islands is Mount Harriet.

3.3 Climatic Conditions

The Andaman and Nicobar Islands experience tropical humid seasons. These islands have a distinct wet and dry season with a tropical monsoon climate. The northeast monsoon is dry from November to February, while the southwest monsoon produces substantial rainfall from June to September (Manaullah and Ansari, 2014).

4. SOFTWARE TOOLS

Modelling and optimization are done using the HOMER (Hybrid Optimization Model for Electric Renewables). The National Renewable Energy Laboratory (NREL) in the United States created the HOMER, a computer simulation. This application can be used to simulate a power system's life-cycle cost, which is the sum of the costs associated with installing and maintaining the system over the course of its useful life (Manaullah and Ansari, 2019). The user can compare a variety of design concepts based on the technical and budgetary advantages they offer. It also aids in the comprehension and quantification of the effects of uncertainty or input changes. It is utilized for system designing, simulation, and hybrid renewable energy system optimization for the targeted area. HOMER is very useful for determining the fuel cost and the emission of the gases from the fuel used to generate power. HOMER is used to compare the economics of the energy produced by the different energy sources (Mbungu *et al.* 2020).

5. SIMULATION

5.1 Input to the HOMER

For demonstrating and obtaining results in HOMER, the information required is daily load profile, economic data, Rated capacity of wind turbine, rated capacity of flat plate PV, nominal capacity of battery and sensitive cases - diesel fuel price, hub height (Roy *et al.* 2022).

5.2 Renewable Energy Sources Available at Andaman and Nicobar Islands

5.2.1 Solar Energy

Solar energy is a powerful energy source that may be harnessed with the aid of photovoltaic solar panels. The southern region of India has very huge irradiation of sun. Solar irradiance is measured in watts per square meter in SI units. Andaman and Nicobar Islands are close to the equatorial line, so this will help to generate solar power efficiently with the help of solar panels. Solar panels are connected to batteries to store the energy for power distribution in islands (Singh *et al.* 2018). Energy from solar (p-v) monocrystalline:

$$E = A * r * H * Pr \qquad \text{……….} \qquad (1)$$

where E= Energy (kWh), r = Yield of solar, H = Annual average solar radiation, pr = Performance ratio (value=0.75), A = Solar panel area.

The monthly average solar global horizontal irradiance (GHI) for the Andaman and Nicobar Islands is downloaded from the NASA solar energy database. Daily average radiation is 5.20 kWh/m^2 (Manaullah and Ansari, 2014). Maximum daily radiation is 6.330 kWh/m^2 per day for the month of April and minimum daily radiation is 4.510 kWh/m^2 for the month of June.

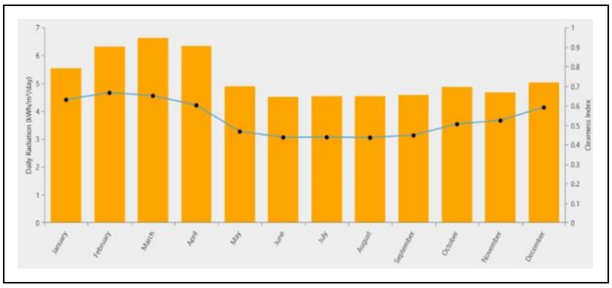


Fig. 2 Daily radiation and clearness index

Average clearness index is 0.532. The maximum clearness index is 0.665 for the month of February and the minimum clearness index is 0.435 for the month of August. The annual report of daily radiation and clearness index is shown in Figure. 2.

5.2.2 Wind Energy

The unequal heating of the atmosphere by the sun, the unevenness of the planet's surface, and the rotation of the earth all influence the velocity of winds. There are many distinct types of land and water on the planet's surface. The varied speeds at which heat from the sun is absorbed by various surfaces induce temperature fluctuations, which in turn cause winds. During the day, the air over land heats up faster than the air over water (Mohammad *et al.* 2023). Winds are created as heavier, cooler air rushes in to replace the rising, expanding warm air over the earth. At night, the winds are inverted because the air cools faster over land than it does over sea. Similarly, the massive air winds that circle the Earth are created by the fact that land near the equator receives more solar energy than land near the North and South Poles. The amount of power generated by the wind is related to the cube of the wind's speed. As a result, the amount of energy that can be extracted from the wind declines very quickly as its speed decreases. On the other hand, the amount of energy in the wind increases very quickly as the wind speed increases. But the range of useful wind speed is between 4 and 35 m/s. For a wind turbine to operate at its best, a minimum required speed of 6 m/s must be maintained. The average wind speed is mentioned in Fig. 3. The wind power potential of a location is largely determined by a wind power density of more than 200 W/m^2 at 50 m height. The following is a straightforward equation for the power of the wind. The power contained in a wind column of a particular size travelling at a particular velocity is described by this equation.

$$P = 1/2 * \rho * \pi * r^2 * v^3 \quad \ldots\ldots. \quad (2)$$

where P = Wind power (watts), ρ = Density of Air (kg/m^2), r = Radius of swept area (m^2), V = Wind speed (m/s), and π=3.14.

