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Optimal Sizing and Cost Minimisation of Green Microgrid with Reduction in Environmental Emissions

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ABSTRACT :

In the quest for sustainable energy solutions, the optimal sizing and cost minimisation of green microgrids have emerged as critical areas of research. This paper presents an in-depth analysis of a green microgrid system, focusing on achieving the lowest possible costs while reducing environmental emissions. Using HOMER software, the study evaluates the cost and sizing of various components at different renewable fraction values, highlighting the trade-offs between economic and environmental objectives. The results demonstrate that an optimal balance can be achieved, where significant cost savings and emission reductions are possible without compromising system reliability. This research provides valuable insights into the design and operation of green microgrids, offering practical guidelines for integrating renewable energy sources in a cost-effective and environmentally sustainable manner.

Keywords: Renewable energy, hybrid energy system (HES), Environmental emission

Introduction :

The increasing global demand for energy, coupled with the urgent need to mitigate climate change, has driven significant interest in the development of green microgrids. Green microgrids, which integrate renewable energy sources (RES) such as solar, wind, biomass, and small hydro power, offer a decentralized and sustainable approach to energy generation. These systems not only enhance energy security and reliability but also reduce greenhouse gas emissions and dependence on fossil fuels [1-3]. Optimal sizing and cost minimisation are crucial for the successful implementation of green microgrids. Properly sized microgrid components ensure that the system meets energy demand efficiently, without incurring unnecessary costs or compromising performance. Moreover, minimizing the costs associated with green microgrid deployment and operation makes renewable energy more accessible and economically viable, encouraging wider adoption [4,5]. In this context, the HOMER (Hybrid Optimization Model for Electric Renewables) software has become a valuable tool for researchers and practitioners [6-9]. HOMER allows for the simulation and optimization of microgrid systems, enabling detailed analysis of various configurations and scenarios. By evaluating the cost and performance of different system designs at varying levels of renewable energy penetration, HOMER helps identify the most cost-effective and environmentally friendly solutions [10-13]. This paper focuses on the optimal sizing and cost minimisation of a green microgrid, with an emphasis on reducing environmental emissions. Through comprehensive simulations using HOMER software, the study examines the impact of different renewable fraction values on system cost, sizing, and emission reduction. The findings highlight the potential for achieving an optimal balance between economic and environmental goals, providing practical insights for the design and implementation of sustainable energy systems. The subsequent sections of this paper will delve into the methodology and results of the HOMER simulations, discuss the implications of the findings, and offer recommendations for future research and practical applications. By addressing the key challenges and opportunities in the optimal sizing and cost minimisation of green microgrids, this study aims to contribute to the advancement of sustainable energy technologies and support the global transition towards a low-carbon future.

Resource Assessment and input credential

The successful planning and optimization of hybrid energy systems (HES) require accurate and comprehensive resource assessment and input data. HOMER (Hybrid Optimization of Multiple Energy Resources) software is widely used for modeling and optimizing microgrid and hybrid energy systems. It allows users to simulate various configurations and assess the performance of renewable and conventional energy sources under different scenarios. This chapter delves into the importance of resource assessment and the process of gathering and inputting data into HOMER software, ensuring that the system design is both efficient and cost-effective.

2.1 Importance of Resource Assessment

Resource assessment is a critical step in the planning of hybrid energy systems as it determines the availability and variability of renewable energy sources [46-50]. Accurate assessment ensures that the system is designed to meet the energy demand reliably and efficiently. The key components of resource assessment include:

- Solar Resource Assessment: Evaluating the solar irradiance and potential solar power generation at the site.
- Wind Resource Assessment: Analyzing wind speed data to determine the feasibility of wind power generation.
- Hydropower Resource Assessment: Assessing the flow rates and water availability for potential hydropower projects.
- Biomass Resource Assessment: Identifying the availability of biomass resources for energy production.

Accurate resource assessment helps in optimizing the size and configuration of the energy system components, ensuring maximum utilization of available resources, and minimizing costs and environmental impact.

