p-ISSN: 0972-6268 (Print copies up to 2016)

e-ISSN: 2395-3454

Vol. 23

No. 3 pp. 1261-1283

2024

NATURE ENVIRONMENT & POLLUTION TECHNOLOGY

Original Research Paper



https://doi.org/10.46488/NEPT.2024.v23i03.003

Open Access Journal

Techno-Economic Analysis of Solar, Wind, and Biomass Hybrid Renewable Energy Systems to Meet Electricity Demand of a Small Village in Bihar State of India

Anant Arun Patil*, Rajesh Arora*, Ranjana Arora*, and S. N. Sridhara**, Department of Mechanical Engineering, Amity University, Gurgaon-122413, Haryana, India **Solar Engineering Department, Amity University, Gurgaon-122413, Haryana, India **Hindustan Institute of Technology and Science, Chennai-603103, Tamil Nadu, India †Corresponding author: Rajesh Arora; rajesharora1219@gmail.com

Nat. Env. & Poll. Tech. Website: www.neptjournal.com

Received: 24-04-2024 Revised: 16-05-2024 Accepted: 04-06-2024

Key Words:Solar energy Biomass energy Renewable energy HRES

COE

ABSTRACT

This study examines the potential use of Hybrid Renewable Energy Systems (consisting of photovoltaic, wind, bio, and diesel sources) both with and without the inclusion of battery storage in the eastern region of India. An evaluation is conducted to determine the economic viability of several system configurations, and the most efficient system is selected using HOMER software. The investigation focused on six distinct scenarios to meet the energy needs of a village community. The goal was to satisfy a daily load need of 1093.7 kWh, with a peak demand of 153.63 kW. The study examined many factors, such as system efficiency, financial viability, and ecological consequences. The primary aim of the research was to compare the power costs associated with different designs of HRES. Detailed technocommercial assessments were carried out to examine the energy production, consumption, and financial impacts of each scenario. This research provides valuable insights for individuals and organizations seeking reliable and long-lasting energy solutions by analyzing the potential benefits and drawbacks of implementing HRES in rural areas. An evaluation is conducted to determine the energy contribution of each element within an RES, as well as the influence of HRES on energy expenses and net present value. The findings of this study reveal that the optimized hybrid system comprises 133 kW photovoltaic arrays, a 130-kW wind turbine, a 0.2 kW biogas generator, a 100-kW diesel generator, a 540-kWh battery bank with nominal capacity, and a 58-kW converter. This system has a minimum COE of 0.347\$/kWh and NPC of \$1.71M. The research offers useful insights for designers, scholars, and policymakers on the existing design constraints and policies of biomass-based hybrid systems.

INTRODUCTION

Energy is getting more and more recognized as a major sector. During the past several decades, the number of sources of clean energy and related technologies has increased rapidly on a worldwide scale. Governments throughout the globe around every continent, new laws and regulations have been passed to promote the use of RET. These measures include, in addition to laws, the advancement of energy connection plans, the promotion of clean energy technology, and the increase in the efficiency of energy (Perera et al. 2013, Bandara et al. 2012, Bansal et al. 2013, Balcombe et al. 2013, Moghavvemi et al. 2013). Many storage systems, backup energy sources, and RES have been created. Since RESs are intermittent, to ensure continuous power supply, this suggests that by connecting these alternative energy

sources to standard electrical infrastructure, electrical power can be supplied. This will increase the long-term stability of energy supply, especially in nations that rely on outside generators to satisfy various kinds of demand. (Meyar & Vaez 2012, Hoicka & Rowlands 2011, Ismail et al. 2013, Mekhilef et al. 2013). The combination of conventional and renewable energy sources can optimize the dependability of renewable energy sources under challenging environmental circumstances, reduce the limits associated with them, and open investment opportunities that would not otherwise be feasible (Gupta & Purohit 2013). The study of hybrid technologies and the wide range of applications they are provide currently receiving a significant amount of scientific attention. Academic research has investigated a variety of arrangements. A review of the literature on electricity in rural areas shows that one of the most crucial ways to

provide reliable, high-quality power for a variety of uses to areas without access to the electrical system is via sources of clean energy (Ma et al. 2013, Mekhilef et al. 2012, Harish et al. 2014).

An essential component of any nation's industrialization, urbanization, and economic growth is electricity (Khare et al. 2013). To create electricity, a variety of standard and nontraditional power sources have been used. Two of the most common types of energy are RES, such as solar and wind power systems. Because of their versatility and environmental benefits, RES-such as wind and solar power are becoming more common (Elhadidy & Shaahid 2000). In the previous 20 years, a remarkable advancement in the field of solar wind, with a shift from standalone to integrated systems has been widely used (Nema et al. 2010). Energy from solar and wind systems operates regularly in both independent and grid-connected modes due to the stochastic nature of both power sources; however, its efficiency is reduced. Sources of clean energy are utilized to provide grid-integrated hybrid energy, which mitigates the unpredictability of nature. Conventional and renewable energy sources are integrated into a system that uses hybrid renewable energy (HRE). Additionally, two or more standalone or grid-connected RES may be included. The HRES operates in two modes: sequential and simultaneous, combining significant solar and wind resources. Even though they generate power alternately in sequential mode, both solar and wind power plants do it concurrently in simultaneous mode (Elhadidy & Shaahid

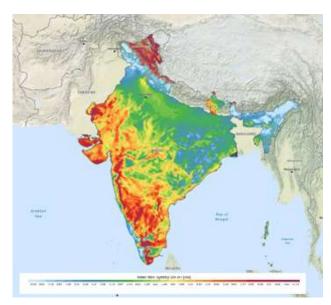
India Solar Resource
Global Horizontal Irradiume - Annual Average
This has projects model estimates of annual average
This has projects model estimates of annual average
This has project model estimates of annual average
This has project model estimates of annual average policy beneated irradium estimates of policy and the control of the second control of the cont

Source: (NSRDB 2024).

Fig. 1: Annual Global Horizontal Irradiation

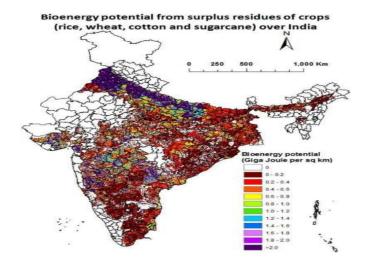
2004, Notton & Muselli 1996). The objective of the ideal simulation is to analyze a photovoltaic wind-biogas-pumped hydroelectric off-grid hybrid system for rural electrification in Sub-Saharan Africa. The researchers found that Djoundé, a remote hamlet in northern Cameroon, has implemented a comprehensive off-grid HES that relies entirely on renewable sources. This system includes wind turbines, photovoltaic arrays, and a biogas generator to meet the population's power requirements (Yimen et al. 2018). The optimal allocation of the whole load has been accomplished by harnessing wind, sun, and biomass resources. When there is very little need for energy in the local area, any extra power is sent to the national power system. According to techno-economic feasibility research, a hybrid power system can generate energy over 50 megawatts (Ahmad et al. 2018).