The wind power density was observed at 55.30 to 106.60 W/m^2 at Andaman and Nicobar Islands. The average wind speed of the islands is 6.25 m/s.

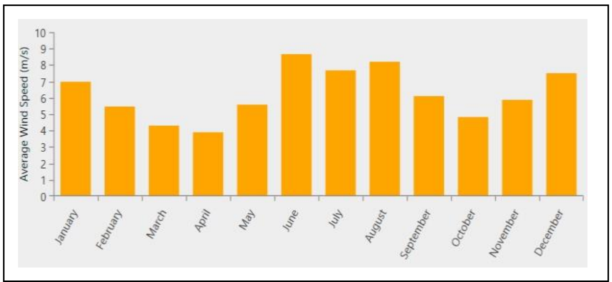


Fig. 3: Average wind speed

Table 1. Clearness index, daily radiation and average wind speed for Islands

Month	Clearness index	Daily radiation (kWh/m^2/day)	Average wind speed(m/s)
January	0.629	5.53	6.95
February	0.665	6.31	5.44
March	0.649	6.62	4.29
April	0.601	6.33	3.19
May	0.466	4.88	5.61
June	0.436	4.51	8.65
July	0.437	4.53	7.65
August	0.437	4.54	8.22
September	0.447	4.58	6.08
October	0.504	4.87	4.81
November	0.523	4.66	5.87
December	0.59	5.03	7.51
Average	**0.532**	**5.2**	**6.25**

The annual average clearness index is 0.532, whereas the highest solar clearness index is 0.665 in February and the lowest solar clearness index is 0.436 in the month of June. The average daily radiation is 5.20 kWh/m^2/day, whereas the highest solar radiation is 6.62 kWh/m^2/day and the lowest is 4.51 in the month of June. The average wind speed is 6.25m/s, whereas the highest speed is 8.65m/s in the month of June and the lowest is 3.19m/s in the month of April as mentioned in Table 1. The average load of the islands in July month is the highest which is 22,625.59 kW and the lowest for January month is 15,120.07 kW (Fig. 4). Figure 5 shows the monthly average load profile. Table 2 shows that the baseline average load is 165.59 kWh/day and the scaled load is 457983.3 kWh/day. The average baseline power is 6.9 kW and for scaled, it is 19082.64 kW. Peak power at baseline is 23.31 kW and scaled power is 64480.54 kW with a load factor of 0.3.

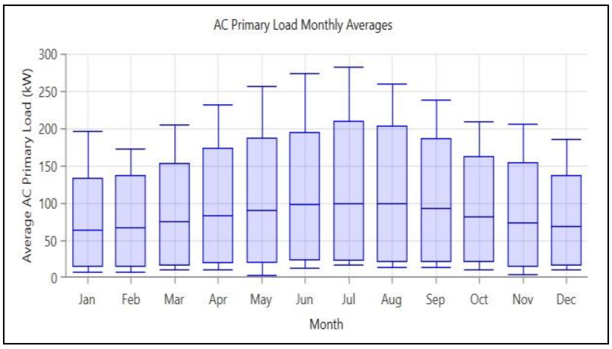


Fig. 5 Monthly average load profile

6. ARCHITECTURE OF HYBRID MODEL FOR ANDAMAN AND NICOBAR ISLANDS

In Andaman and Nicobar Islands, the power is mainly generated through diesel generators which are very costly in terms of operation and cause pollution. So, the aim is to decrease the dependency on the diesel generator and promote a hybrid renewable energy system for islands, which is not connected to the grid. With the help of HOMER simulation, the proposed model is performed to give the optimum outcome. In this work, the proposed model consists of diesel, wind, PV and battery hybrid systems as shown in Fig. 6.