2.2 Gathering Input Data for HOMER Software

The quality of the simulation results in HOMER depends heavily on the accuracy and reliability of the input data. The primary input data required for HOMER includes [14]:

- Load Profiles: Detailed information on the energy consumption patterns over time, including daily and seasonal variations.
- Renewable Resource Data: Historical data on solar irradiance, wind speeds, and other renewable resources relevant to the site.
- Cost Data: Information on the capital costs, operational and maintenance costs, and replacement costs of system components.
- Technical Specifications: Information about the technical specifications and performance traits of the solar panels, wind turbines, batteries, and generators that make up the energy system.

These specifications are essential for modeling the performance and longevity of the hybrid energy system. The location chosen for the work is a small town named Poongavanapuram in District Chennai, in Tamil Nadu, India. The coordinates of the locations are 130 5.1’N to 800 16.2’E. The peak value of the load at small town is 1313.6 kW. The aerial value for the site is reported in Figure 1. The complete load profile is presented in the Figure 2.

Figure 1: Aerial view of the selected site in India

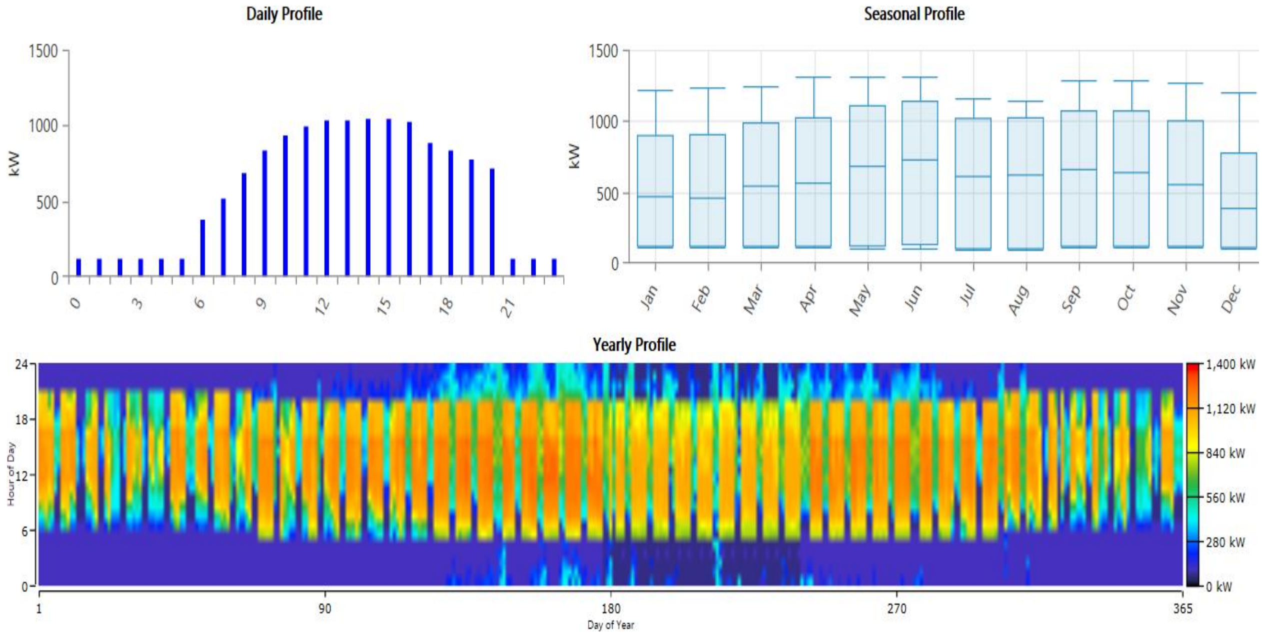

Figure 2: Representation of load profile for the selected site of Tamil Nadu, India

The load profile image from HOMER software provides a comprehensive overview of the energy demand patterns of a system over different time scales: daily, seasonal, and yearly. This information is crucial for designing and optimizing a hybrid energy system. The load profile image from HOMER software provides essential insights into the energy demand patterns of the system on daily, seasonal, and yearly bases. Understanding these patterns is crucial for designing a hybrid energy system that can meet the demand reliably and efficiently. The daily profile highlights the hourly variations, the seasonal profile shows the monthly variations, and the yearly profile gives a comprehensive view of how the demand fluctuates throughout the year. This data is fundamental for optimizing the size and configuration of the system components, ensuring that the system is both cost-effective and capable of meeting the energy needs.