The Indian government concentrated on electrifying every unconnected family in the nation while slowly working towards 100% rural electrification. After analyzing in research, it was determined that the main obstacles to household electrification were the following: a lack of knowledge, the expense of establishing new connections, the complexity of the process, and other logistical challenges. The Indian government meticulously planned and implemented the Pradhan Mantri Sahaj Bijli Har Ghar Yojana, also known as Saubhagya, was launched in October 2017 with a specific focus on ensuring electricity access to all households in the country, especially those who were previously unelectrified. The Saubhagya plan is a massive endeavor aimed at achieving universal electrification, making



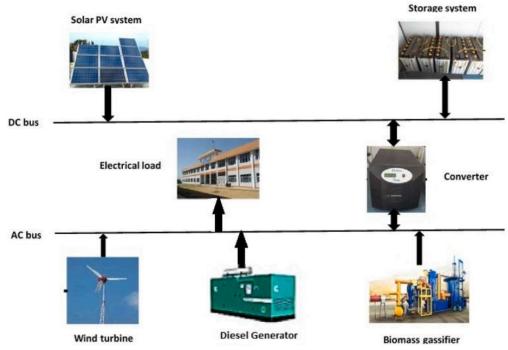
Source: (Wikipedia 2024).

Fig. 2: Mean Wind Speed



Source: (Bhuvan 2024).

Fig. 3: Bioenergy potential over India



Source: (Malik et al. 2019).

Fig. 4: Hybrid Renewable Energy System.

it one of the biggest in the world. It involves the collaborative efforts of the Centre and the States (Saubhagya Dashboard 2024). Fig. 1. and Fig. 2 show annual global horizontal irradiation (NSRDB 2024) and wind speed (Wikipedia 2024).

Fig. 3 gives overall bioenergy potential in India from residues of crops rice, wheat, cotton, and sugarcane (Bhuvan 2024). The representation of HRES presented in Fig. 4 (Malik

et al. 2019). Fig. 5 describes the Schematic representation of HOMER software (HOMER Pro 2024). The procedures to apply the recommended HES in HOMER are shown in Fig. 4. Finding the location's load profile and then obtaining the solar irradiation potential and wind speed potential are the two main steps in the process. Then, we model the system using various components. The component sizes are

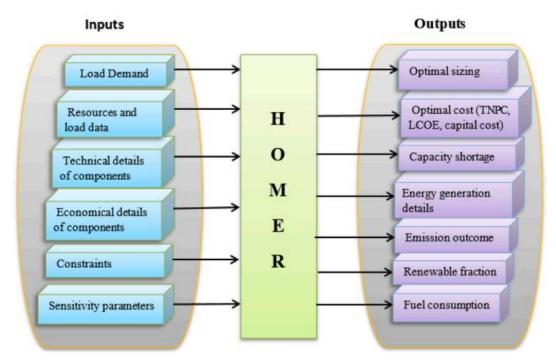


Fig. 5: Schematic representation of HOMER software (HOMER Pro 2024).

included, along with the economic characteristics. To do our model's cost optimization assessment, optimization is carried out. COE analyzes the whole simulated outcome to provide satisfying findings and determines whether the chosen outcome fulfills the study's purpose. HOMER categorizes its results according to a low-cost partnership.

This research paper presents an optimal approach for determining the appropriate dimensions and functioning of an HES that combines wind and biomass gasification. A case study is done using real-time load demand data acquired from a facility. The wind-biomass gasifier HES is also analyzed in economic research (Balamurugan et al. 2011). This study investigates the economic viability of a hybrid power system that combines biomass, photovoltaic (PV), and wind generators to fulfill the electricity requirements of isolated locations (Maherchandani et al. 2012). Conventional ways of meeting energy demand are impractical due to most of the cost involved in transportation and electrical distribution to these remote places. These days, a lot of places use hybrid electrical systems, with diesel generators serving as vital backup power sources. The primary justification for a hybrid system that uses biomass as a fuel source is the accessibility of biomass, such as goat, cow, or buffalo dung, at reasonable prices in rural regions. Biomass sources can provide electricity on overcast days and in the absence of the minimum wind requirement. The goal of the project is to determine whether combining solar PV and biomass resources can fulfill the long-term economic and technological sustainability of fulfilling the energy needs of Tola Dhumnadih Village in Banka District, Bihar. The primary aims of this study are to explore the potential of these sustainable energy sources, examine their ability to meet the village's electricity needs, evaluate the project's financial feasibility and expenses, and offer suggestions for the development of a dependable, reasonably priced, and ecofriendly energy source that could be used as a model for rural electrification in comparable areas. Ultimately, the project seeks to provide frameworks and insights into how energy from renewable sources might be used in distant areas to support long-term growth for independence from fossil fuels.

PAST STUDIES

A hybrid electrical system generates energy from many of these sources at the same time. The biggest benefit of HES is its ability to meet energy demands. Usually, applicable in stand-alone applications for isolated areas without access to an electrical grid. Numerous research works on renewable hybrid energy sources have been published in scholarly journals. This study's review of the literature is restricted to PV-wind-biomass HRES. Anant et al. and associates evaluated the financial viability of solar, biomass, and wind turbines for generating grid power to meet the needs of rural areas (Patil et al. 2023). Meanwhile, a business has proposed HRES for Balamurugan and three Indian city-states. Making

use of an appropriate model, created by the HOMER software creators, divides the electrical power across the tasks based on significance. Researchers used a statistical approach to calculate that the price of power is US\$ 0.1095 (Balamurugan et al. 2009). In Kakavayal, Kerala, India, Kumaravel and Ashok also used biomass-based HRES to electrify local villages. Using the HOMER program, they ascertained the ideal HRES configuration for biomass, solar, wind, and storage. The parametric assessment revealed that the energy cost amounted to 0.164\$/kWh (Kumaravel & Ashok 2015). A study of the costs associated with implementing an ecologically friendly electricity delivery mechanism for residential usage was done for the hamlet. They modeled and optimized their wind PV hybrid system using HOMER software. They found seven distinct hybrid systems that are emulated, both with and without battery storage. The HES consisting of photovoltaic cells, biomass energy producer, and batteries is determined to be the best design, resulting in the lowest energy cost per kWh at an anticipated TNPC of \$76080, with 41% PV and 59% biomass part (Malik et al. 2021, Malik et al. 2019). Sustainable application is significantly hampered by the intermittent presence of renewable resources in the settlements. Combining two or more green energies might be the best way to tackle the irregularity of those assets, the expenditures associated with producing energy, and the general efficacy of the system, including power dependability (Neves et al. 2014, Chandel et al. 2016).