Table 2. Average load and Peak load

Metric	Baseline	Scaled
Average load/day (kWh/day)	165.59	457983.3
Average load (kW)	6.9	19082.64
Peak load (kW)	23.31	64480.54
Load factor	0.3	0.3

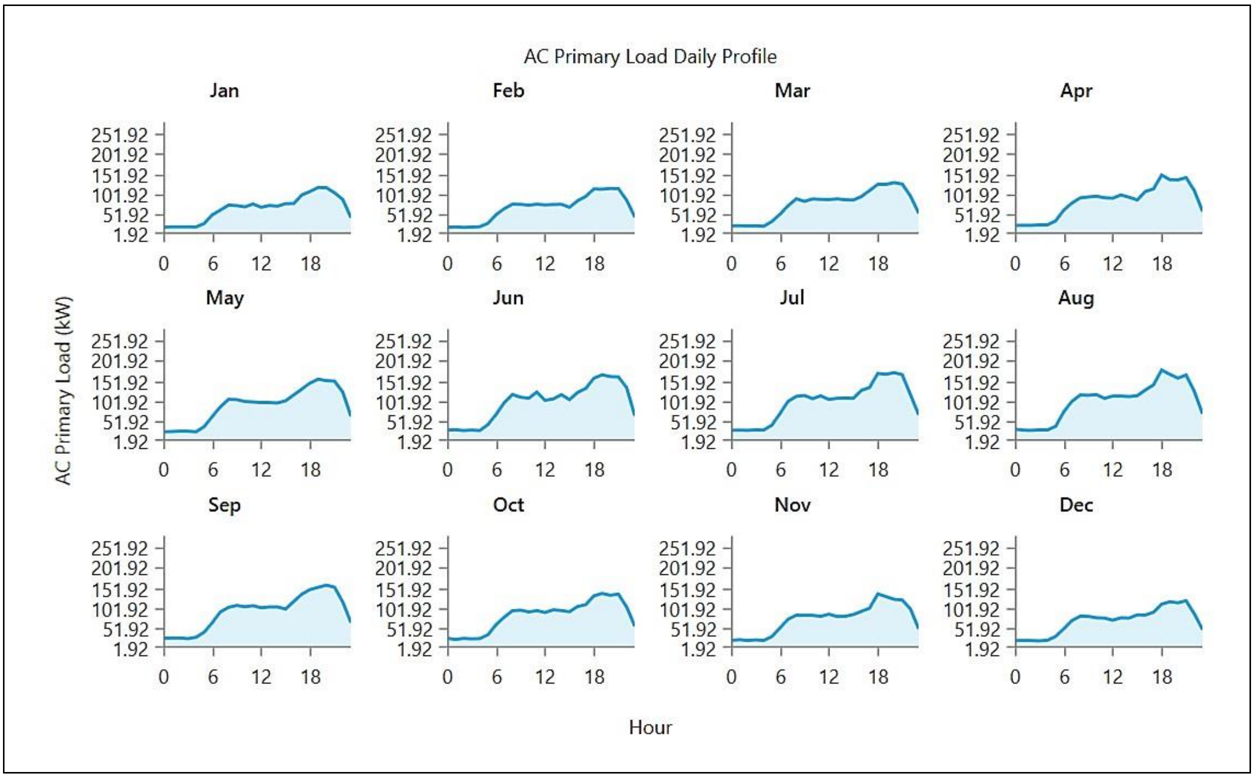
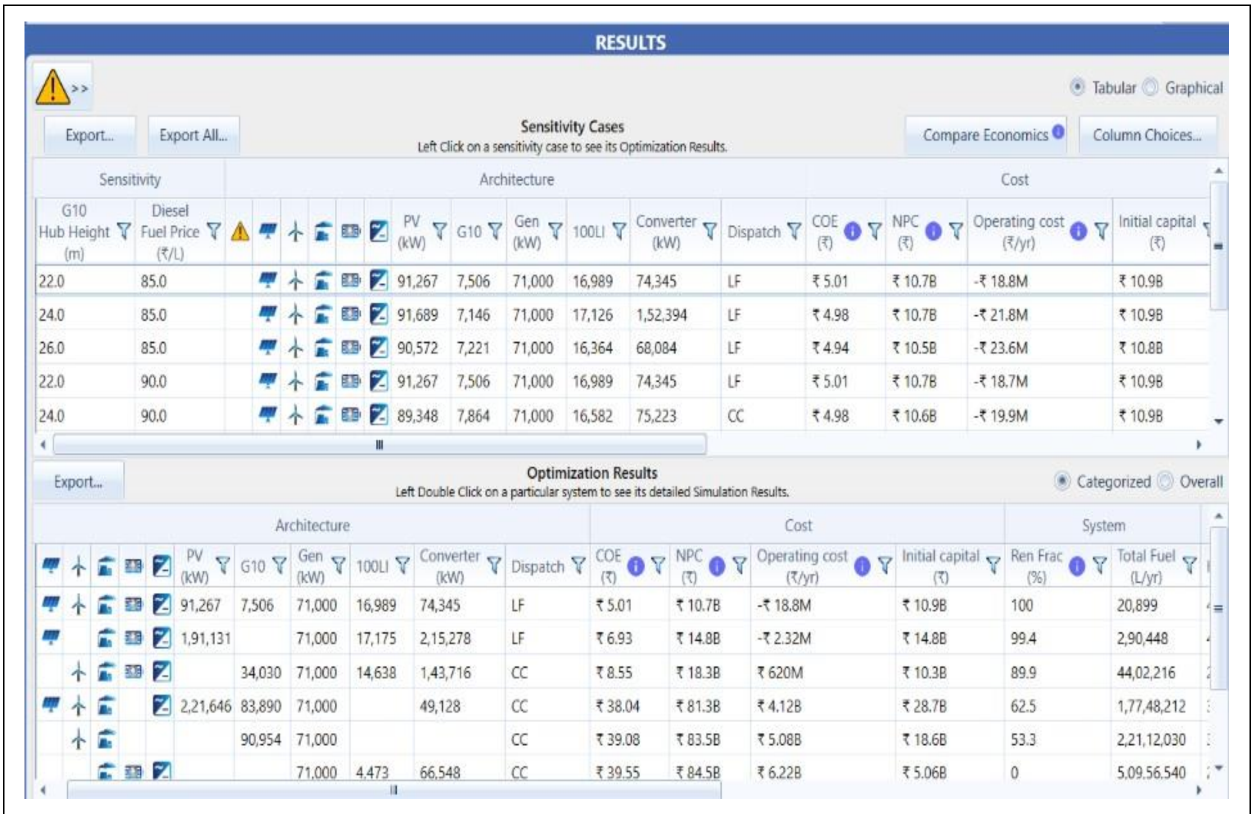


