

# FEASIBILITY ANALYSIS OF HYBRID RENEWABLE ENERGY SYSTEMS FOR SUSTAINABLE DEVELOPMENT: A REVIEW

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## ABSTRACT

The rapid growth of renewable energy markets has significantly increased interest in integrating multiple power sources into Hybrid Renewable Energy Systems (HRES). These systems enhance fuel efficiency, economic viability, reliability, and flexibility while addressing the limitations of standalone renewable energy technologies. However, the inherent variability of solar and wind energy presents a key challenge. Wind energy generation often misaligns with load demand, leading to potential energy wastage, while solar energy is only available during daylight hours. By incorporating energy storage and a mix of renewable and nonrenewable sources, hybrid systems help mitigate fluctuations and uncertainties in renewable energy availability. To ensure optimal performance, the design of HRES requires careful optimization of numerous system parameters and variables. This chapter provides an overview of optimal system sizing techniques and the various optimization algorithms used in HRES design, alongside the key objective functions considered in such systems.

## 1. INTRODUCTION

The adoption of solar and wind energy has grown steadily, driven by declining costs and the need for sustainable energy solutions, particularly since the oil crises of the 1970s [1]. However, the intermittent nature of these resources poses a significant challenge, as their generation depends on fluctuating environmental conditions such as solar irradiance and wind speed [2]. To address this issue, hybrid systems integrate multiple renewable sources, energy storage, and dispatchable energy resources such as biogas and fuel cells, ensuring a stable power supply. HRES typically consist of a combination of power generation sources, such as wind turbines, solar panels, and diesel generators, alongside battery storage and an intelligent power management system that optimally regulates energy distribution [4]. Microgrids, which function as integrated energy networks, exemplify HRES by incorporating renewable energy, storage, and loads. These systems are gaining traction due to their ability to provide high-quality power, enhance energy efficiency, reduce carbon emissions, and lower overall costs. Notably, microgrids can operate in an "islanded" mode, allowing them to disconnect from the main grid during disturbances or voltage fluctuations [5]. To maximize efficiency and performance, HRES design must adhere to physical and technical constraints while optimizing system configurations [6]. Advanced optimization tools and techniques play a crucial role in achieving these objectives.

## 2. OPTIMAL SIZING FOR HYBRID RENEWABLE ENERGY SYSTEMS

To achieve cost-effectiveness, reliability, and operational efficiency, HRES require proper component sizing [7]. Various studies have explored optimization parameters, including system components, load characteristics, and sizing methodologies. Table 1 summarizes the key optimization parameters considered in different HRES studies.

The optimization of HRES is typically guided by economic and technical objectives:

- Economic Objectives** – These focus on minimizing the cost of energy production, including parameters such as Levelized Cost of Energy (LCOE), Net Present Cost (NPC), and other financial considerations [8].
- Technical Objectives** – This aim to maximize system reliability, efficiency, and environmental sustainability while ensuring the energy supply meets demand optimally. A key goal is to minimize greenhouse gas emissions [9]. While HRES generally require significant initial capital investment, their operational and maintenance costs are relatively low [10-11].

Therefore, optimizing system parameters is essential to balance upfront expenditures with long-term cost savings.

References	Hybrid System	Load Specifications	Optimized Parameters
[4]	Wind/PV/Battery	250kW peak, 30kW base	Size, NPC, LCOE, Efficiency
[5]	Wind/PV/Micro urbine/Battery	2kW constant	Size, NPC, LCOE, System Reliability
[6]	Wind/PV/Diesel/Battery	30kW peak, 6kW base	Size, NPC, LCOE, Emission Factor,

			O&M Cost
[7]	Wind/PV/Battery	1800W	Size, NPC, LCOE, Grid Independence
[8]	Wind/Diesel/Battery	4kW peak, 0.3kW base	NPC, LCOE, Emission Factor, Cost Savings
[9]	Wind/PV/Energy Storage	1.2MW peak, 0.5MW base	Size, NPC, LCOE, Energy Dispatch Strategy
[10]	Wind/PV/Energy Storage	1.2MW constant	Size, NPC, LCOE, CO <sub>2</sub> Reduction

### 3. KEY COST OPTIMIZATION CRITERIA

**a) Minimizing the Levelized Cost of Energy (LCOE):** LCOE represents the total system cost divided by the total energy produced over its lifetime, making it a key metric for cost efficiency. Many studies emphasize reducing LCOE to ensure economically viable energy solutions.

**b) Minimizing Net Present Cost (NPC):** NPC accounts for the total present value of system costs, including installation, maintenance, and replacement expenses throughout its lifespan. Reducing NPC is essential for cost-effective hybrid system implementation.

**c) Minimizing Additional Cost Factors:** Several other financial metrics, such as Life Cycle Cost (LCC), Levelized Unit Electricity Cost (LUEC), Annualized Cost of the System (ACS), Capital Cost (CC), Total Cost of the System (TCS), and Average Generation Cost (AGC), play crucial roles in evaluating the financial feasibility of HRES.

### 4. CONCLUSION

This study explores various HRES configurations and their associated optimization parameters. Critical factors such as system sizing, NPC, LCOE, and emissions reduction are essential in designing efficient hybrid energy systems. By leveraging site-specific data, hybrid systems can be optimized using software tools like HOMER Pro to assess their economic and technical feasibility in meeting electricity demand reliably and cost-effectively.

### 5. REFERENCES

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