Several researchers have examined the assessment and analysis of the practicality and effectiveness of off-grid HES infrastructure in India and other nations to provide rural power supply. For instance, Karki et al. evaluated the HRES feasibility for a small island in India to assess the effects of dispersed source utilization on net current cost, energy expenses, and CO₂ emissions (Karki et al. 2008). The technical-economic assessment of various HRES achievements for the country's rural areas was investigated (Chambon et al. 2020). In five states in India without power, including Uttarakhand, Bhatt et al. Explored the capabilities of a disengaged HRES. The optimal COE generation, assuming a 94% renewables share, was found to be 0.197 \$/ kWh (Bhatt et al. 2016). A framework for optimization was developed by Chauhan and colleagues for HRES based on the electric load needs of 48 non-electrified country small towns in the Chamoli district of the Indian state of Uttarakhand (Chauhan & Saini 2016). To satisfy the increasing demand, Malik et al. suggested incorporating a plant-based gasifier with the present PV/WT hybrid system (Malik et al. 2020). Li et al. After studying the viability of merging systems that utilize different battery types, utilizing energy generators rather than lithium-i along with battery packs with lead acid, zinc-bromine form batteries are more cost-effective to employ (Li et al. 2020). An investigation was conducted to assess the practicality of using HRES to meet the energy needs of a remote hamlet in Iran. by Rad et al. The results indicated that an integrated HRES with PV, WT, and BG is the optimum choice. Although the total cost will still increase by 33-37%, adding fuel cell technology would increase system flexibility further (Rad et al. 2020). Vendoti et al. conducted a comprehensive examination of HRES from both a technical and economic perspective to determine which options would best satisfy the load demands of the country's communities. Based on the study, PV-WT-BG-FC-Battery-based HRES was shown to be the most efficient design with the lowest COE of 0.214 \$/kWh (Vendoti et al. 2021). Malik et al. provided a comprehensive analysis. It found that bioenergy integrated systems offer a cheap and environmentally friendly solution to powering rural areas (Malik et al. 2021). Salehin et al. proposed establishing an HRES to deliver energy to Bangladesh's isolated island of Adarsha Char (Salehin et al. 2014). Sigarchian et al. completed the sensitivity analysis and optimization of HRES for Kenyan villages that lack power. An analysis of the literature suggests that the major focus of research is on hybrid electrical systems enabling rural electrification using solar and wind power. However, research on biomass-based hybrid buildings for hilly terrain has been severely lacking (Sigarchian et al. 2015).

Taele et al. found that constructing small-scale solar energy systems in Lesotho communities reduced electricity loss, removed huge fuel storage, and prevented multiple breakdowns (Taele et al. 2012). Patil et al. conducted a study in Uttarakhand, India, to explore the incorporation of four distinct renewable energy sources (Kanase et al. 2010). This was done to address the requirements for cooking and electricity in seven communities. Baghdadi et al. conducted a study on the efficiency of a hybrid PV-wind diesel battery in the Adrar region of southern Algeria (Baghdadi et al. 2015).

Based on the calculations, the most realistic approach to satisfy the load demand is to combine a 3-kW hydrogen fuel cell with 5 kW of solar output with the least amount of non-permanent current (NPC) and zero% electricity shortage. According to Lau et al., combining batteries with diesel and solar power sources might drastically reduce dependency on the finite fuel supply (Lau et al. 2010). Yilmaz and Selim looked at many concepts for turning biomass into electricity and combining it with different renewable energy sources (Yılmaz & Selim 2013). The study shows that load demand may be efficiently satisfied with the appropriate mix of renewable energy sources and technological advancements. Rahman et al. examined the technological and economical

optimization of hybrid bioenergy & solar systems to replace traditional facilities, it is necessary to satisfy both thermal (cooking) and electric requirements (Rahman et al. 2014). Ozden's capacity in Ankara, Turkey, Tari studied the energy

output exertion using a combination of solar-hydrogen technology. The total efficacy of this hybrid approach is 6.21%, while the performance of the hydrogen-generating cycle is 40.06 percent, according to the data. The researchers

Table 1: The results of some HES that were installed to electrify rural areas.

Ref	Location	HRE technologies						Energy	COE	Findings	
		PV	WT	DG	BG	В	С	consumption			
(Ajlan et al. 2017).	Shafar, Yemen					$\sqrt{}$		886 kWh/day	0.137 \$/kWh	The current and future feasibility of hybrid PV/WT/diesel systems over 100% RE and diesel systems.	
(Dawoud et al. 2015).	Hurghada, Egypt	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	1153 kWh/ day	0.139 \$/kWh	HRES implementation over diesel-only load demand electrification has economic and environmental benefits.	
(Sawle et al. 2018).	India	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	10.6 kWh/day	0.195 \$/kWh	Different optimization strategies were used to tackle the problem. According to the findings, TLBO is an effective instrument for dealing with any issue objectives and providing an appropriate solution.	
(Shahzad et al. 2017).	Layyah, Pakistan	$\sqrt{}$				$\sqrt{}$	$\sqrt{}$	168.36 kWh/ day	5.51 Rs/kWh	Evaluated the hybrid system's techno-economic viability for use in agriculture.	
(Gan et al. 2015).	Bishopton, Scotland	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	15 kWh/day	0.677 £/kWh	Create an optimal HRES modelling and scaling tool. Compare battery and diesel sizes and choose the one with the lowest life-cycle cost.	
(Mandal et al. 2018).	Chorasariadho, Bangladesh	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	242.56 kWh/ day	0.37 \$/kWh	In contrast to grid-connected and solar home systems, an optimized off-grid HRE was exhibited. Different perspectives on hybridized energy systems' technical, economic, environmental, and social performance were explored.	
(Shaahid & El-Amin 2009).	Rafha, KSA	$\sqrt{}$		$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	44 kWh/day	0.170 \$/kWh	Compared COE, fuel operating minutes, and carbon dioxide emissions with different PV/battery capacities.	
(Akinyele 2017).	Gwagwalada Nigeria	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	12.51 kWh/ day	0.3145 \$/ kWh	Different hybrid system designs with increasing load needs are tested for battery performance and reliability.	
(Khan et al. 2017).	Amritsar, India	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	1.3 kWh/day	0.164 \$/kWh	Show the hybrid system as the best practical alternative for serving the load with the lowest COE and highest power generation.	
(Padrón et al. 2019).	Lanzarote, Canary Islands.	$\sqrt{}$		$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	250 kW KWh/day	0.404 \$/kWh	From a technological and economic standpoint, a standard HRES was proposed and assessed to ensure the power needs of an autonomous desalination system.	
	Present Cases Study	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	1093.75 kWh/day	0.343 \$/kWh	Of the six different cases of HRES (PV+WT+BGG+DG+B) comes with the Lowest NPC and COE.	