Fig. 4: Scaled Daily load profile



G10 Hub Height (m)	Diesel Fuel Price (₹/L)	PV (kW)	G10	Gen (kW)	100LI	Converter (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹/yr)	Initial capital (₹)
22.0	85.0	91,267	7,506	71,000	16,989	74,345	LF	₹ 5.01	₹ 10.7B	-₹ 18.8M	₹ 10.9B
24.0	85.0	91,689	7,146	71,000	17,126	1,52,394	LF	₹ 4.98	₹ 10.7B	-₹ 21.8M	₹ 10.9B
26.0	85.0	90,572	7,221	71,000	16,364	68,084	LF	₹ 4.94	₹ 10.5B	-₹ 23.6M	₹ 10.8B
22.0	90.0	91,267	7,506	71,000	16,989	74,345	LF	₹ 5.01	₹ 10.7B	-₹ 18.7M	₹ 10.9B
24.0	90.0	89,348	7,864	71,000	16,582	75,223	CC	₹ 4.98	₹ 10.6B	-₹ 19.9M	₹ 10.9B

PV (kW)	G10	Gen (kW)	100LI	Converter (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹/yr)	Initial capital (₹)	Ren Frac (%)	Total Fuel (L/yr)
91,267	7,506	71,000	16,989	74,345	LF	₹ 5.01	₹ 10.7B	-₹ 18.8M	₹ 10.9B	100	20,899
1,91,131		71,000	17,175	2,15,278	LF	₹ 6.93	₹ 14.8B	-₹ 2.32M	₹ 14.8B	99.4	2,90,448
	34,030	71,000	14,638	1,43,716	CC	₹ 8.55	₹ 18.3B	₹ 620M	₹ 10.3B	89.9	44,02,216
2,21,646	83,890	71,000		49,128	CC	₹ 38.04	₹ 81.3B	₹ 4.12B	₹ 28.7B	62.5	1,77,48,212
	90,954	71,000			CC	₹ 39.08	₹ 83.5B	₹ 5.08B	₹ 18.6B	53.3	2,21,12,030
		71,000	4,473	66,548	CC	₹ 39.55	₹ 84.5B	₹ 6.22B	₹ 5.06B	0	5,09,56,540

Fig. 7: HOMER sensitivity and optimization results for Islands

Table 3. Comparison between Hybrid system and Diesel-only system (Andaman and Nicobar)