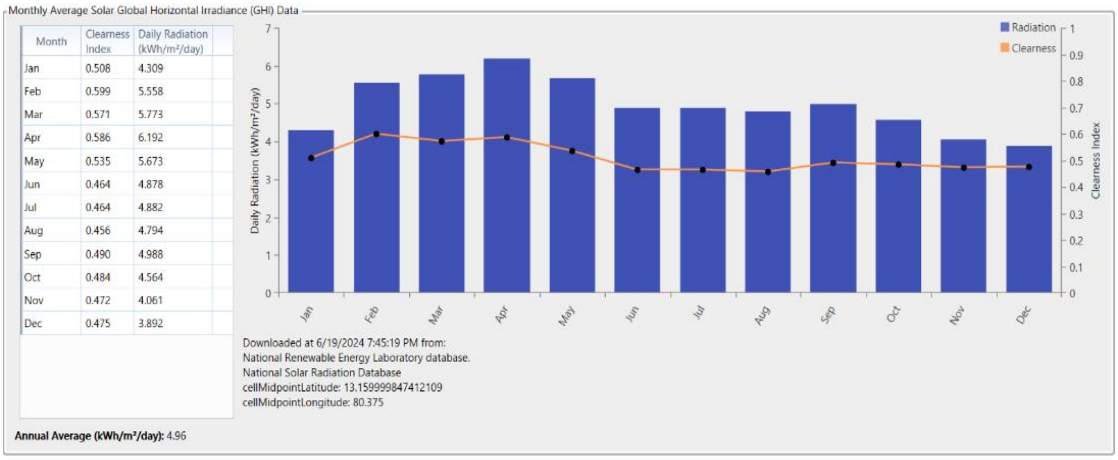

Figure 3. Representation of solar resource profile for the chosen site

The solar resource profile in Figure 3 from HOMER software provides detailed information about the solar energy potential at a specific location throughout the year. This data is crucial for designing and optimizing solar photovoltaic (PV) systems. The image includes monthly average values of solar global horizontal irradiance (GHI), clearness index, and daily radiation. The solar resource profile image from HOMER software provides essential data for understanding the solar energy potential of a specific location over the course of a year. By analyzing the monthly variations in GHI, clearness index, and daily radiation, one can make informed decisions about the design and optimization of solar PV systems. This data helps in estimating the potential solar power generation, planning for energy storage, and ensuring that the solar energy system is sized appropriately to meet the energy demand effectively.