Table 2: Summary of Hybrid Renewable Energy System (HRES) Configuration and Results.

Ref	Location	HRE	HRE technologies					Energy con-	COE	Findings	
		PV	PV WT D		BG B C		С	sumption			
Present Study Case 1	Tola Dhumnadih, Bihar	$\sqrt{}$				$\sqrt{}$	$\sqrt{}$	1093.75 kWh/day	0.467 \$/kWh	HRES developed for the lowest COE to meet load requirements using Solar PV (415 KW) + Wind (183 no's) + Battery (2820 no's) + Converter (141KW).	
Present Study Case 2	Tola Dhumnadih, Bihar	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	1093.75 kWh/day	0.461 \$/kWh	HRES developed for the lowest COE to meet load requirements using Solar PV (427 KW) + Wind (186 no's) + Biogas Generator (0.4 KW) + Battery (2700 no's) + Converter (154KW).	
Present Study Case 3	Tola Dhumnadih, Bihar	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	1093.75 kWh/day	0.347 \$/kWh	HRES developed for the lowest COE to meet load requirements using Solar PV (131 KW) + Wind (130 no's) + Biogas Generator (0.2 KW) + Diesel Generator (100 KW) + Battery (540 no's) + Converter (58.0 KW).	
Present Study Case 4	Tola Dhumnadih, Bihar	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	1093.75 kWh/day	0.594 \$/kWh	HRES developed for the lowest COE to meet load requirements using Solar PV (283KW) + Wind (235 no's) + Biogas Generator (2 KW) + Diesel Generator (150 KW) + Converter (46.9 KW).	
Present Study Case 5	Tola Dhumnadih, Bihar	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$		$\sqrt{}$	$\sqrt{}$	1093.75 kWh/day	0.348 \$/kWh	HRES developed for the lowest COE to meet load requirements using Solar PV (133 KW) + Wind (125 no's) + Diesel Generator (100 KW) + Battery (530 no's) + Converter (55.7 KW).	
Present Study Case 6	Tola Dhumnadih, Bihar	$\sqrt{}$	$\sqrt{}$	$\sqrt{}$			$\sqrt{}$	1093.75 kWh/day	0.598 \$/kWh	HRES developed for the lowest COE to meet load requirements using Solar PV (282 KW) + Wind (238 no's) + Diesel Generator (150 KW) + Converter (39.6 KW).	

also suggested that hybrid PV-hydrogen systems outperform PV-battery solutions in terms of performance (Ozden & Tari 2016). Shi et al. created an HRE using an inspired evolutionary algorithm. System optimization includes decreasing fuel usage, the system's yearly cost, and the chance of an outage (Shi et al. 2015). Forough and Roshandel employ multiple goals shrinking vista techniques to find the optimal electric-car timetable. Two objective functions were evaluated: the price of diesel fuel as batteries depleted (Forough & Roshandel 2017). Castellanos et al. investigated several combinations of PV cells, biogas the digester, and a single power & warming unit in a tiny community in West Bengal, India, using micro-grid modeling simulation. The outcome indicates the integration of an inverter rectifier energy system (IRES) with photovoltaic (PV) technology, an anaerobic digester, and a compact turbine. have reduced the total capital and electrical expenses of the project (Castellanos et al. 2015).

The most efficient design of the HRES may have been determined by the research employing a variety of optimization approaches in conjunction with the HOMER software. Sensitivity analysis may be used to analyze changes in variables

such as load demand fluctuations, resource availability, or technology improvements to help enhance comprehension of the system's performance in different scenarios. Consider dynamic variables such as meteorological trends, fluctuations tied to different seasons, and the uncertain behavior of renewable energy sources. By including fluctuations in the accessibility of solar and biomass, the HOMER model may be enhanced by the integration of real-time data and forecasting methods. By addressing these research deficiencies, the study would enhance its comprehensiveness and accuracy, providing a more precise assessment of the economic viability, efficiency, and sustainability of the hybrid green energy source that Tola Dhumnadih Village in the Banka District of Bihar intends to use. The results of some HES that were installed to electrify rural areas are shown in Table 1 which gives insights into the location and the technology used for electrification. Table 2 gives the summary of the Hybrid Renewable Energy System (HRES) configuration and results.

MATERIALS AND METHODS

A comprehensive examination was carried out at the location

in Tola Dhumnadih Village, located in the Banka District of Bihar, India. These investigations were carried out to collect information on the socioeconomic makeup of the community, the climate in the area, the quantity of land available for infrastructure, and the usage habits of energy. The gathering and examination of meteorological data, such as temperature, solar and wind radiation, biomass, and electric consumption, was necessary for accurate modeling. Utilizing a variety of energy systems to electrify a complete town utilizing solar, wind, bioenergy, diesel generators, and battery banks, six alternative energy models were developed and simulated using the HOMER software. The objective is to build a battery-powered HES that includes wind turbines, generators, converters, solar PV panels, and other components while taking into consideration the energy requirements and environmental characteristics of Tola Dhumnadih Village.

Site Selection and Data Collection

Tola Dhumnadih Village, a town in Banka, Bihar, was chosen as the main subject of the feasibility study due to its advantageous socioeconomic, physical, and energy-related attributes. Information on the topography and climate of Tola Dhumnadih, including elevation, weather patterns, latitude, and longitude of the place, and so on gathering historical as well as current data on things like the sun's average monthly irradiance, wind speed, and the area's biomass resources. Fig. 6. shows the flow diagram of the methodology for the calculation of biomass from the Bhuvan spatial information system of biomass potential from crop residues (Bhuvan 2024).

Case Study and Description

India has a predominantly rural population, with about 600,000 villages accounting for 72.2% of its people's resources. Rural regions consume around 40% of total energy, with the home sector accounting for 55-60% of energy usage. A few of the most important problems are these having direct and indirect implications on energy supply for rural areas. There is a shortage of both commercial and traditional energy and there is more space between supply and demand. Growing populations constantly put more strain on conventional energy sources like wood. Ecological issues are being brought on by urbanization and the deforestation that follows. Since fossil fuels are running out, and the resulting contamination of the environment, a heavy reliance on commercial fuels like coal and oil as a temporary solution to fulfill rising demand is concerning. Remote rural locations that receive energy supplies are linked to substantial transmission and transportation losses of around 22.4%. Therefore, focus should be placed on energy audits in a way that guarantees accessible, sustainable, and

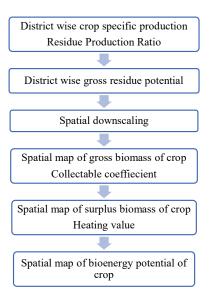


Fig. 6: Flow-Diagram of the Methodology (Bhuvan 2024).

clean energy.