Sensitivity variables		Hybrid system					Diesel only		
Cost of diesel fuel (₹/L)	Hub height (m)	System	NPC (₹)	COE (₹/kWh)	Renewable fraction (%)	Emission of CO_2 (kg/year)	NPC (₹)	COE (₹/kWh)	Emission of CO_2 (kg/year)
85	22	PV-diesel-battery	10.7 B	5.01		56,152	146 B	68.44	
85	24	PV-diesel-battery	10.7 B	4.98		7,17,039	146 B	68.44	
85	26	Wind-PV-diesel-battery	10.5 B	4.94		13,690	146 B	68.44	
90	22	Wind-PV-diesel-battery	10.7 B	5.01		13,690	150 B	70.1	
90	24	Wind-PV-diesel-battery	10.6 B	4.98	100	1,06,85,160	150 B	70.1	14,57,13,282
90	26	Wind-PV-diesel-battery	10.5 B	4.94		27,418	150 B	70.1	
95	22	PV-diesel-battery	10.7 B	5		7,17,039	153 B	71.77	
95	24	PV-diesel-battery	10.6 B	4.98		12,583	153 B	71.77	
95	26	Wind-PV-diesel-battery	10.6 B	4.95		13,690	153 B	71.77	

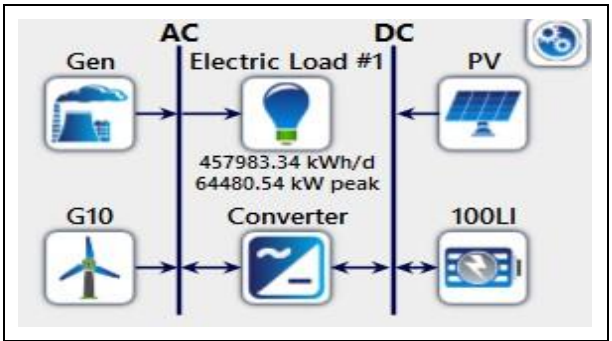


Fig. 6: Designed Hybrid System for Andaman and Nicobar Islands

7. RESULT AND DISCUSSION

Figure 7 depicts the HOMER optimization and sensitivity results. The upper portion of the image shows the results of several sensitivity variables, while the lower section shows the results of a single sensitivity variable optimization. The sensitivity variables for fuel prices were ₹85/L, ₹90/L, and ₹95/L, whereas the sensitivity factors for hub height were 22, 24, and 26 meters.

The best combination of hybrid systems can be found from Table 3. It is shown that NPC for diesel only system is ₹146B, whereas the NPC for hybrid system is ₹10.5B, COE for diesel only system is 68.44 ₹/kWh, whereas for hybrid system, the cost is 4.94 ₹/kWh when fuel is 85₹/L and hub height is 26 m. The emission of CO_2 in diesel only system is 14,57,13,282 kg/year and for hybrid system, it is 13,690 kg/year .

Table 4. Emissions from the proposed Hybrid system and the Diesel-only system

Pollutant	Emission by diesel only (kg/year)	Emission by proposed Hybrid system (kg/year)	Net emission reduction (kg/year)
Carbon dioxide	14,73,13,555	31,592	14,72,81,963
Carbon monoxide	9,28,583	199	9,28,384
Unburned hydrocarbons	40,520	8.69	40,511.31
Particulate matter	5,628	1.21	56,27.79
Sulphur dioxide	3,60,736	77.4	3,60,658.60
Nitrogen oxides	8,72,306	187	8,72,119

The emissions of various pollutants from both the proposed hybrid system and diesel alone are shown in Table 4. The principal pollutants are carbon dioxide, carbon monoxide, unburned hydrocarbons, sulphur dioxide, and nitrogen oxide. The presented information makes it clear that there are considerable differences between the emissions produced by the proposed hybrid system and those produced by a diesel generator alone. In comparison to a suggested hybrid system, carbon dioxide emissions for a diesel-only system are 147,313,555 kg/year and 31,592 kg/year, respectively. Similar numbers for carbon monoxide are 199 kg/year for hybrid systems and 9,28,583 kg/year for diesel-only systems. A diesel-only system emits 3,60,736 kg of sulphur dioxide annually, compared to a hybrid system's 77.4 kg.

6. CONCLUSION

The results of HOMER's sensitivity and optimization results are displayed in Figure. 7. HOMER simulates the suggested model for thousands of combinations in order to produce the best outcome. The finest outcomes are obtained when wind, diesel, photovoltaic batteries, and converters are combined. This combination results in the lowest NPC and COE, ₹10.6B and ₹4.98, respectively. For sensitivity analysis, hub height (m) and fuel rate (₹) have been included as sensitivity variables. With fuel priced at ₹85 per litre and a 24 m Hub height, the aforementioned optimal choice has the lowest NPC of 10.7 billion rupees and the lowest COE of 4.98. Comparing the proposed hybrid system to the conventional diesel alone system, there is a net reduction in the emissions of the various pollutants.

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CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interest or personal relationship that could have appeared to influence the work reported in this paper.

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