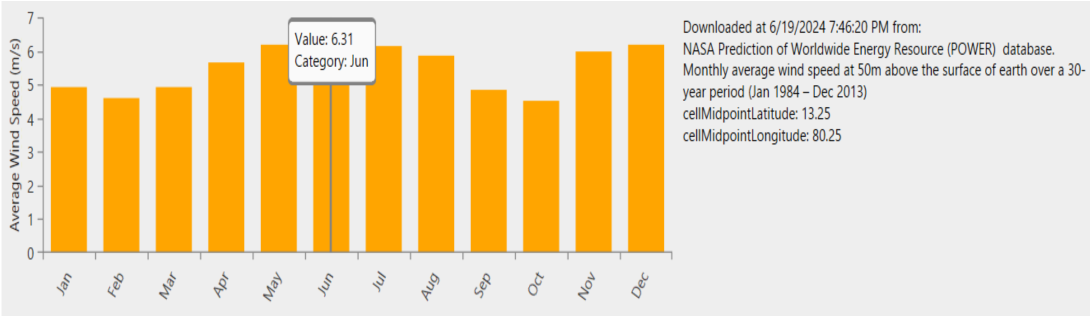

Figure 4: Representation of complete wind resource profile for Tamil Nadu, India

The wind resource profile in Figure 4 from HOMER software provides detailed information about the wind energy potential at a specific location throughout the year. This data is crucial for designing and optimizing wind energy systems. The image typically includes monthly average wind speed data, wind speed distribution, and variations over different timescales. The wind resource profile image from HOMER software provides essential data for understanding the wind energy potential of a specific location over different time scales. By analyzing the monthly average wind speeds, wind speed distribution, and daily and annual variations, one can make informed decisions about the design and optimization of wind energy systems. This data helps in selecting the appropriate wind turbine, estimating potential power generation, and ensuring that the wind energy system is sized correctly to meet the energy demand effectively. The hydro resource profile image from HOMER software provides detailed information about the availability of water resources for hydropower generation at a specific location throughout the year. This data is crucial for designing and optimizing hydroelectric systems. The image typically includes monthly average stream flow data, which indicates the potential for energy generation from water flow.

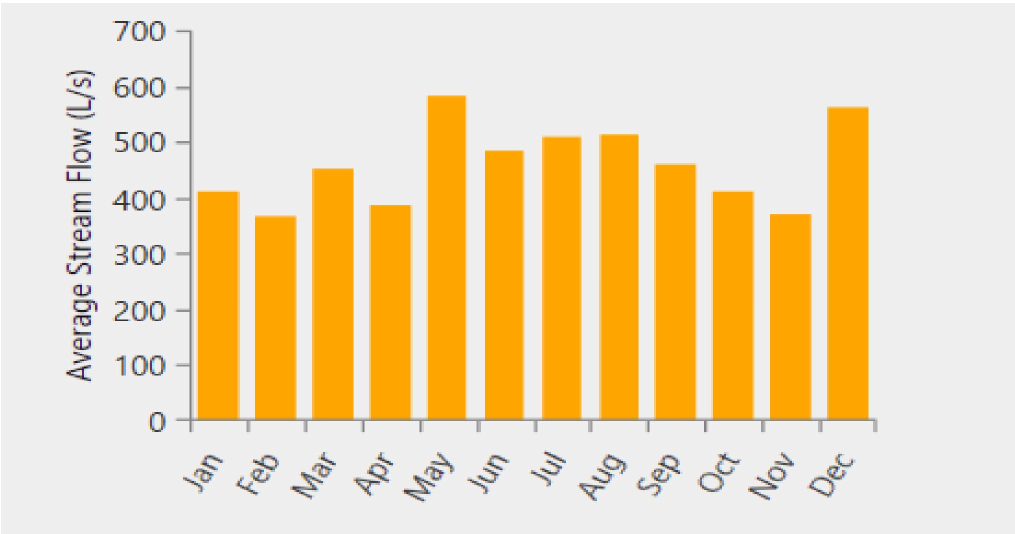

Figure 5: Representation of hydro flow profile for the selected site

The hydro resource profile image from HOMER software provides essential data for understanding the availability and variability of water resources for hydropower generation throughout the year. By analyzing the monthly average stream flow data, one can make informed decisions about the design and optimization of hydroelectric systems. This data helps in estimating the potential power generation, planning for periods of high and low water availability, and ensuring that the hydroelectric system is sized appropriately to meet the energy demand effectively. Understanding these variations is crucial for maximizing the efficiency and reliability of hydropower systems.

Result and Discussion :

The study involves a comprehensive assessment of resource availability, load profiles, and system components, using HOMER software to simulate and optimize various configurations. The objective is to identify the most efficient and sustainable hybrid microgrid design that meets energy demands while minimizing costs and environmental impacts. The introduction of renewable energy sources into microgrids not only addresses environmental concerns but also enhances energy resilience and reliability. Hybrid systems can provide continuous power supply even during periods when individual renewable sources are intermittent. For example, solar power is abundant during the day but unavailable at night, while wind power can vary based on weather conditions. By combining these sources with energy storage systems, such as batteries, and possibly backup generators, hybrid microgrids can ensure a stable and reliable energy supply. By addressing the critical need for sustainable and reliable energy solutions, this research contributes to the broader goal of transitioning to a low-carbon energy future. The findings and methodologies presented in this thesis can serve as a valuable resource for researchers, policymakers, and practitioners involved in the development and deployment of green energy systems, paving the way for more efficient and environmentally friendly power generation.