The primary location for the case study is the Chanan Taluka, specifically the little village of Chanan. The town has 1890 residents, 999 of whom are males and 891 of them are women. There are 350 homes in the neighborhood. 389 children make up the whole population. The entire land area of the settlement is around 252.05 acres or 102 hectares. The information supplied provides a demographic overview of the hamlet and provides a breakdown of those living there by gender, number of children, and houses. A deep understanding of these demographics is required to achieve a range of planning, administrative, and construction goals, including resource distribution, social assistance planning, facility building, and other community-specific efforts (Census 2011 India, Indian Village Directory 2024).

Fig. 7 represents the Google Earth and Google Map location of Tola Dhumnadih with latitude 24°46′54.97″N and longitude 86°30'20.77"E region in Banka, Bihar (Google Maps 2024).

The main goal is to assess the viability from a financial standpoint of several alternative power sources. by contrasting the costs of biomass generators, PV systems, wind turbines, and batteries. In addition, one of the objectives of the study is to estimate the hourly values of the monthly electric load for the designated region.

Energy Feasibility Studies for Solar, Wind and Biomass

The energy feasibility study conducted in the Tola Dhumnadih region of Banka, Bihar, thoroughly investigates the utilization of biomass, solar, and wind energy sources for electricity production. This research aims to evaluate



Fig. 7: Tola Dhumnadih region in Banka, Bihar (Google Maps 2024).

the viability and achievability of different renewable energy sources in meeting the energy requirements of the region. Comprehensive evaluations of wind, solar, biomass, and battery energy are included in the research. A variety of aspects are considered, such as resource availability, economic viability, technological feasibility, and environmental effects.

The research evaluates solar radiation levels, solar PV system availability, and the viability of installing them in the Tola Dhumnadih area. Land availability, sun insolation levels, and the financial sustainability of solar power-producing technologies are all taken into account. To assess the wind speed and energy potential of the Tola Dhumnadih area, wind patterns, wind speeds, and topographical concerns must be determined.

The objective of the research is to examine the feasibility of wind-generating projects from both a technical and financial perspective to determine if it is viable to generate energy using wind turbines. The research investigates the feasibility of using local biomass resources to create power. This comprises examining the many forms of biomass that are readily available, their potential for energy generation through processes such as gasification or biogas production, and the economic viability of implementing biomass-based energy systems.

Daily Load Analysis

The daily average connected load for different times of the day is shown in Fig. 8 and observed that the maximum requirement of connected load in the evening timing from 5

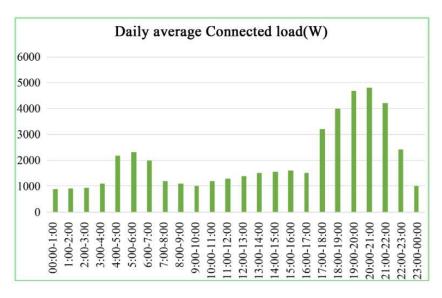


Fig. 8: Comparison of time and average daily connected load, Community 2 (Verma et al. 2015).

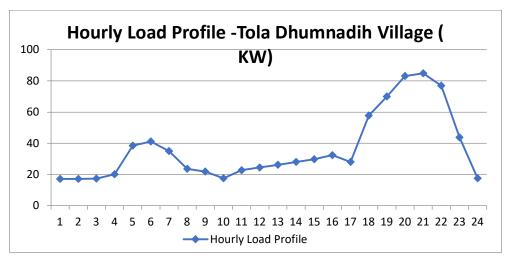


Fig. 9: Hourly Load Profile -Tola Dhumnadih Village.

pm to 10 pm (Verma et al. 2015). Similarly, Fig. 9. Hourly Load Profile calculated for Tola Dhumnadih Village.

Monthly Load Analysis

Using HOMER software, the monthly load study for the Tola Dhumnadih area in Banka, Bihar, comprises a detailed assessment of energy demand patterns. Options include using a generator and battery that runs on diesel in addition to utilizing 100% energy from renewable sources. To meet the neighborhood's power demands, this research will analyze how feasible it is to provide the best possible layout with an energy system based on renewable sources. The HOMER program is used to simulate and model the process of replacing the current electricity supply system with purely sustainable RES.

To have a better understanding of the fluctuating energy demand, load profiles at different times of day and seasons are analyzed. This entails figuring out if employing these resources to effectively meet the specified load profiles is viable. The study assesses the extent to which a diesel generator contributes to the integration of renewable energy sources in the energy system. The HOMER project facilitates the more efficient use of diesel generators and batteries, especially as a backup or in situations when demand may be partially satisfied by renewable energy sources, or as an additional resource to deliver a consistent power supply. The examination includes technical factors like optimizing the diesel generator's well and how big the green energy parts are. Economic assessments are also conducted to find the most economically viable energy option and to assess the cost-effectiveness of the recommended system. In Table 3 the cost of each component explains each component required for HRE generation (Verma et al. 2015, Malik et al. 2021).

The information gathered for an annual load includes all the information on the amount of power consumed or required at a certain location over a full year. These data are required to evaluate the overall energy requirements of a given area and the patterns in those requirements. When creating more energy-efficient technologies, it's critical to consider the variations in electricity use that happen overnight as well as the projected 25% growth in population and level of life. When peak and off-peak hours are identified

Table 3: Cost of each Component.

Components	Capacity	Cost of capital [\$]	Replacement Cost [\$]	O & M [\$/yr]	Duration [yrs/hrs]
PV (Malik et al. 2021)	1 kW	741.00	741.00	25	25 yrs
Wind Turbines (Sawle et al. 2021)	1 kW	1,200	850	20	20 yrs
Diesel Generators (Malik et al. 2021)	1 kW	500	500	0.030	15,000 hrs
Batteries (Malik et al. 2021)	12V	273	211	5.96	10 yrs
Converter (Malik et al. 2021)	1 kW	116	116	3	10 yrs
Biomass Generators (Malik et al. 2021)	1 kW	1162	872	0.010	15,000 hrs

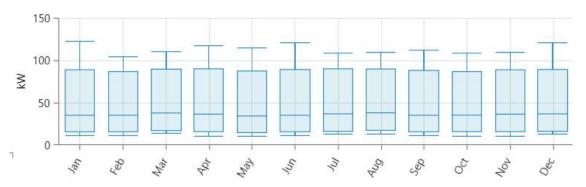


Fig. 10: Yearly Load Data (HOMER Pro 2024).

Table 4: Random variability.

Random Variability					
Day-to-Day [%]	10				
Timestep [%]	10				

using hourly data, utilities may improve the processes involved in generating electricity and supplying that energy. In Fig. 10 yearly Load Data given for each month of the year (HOMER Pro 2024).