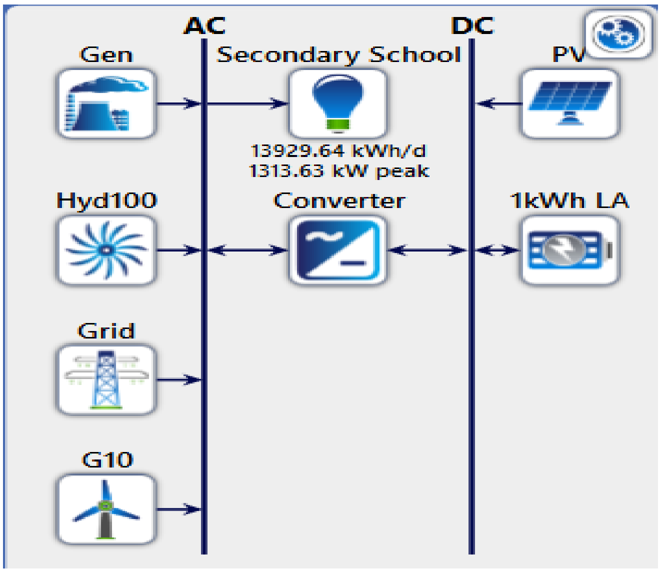

Figure 6. Representation of the proposed hybrid microgrid system for selected site

The Figure 6 is likely a depiction of a hybrid energy system modeled in HOMER software, though it could also be a simplified schematic of a microgrid. Here's a breakdown of the possible components:

- Wind Turbine (Gen): This generates electricity from the wind.
- Solar Panels (PV): These generate electricity from sunlight. The text specifies 13929.64 kWh/day of energy generation and a peak capacity of 1313.63 kW.
- Converter: This converts DC electricity from the solar panels into AC electricity for use in the building.
- Battery (1kWh LA): This battery stores 1 kWh of energy. LA likely refers to Lead Acid, a common battery technology.
- Grid (Grid, G10): This refers to the connection to the utility grid.

The text labels don't indicate a Hyd100 component, but it is possible it's another way of indicating a hydropower source or connection. HOMER software is used to simulate these kinds of hybrid energy systems, which can include a combination of renewable energy sources, storage devices and conventional generators. HOMER helps you assess the economic and technical feasibility of a proposed system design. By inputting data such as solar irradiance, wind resource, energy load and equipment costs, HOMER can compare different system configurations to find the most cost-effective and reliable option for a particular set of requirements.

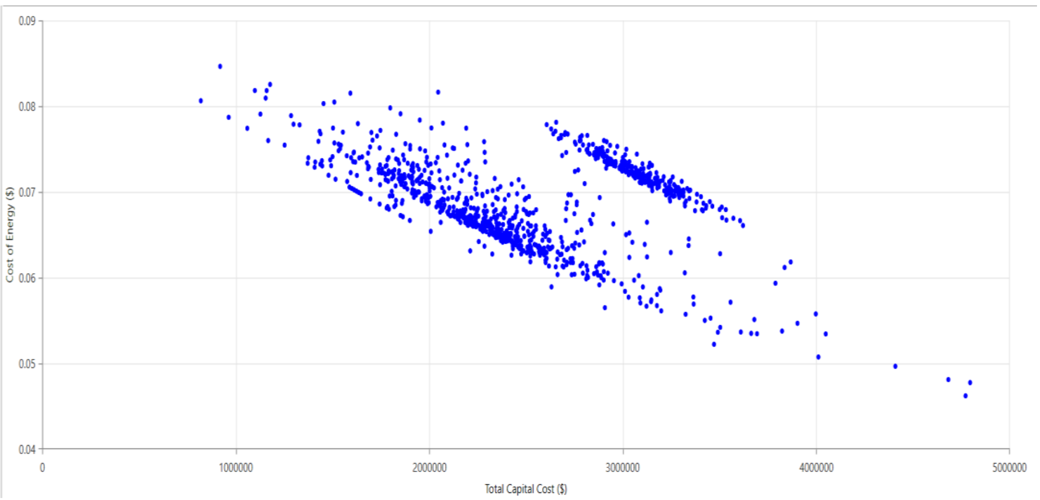

Figure 7: Optimization plot for the energy cost value at different renewable fraction