Here are detailed instructions for Yearly Load Data:

Using Daily or Hourly Data:

Data Collection: Gather daily or hourly energy use data for the full year.

To find the total yearly consumption, add up how much energy is used each day or hour of the year.

- a. For daily data, total energy uses from January 1st to December 31st of each year.
- b. For Hourly Data: Add up the energy usage for each hour of the year, which amounts to 8760 hours in a non-leap year.

These parameters represent the extent to which the variables or conditions of the simulated system are permitted

to change freely both inside the modeled scenario and daily. 10% variability indicates a significant amount of uncertainty in the model, which might be used to imitate real-world situations or explain the unpredictable nature of the system. Table 4 explains the random variability parameters considered for the HOMER simulation model also in Fig. 11 load details are shown with respect to peak load and average load.

This is the total amount of solar radiation collected by a certain area per unit of time, commonly represented in kWh/m²/day. Monthly average solar irradiance measurements are essential in determining the quantity of daylight that impacts a specific location, a characteristic that directly determines solar panels' ability to create electricity. In Fig. 12 the maximum solar radiation observed in April was 6.34 kWh/m²/day, and the minimum came in December at 4 kWh/m²/day. The average solar radiation available at Tola Dhumnadih village is 4.89 kWh/m²/day (HOMER Pro 2024).

Monthly average wind speed data is critical for assessing a region's ability to generate wind energy. This data is crucial for computing average monthly wind conditions, which can impact the economics and performance of wind energy schemes. The mean wind speed for a given month is measured in meters per second. It depicts the present weather conditions for the given period. The typical monthly value

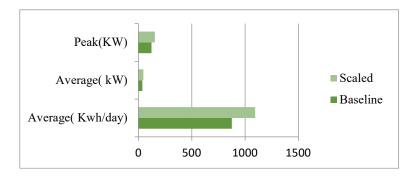


Fig. 11: Load details.

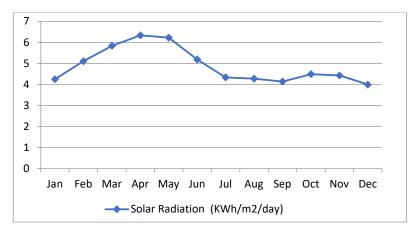


Fig. 12: Monthly average solar global horizontal irradiance data.

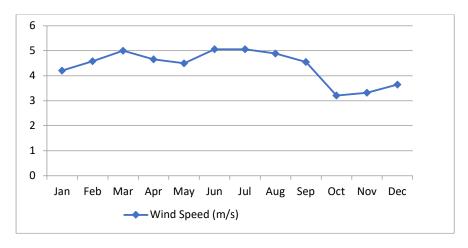


Fig. 13: Monthly average wind speed data.

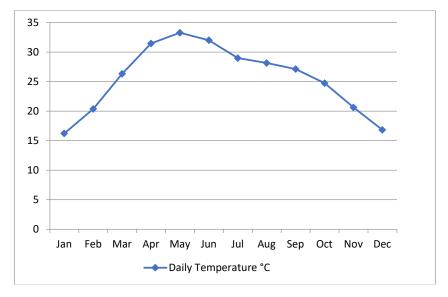


Fig. 14: Daily average temperature data.

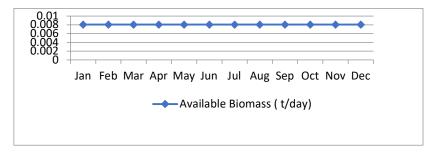


Fig. 15: Daily average available biomass data.

of the wind speed, incorporating temperature data, refers to the projected mean temperatures observed at a certain geographical place for every month of the year.

Fig. 13 and Fig. 14 show the computed wind velocity and temperature for the specified village area on a monthly and annual basis. The greatest wind speed at Tola Dhumnadih village in July was 5.060 m/s, while the minimum was 3.32 m/s in November, for a yearly average of 4.39 m/s. Similarly, the highest temperature in May is 33.23 degrees Celsius, while the lowest temp in January is 16.23 (HOMER Pro 2024).

The daily average available biomass statistics show the average amount of natural issues, or biomass that can be found or might be found in an area or region every month of the year shown in Fig 15 (Patil et al. 2023). This data is very important for finding out how helpful and readily available organic materials are for many things, including producing energy, agriculture, and studying the environment.

Here are detailed Calculation for Biomass Data:

Acers = 252.04 acres

Total Surplus Biomass [kg] = 7900000 kg

Biomass in the village [kg/year] = 2666.79

Biomass in the village [ton/day] = 0.008

RESULTS AND DISCUSSION

This research assesses alternative energy sources using storage cells, alongside traditional energy sources as a contingency, to identify a viable solution that can fulfill the local power demand while simultaneously reducing emissions and cost considerations such as the COE, NPC, and operation and maintenance expenses (O & M). At times, a diesel generator must be used when storage cells are insufficient to meet the high demand, especially in cases when non-conventional resources are being utilized.

A. Techno-economic and Optimal Energy Flow Research

The initial optimization criteria for the study consist of a

scaled average daily electric demand for a load of 1093.75 kWh per year. The average annual wind potential is 4.39 meters per second, the yearly average solar potential is 4.89 kilowatt-hours per square meter per day, the annual average biomass is 0.008 metric tonnes per day, the nominal rate of discount is 12.5%, and the inflation rate is 5.75%. The project's lifetime is 25 years. This research examines alternative energy sources that use storage cells to provide an appropriate solution that may satisfy local energy demand while simultaneously reducing cost considerations (such as cost of energy, net present cost, and operations and maintenance) and emissions. Diesel generators are seldom used until unconventional supplies, supported by storage cells, are unable to meet peak demand. HOMER conducts many simulations in this research to get the best outcomes for High Renewable Energy Systems (HRES).

Optimization Result

After giving the essential input parameters outlined in earlier portions of the study, all six HRES setups with and without battery storage and a diesel generator are simulated based on demand load and locally available RES. The following parameters are used to compare the simulated optimum configurations: NPC, LCOE, capacity shortfall, surplus electricity generation, CO_2 emissions, renewable portion, operational cost, fuel consumption, and initial capital cost, with a focus on LCOE.

Table 5 displays the overall optimized HRES configuration and simulation findings for every stated situation.

The LCOE, NPC, initial capital cost (ICC), and operating cost (OC) of all the cases with and without storage are shown in Figs. 7 and 8.

Net Present Cost

The net present cost (or life-cycle cost) of a Component is the present value of all the costs of installing and operating the Component over the project lifetime, minus the present value of all the revenues that it earns over the project lifetime.

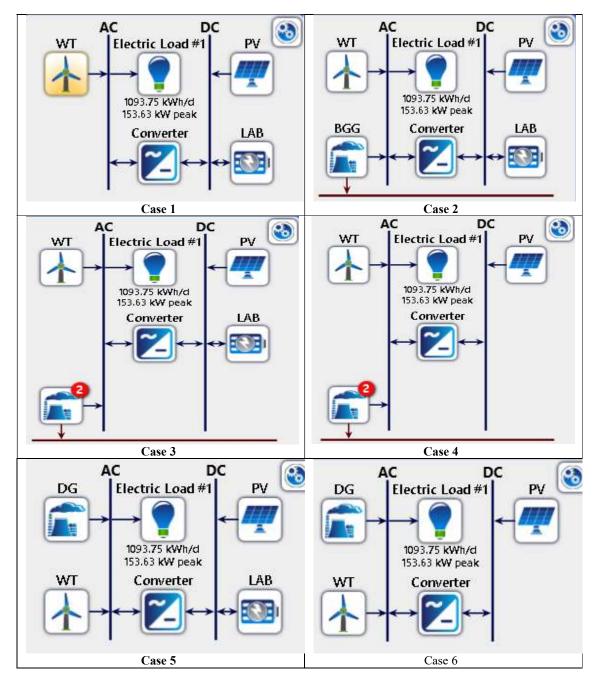


Fig. 16: Homer design model configuration.

Levelized Cost of Energy

LCOE measures lifetime costs divided by energy production, which also determines the present value of a power plant's total operating costs over an expected lifetime and compares diverse technologies, such as wind, solar, and bioenergy, with varying life periods, project sizes, capital costs, risk, return, and capacity.

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_{t} + M_{t} + F_{t}}{(1+r)^{t}}}{\sum_{t=1}^{n} \frac{E_{t}}{(1+r)^{t}}}$$

 I_t = Investment expenditures in year t

 M_t = Operations and maintenance expenditures in year t

Table 5: Cost of each component.

Tola Dhumnadih Village Techno -Commercial Evaluation for Different HRES								
Case		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	
HRES Configuration Units		PV - WT-	PV - WT -	PV - WT - BGG	PV - WT -	PV - WT- DG	PV-WT-	
Results	_	LAB	BGG - LAB	- DG - LAB	BGG -DG	- LAB	DG	
PV	(KW)	415	427	131	283	133	282	
WT	(Qty)	183	186	130	235	125	238	
DG	(KW)	-	-	100	150	100	150	
BGG	(KW)	-	0.4	0.2	2	-	-	
Converter	(KW)	141	154	58.0	46.9	55.7	39.6	
Battery	(Qty)	2820	2700	540	-	530	-	
NPC	(\$)	2.30M	2.27M	1.71M	2.92M	1.71M	2.94M	
COE	(\$)	0.467	0.461	0.347	0.594	0.348	0.598	
Operating Cost	(\$/yr)	80002	78933	101332	190435	102259	192074	
Initial Capital	(\$)	1.31M	1.30M	457223	574475	449470	573878	
Renewable Fraction	(%)	100	100	62.0	32.6	60.7	32	
Emission Carbon Dioxide	(kg/yr)	-	5.38	118214	243424	122032	245597	

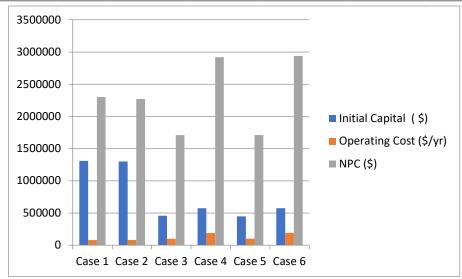


Fig. 17: Net present cost of all HRES cases.

 F_t = Fuel expenditures in year t

 E_t = Electricity generation in year t

r = Discount rate

n =Life of the system

The cost analysis for each scenario including initial capital cost (ICC), operating cost (OC), and net current cost is displayed in Fig. 17. The HRES setup with solar, wind, diesel generator, and battery in Case 5 has the lowest ICC of \$449470, whereas Case 1 has the highest ICC of \$1310000. Similar calculations are made for the operating costs of each scenario; scenario 6 of the HRES design, which includes

a diesel generator, solar panel, and wind turbine, has the highest operating cost (OC). \$/yr 192074 lowest OC in case 2 solar, wind, biomass generator and battery \$/yr 78933. The NPC of all the instances presented in Fig. 17. and the lowest net present cost (NPC) observed were \$1710000 in case 3 of the HRES configuration of solar, wind, biomass generator, diesel generator, and battery, and the highest net present cost was \$2940000 in case 6 of the HRES configuration of solar, wind, and diesel generator.

The COE for each instance is displayed in Fig. 18. Case 3 of the HRES configuration, which consists of a solar, wind, biomass generator, diesel generator, and battery, had

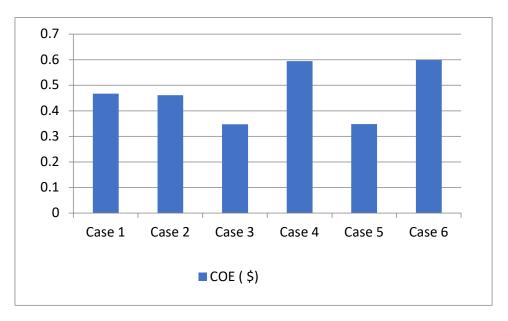


Fig. 18: COE all HRES cases.

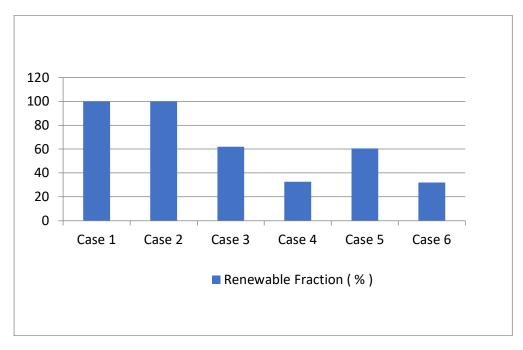


Fig. 19: Renewable fraction.

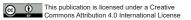
the lowest COE (\$0.347). In contrast, Case 6 of the HRES configuration, which consists of a solar, wind, and diesel generator, had the highest COE (\$0.598).

The renewable fraction is the proportion of the energy given to the load that came from renewable energy sources. The RF for each case is shown in Fig. 19 is displayed and observed that the integrated system's total supply power from renewable sources supplied 100% of the electricity

generated from solar power, wind power, and bioenergy. In contrast, wherever we used the diesel generator at that moment, renewable energy penetration decreased.