The provided optimization plot from HOMER software depicts the relationship between the cost of energy (COE) and the total capital cost for different configurations of a hybrid green microgrid. This type of plot is crucial for understanding the trade-offs between initial investment and the operational cost of energy generation.

PV (kW)	G10	Gen (kW)	1kWh LA	Grid (kW)	Hyd100 (kW)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)
1,735	71			999,999	98.1	959	CC	$5.13M	$0.0650	$214,228	$2.36M	71.4
1,665	88		1	999,999	98.1	923	CC	$5.14M	$0.0632	$203,272	$2.51M	73.5
2,182				999,999	98.1	1,165	CC	$5.27M	$0.0716	$263,990	$1.86M	60.4
2,135			28	999,999	98.1	1,115	CC	$5.29M	$0.0726	$268,325	$1.82M	59.5
	127			999,999	98.1		CC	$5.38M	$0.0698	$288,762	$1.65M	55.1
	138		10	999,999	98.1	7.80	CC	$5.40M	$0.0683	$279,385	$1.78M	57.4
1,735	71	1,500		999,999	98.1	959	CC	$5.68M	$0.0719	$201,219	$3.08M	71.4
1,665	88	1,500	1	999,999	98.1	923	CC	$5.69M	$0.0699	$190,264	$3.23M	73.5
2,182		1,500		999,999	98.1	1,165	CC	$5.82M	$0.0791	$250,981	$2.58M	60.4
2,226		1,500	23	999,999	98.1	1,227	CC	$5.84M	$0.0784	$248,573	$2.63M	61.3
				999,999	98.1		CC	$5.88M	$0.0895	$445,534	$123,210	13.2
			30	999,999	98.1	2.57	CC	$5.90M	$0.0898	$446,462	$132,903	13.2
	127	1,500		999,999	98.1		CC	$5.93M	$0.0770	$275,753	$2.37M	55.1
	138	1,500	10	999,999	98.1	7.80	CC	$5.95M	$0.0753	$266,376	$2.50M	57.4
		1,500		999,999	98.1		CC	$6.43M	$0.0979	$432,526	$843,210	13.2
		1,500	30	999,999	98.1	2.57	CC	$6.46M	$0.0982	$433,453	$852,903	13.2

Figure 8: Optimal sizing and cost values at different renewable energy fraction

The provided results in Figure 8 from HOMER software showcases the optimal sizing and cost assessments for different configurations of the hybrid green microgrid. The results are presented for varying renewable energy fraction values, which indicate the proportion of total energy generated from renewable sources. Let's break down the columns and understand the key metrics provided, and then analyze the most optimal and worst-case scenarios.

Columns Explanation

- *NPC ($)*: Net Present Cost. This represents the total cost of the microgrid over its lifetime, including initial capital, operating, and maintenance costs, discounted to the present value.
- *COE ($)*: Cost of Energy. This is the average cost of generating one kilowatt-hour of electricity, in dollars.
- *Operating cost ($/yr)*: This indicates the annual operating cost for the system.
- *Initial capital ($)*: The initial investment required to set up the microgrid.
- *Ren Frac (%)*: Renewable Fraction. This is the percentage of the total energy supplied by renewable sources.
- *Batch, LCB, LDG, Lk, MV, WCC*: These appear to be parameters or values related to specific components or their states (e.g., batch number, local constraints). Further details may be available in the HOMER software documentation.

Analysis

Optimal Scenario

Configuration:

- *NPC ($):* $5.13M
- *COE ($):* $0.065
- *Operating cost ($/yr):* $214,228
- *Initial capital ($):* $2.36M
- *Ren Frac (%):* 71.4

Explanation:

- This configuration represents one of the most cost-effective setups, with a relatively low COE of $0.065 per kWh and a high renewable fraction of 71.4%. The net present cost is $5.13 million, which indicates a moderate total investment over the microgrid's lifecycle.
- The initial capital cost is $2.36 million, suggesting a substantial but manageable initial investment.
- The annual operating cost is $214,228, which indicates efficient operating conditions.

Worst Case Scenario

Configuration:

- *NPC ($):* $6.46M
- *COE ($):* $0.0982
- *Operating cost ($/yr):* $433,453
- *Initial capital ($):* $852,903
- *Ren Frac (%):* 13.2

Explanation:

- This configuration has the highest COE at $0.0982 per kWh, making it the least cost-efficient in terms of energy production.
- The net present cost is also the highest at $6.46 million, indicating a greater total investment over the system's lifecycle.
- The initial capital cost is $852,903, which is lower than some other configurations but leads to higher operating costs.
- The annual operating cost of $433,453 is the highest among all configurations, indicating less efficient operations.
- With a renewable fraction of only 13.2%, this configuration relies heavily on non-renewable sources, contributing to higher environmental emissions and operational costs.

The results provided by HOMER software demonstrate the critical importance of careful planning and optimization in developing hybrid green microgrids. By evaluating different configurations, this study identifies the most cost-effective and environmentally friendly options, guiding stakeholders towards making informed decisions that balance initial investments, operational costs, and sustainable energy generation. The most optimal configuration offers a high renewable fraction with a low COE, whereas the worst-case scenario highlights the drawbacks of low initial investments leading to higher overall costs and lower sustainability. The environmental emission values can be calculated from the results obtained in the Figures 9 to 13. As we got from the results that at maximum renewable fraction, there will be very less environmental emission and at lower value of renewable fraction, a high value of environmental emission will be obtained.

Quantity	Value	Units
Carbon Dioxide	1,052,614	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	4,564	kg/yr
Nitrogen Oxides	2,232	kg/yr

Figure 9: Environmental emissions value in kg/year at renewable fraction 73 %

The provided table from HOMER software displays the annual emissions of various pollutants generated by the hybrid green microgrid system. Understanding these results is crucial for assessing the environmental impact of the microgrid and ensuring that the system aligns with sustainability goals. Here is a detailed explanation of each parameter:

Emission Metrics

1. **Carbon Dioxide (CO_2)**
   - **Value:** 1,052,614 kg/yr
   - **Description:** Carbon dioxide is a primary greenhouse gas emitted from burning fossil fuels, biomass, and certain industrial processes. High levels of CO_2 contribute significantly to global warming and climate change.
   - **Implications:** The given value indicates the total annual emission of CO_2 by the microgrid. Reducing CO_2 emissions is essential for mitigating climate change.
2. **Carbon Monoxide (CO)**
   - **Value:** 0 kg/yr
   - **Description:** Carbon monoxide is a colorless, odorless gas produced by incomplete combustion of carbon-containing fuels. It is harmful to human health and can contribute to air pollution.
   - **Implications:** The absence of CO emissions suggests efficient combustion processes and proper functioning of the system, leading to complete burning of fuel and minimizing health risks.
3. **Unburned Hydrocarbons (UHC)**
   - **Value:** 0 kg/yr
   - **Description:** Unburned hydrocarbons are pollutants released from the incomplete combustion of fossil fuels. They can react in the atmosphere to form smog and contribute to health issues.

   - **Implications:** Zero emissions of unburned hydrocarbons indicate effective combustion and reduced potential for smog formation and air pollution.
4. **Particulate Matter (PM)**
   - **Value:** 0 kg/yr
   - **Description:** Particulate matter consists of tiny particles or droplets in the air that can be harmful when inhaled. Sources include combustion processes and industrial activities.
   - **Implications:** No particulate matter emissions reflect a clean energy generation process, reducing respiratory health risks and contributing to cleaner air quality.
5. **Sulfur Dioxide (SO_2)**
   - **Value:** 4,564 kg/yr
   - **Description:** Sulfur dioxide is produced from the combustion of fossil fuels containing sulfur. It can lead to acid rain, which harms ecosystems, buildings, and human health.
   - **Implications:** The given value for SO_2 emissions highlights the need to control sulfur content in fuels or implement desulfurization technologies to minimize environmental and health impacts.
6. **Nitrogen Oxides (NO_x)**
   - **Value:** 2,232 kg/yr
   - **Description:** Nitrogen oxides are produced during high-temperature combustion processes. They can cause respiratory problems and contribute to the formation of ground-level ozone and smog.
   - **Implications:** The NO_x emissions indicate a need for combustion optimization or post-combustion treatments to reduce these pollutants and their associated environmental and health effects.

The different values of environmental emissions present in the Given figures below.

Quantity	Value	Units
Carbon Dioxide	1,643,589	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	7,126	kg/yr
Nitrogen Oxides	3,485	kg/yr

Figure 10: Environmental emissions value in kg/year at renewable fraction 57 %

Quantity	Value	Units
Carbon Dioxide	454,821	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	1,972	kg/yr
Nitrogen Oxides	964	kg/yr

Figure 11: Environmental emissions value in kg/year at renewable fraction 90 %

Quantity	Value	Units
Carbon Dioxide	240,337	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	1,042	kg/yr
Nitrogen Oxides	510	kg/yr

Figure 12: Environmental emissions value in kg/year at renewable fraction 98 %

Quantity	Value	Units
Carbon Dioxide	2,790,498	kg/yr
Carbon Monoxide	0	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	12,098	kg/yr
Nitrogen Oxides	5,917	kg/yr

Figure 13: Environmental emissions value in kg/year at renewable fraction 10 %

Summary and Implications

- *Overall Impact:* The table provides a snapshot of the annual emissions of various pollutants from the microgrid. The presence of CO_2, SO_2, and NO_x emissions highlights the environmental impact of the current energy generation processes. Achieving lower emissions of these pollutants is essential for improving air quality and reducing the carbon footprint of the microgrid.
- *Zero Emissions for Some Pollutants:* The absence of CO, UHC, and PM emissions indicates that the combustion processes are relatively efficient and that the system avoids incomplete combustion and the associated health hazards.
- *Focus Areas for Improvement:*
    - *Carbon Dioxide (CO_2):* Strategies to reduce CO_2 could include increasing the renewable energy fraction, improving energy efficiency, and incorporating carbon capture technologies.
    - *Sulfur Dioxide (SO_2):* Reducing SO_2 emissions may involve using low-sulfur fuels or implementing flue gas desulfurization techniques.
    - *Nitrogen Oxides (NO_x):* NO_x emissions can be reduced through advanced combustion technologies, selective catalytic reduction (SCR), or other post-combustion control methods.

The provided emission data is crucial for evaluating the environmental performance of the hybrid green microgrid. While the system shows good performance in avoiding certain pollutants, there is a clear need to address CO_2, SO_2, and NO_x emissions to align with environmental sustainability goals. By focusing on these areas, the microgrid can further minimize its environmental impact and contribute to a cleaner, healthier environment.

Conclusion:

This study demonstrates the potential for optimizing the sizing and cost minimisation of green microgrids while achieving significant reductions in environmental emissions. Using HOMER software, we conducted a detailed analysis of various green microgrid configurations at different renewable fraction values. Our findings reveal that by carefully selecting and sizing renewable energy sources and storage systems, it is possible to create economically viable microgrids that substantially reduce greenhouse gas emissions. The results indicate that higher renewable fraction values generally lead to lower emissions, albeit at an increased cost. However, the optimization process allowed us to identify configurations that strike a balance between cost and environmental benefits. Specifically, we found that certain renewable fraction values provide an optimal point where the additional investment in renewable technologies is justified by the resulting cost savings and emission reductions over the system's lifetime.

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