Monthly Electric Production from all the sources of Electricity Generation

The monthly power output from all case arrangements is given in Fig. 20-25, which demonstrates that solar PV generation



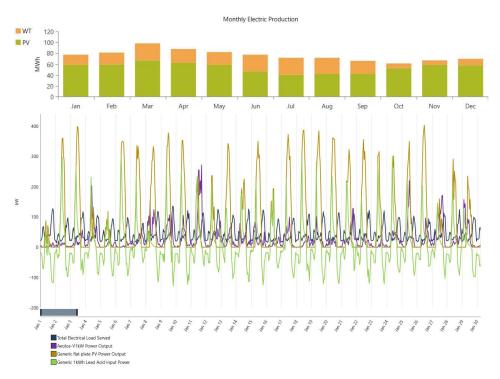


Fig. 20: Case 1 - The monthly energy generation & Electricity generation Pattern from different components of the optimized hybrid system with battery (PV/WT).

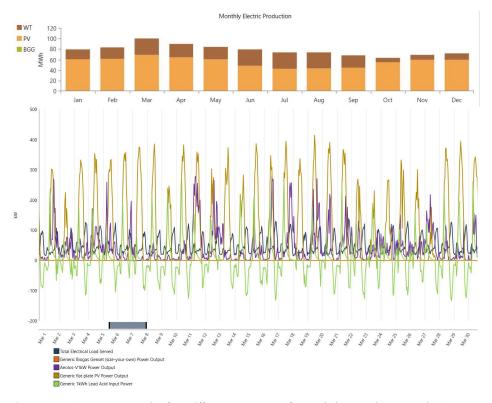


Fig. 21: Case 2 - The monthly energy generation from different components of the optimized hybrid system with battery (PV/WT/BGG).

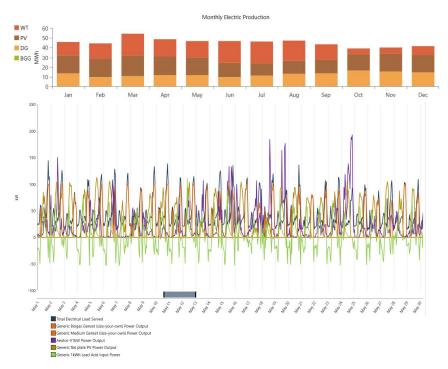


Fig. 22: Case 3 - The monthly energy generation from different components of the optimized hybrid system with battery (PV/WT/BGG/DG).

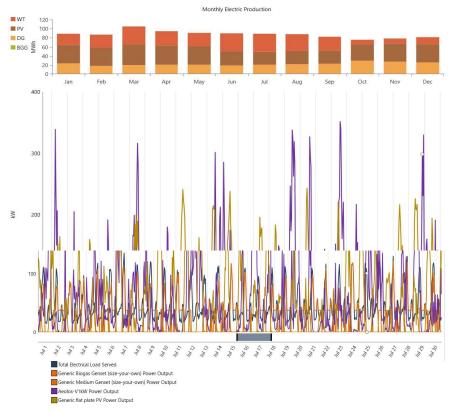


Fig. 23: Case 4 - The monthly energy generation from different components of the optimized hybrid system without battery (PV/WT/BGG/DG).

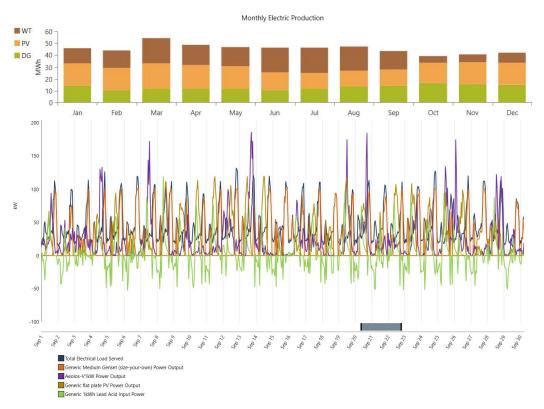


Fig. 24: Case 5 - The monthly energy generation from different components of the optimized hybrid system with battery (PV/WT/DG).

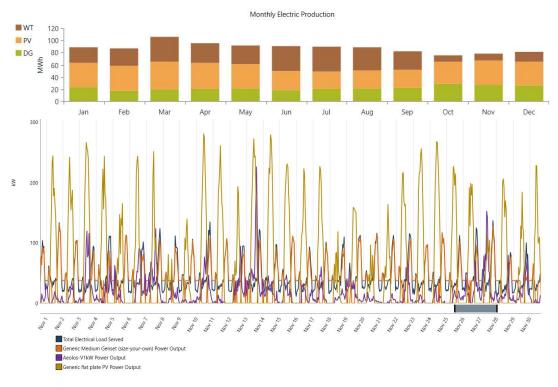


Fig. 25: Case 6 - The monthly energy generation from different components of the optimized hybrid system without battery (PV/WT/DG).

occurs at least in July owing to wet seasons, overcast circumstances, low solar radiation, greater temperatures, and so on. The maximum occurred in November because of favorable sun radiation and low temperatures. Also, wind generation was highest in July and minimum in November due to the climate in India. Furthermore, the creation of excess biomass generators is based on the availability of biomass in the individual village, as well as the usage of diesel generators to determine the best ideal option. Case1 Fig. 20. Solar PV accounts for 71% of electric output, with wind accounting for 29%, unmet electric load at 0.02%, and capacity shortfall at 0.0982%. Fig. 21 depicts an electric production contribution of 71.2% from solar PV, 28.7% from wind, 0.1% from biomass, an unmet electric load of 0.05% and a capacity shortfall of 0.1%. Fig. 22 depicts electric production with a solar PV contribution of 37.4%, wind at 34.5%, diesel generator at 27.9%, biomass at 0.17%, unmet electric load at 0.017%, and capacity shortfall at 0.05%. Fig. 23 depicts electric output with a 42% contribution from solar PV, 32.3% from wind, and 25.6% from diesel generators, with no unmet electric load and a capacity shortfall. Fig. 24 depicts solar PV's 38% contribution to electric output, wind's 33.2%, diesel generator's 28.8%, unmet electric load's 0.026%, and a capacity shortfall of 0.07%. Fig. 25 depicts an electric output contribution of 41.6% from solar PV, 32.6% from wind, and 25.7% from diesel generators, with no unmet electric load and a capacity shortfall.

CONCLUSION AND FUTURE SCOPE

This study examined six distinct examples of HRES with and without batteries and diesel-based power sources in Tola Dhumnadih village, Kishanganj district, Bihar, India. The study's conclusions are consistent with the techno-economic analysis.

- The location in which all the resources are available to configure hybrid renewable energy with a yearly average solar radiation of 4.89 kWh/m2/day, an average monthly wind speed of 4.39 m/s at 10m height, and surplus available biomass potential in a specific village area of 8.12 kg/day with an annual average temperature of 25.52°C.
- After calculation of several combinations of different cases, it is found that the PV-WT BGG DG LAB is the optimal option in terms of cost with a capacity of solar PV (131 KW), wind (130 no's), biomass generator (0.2 KW), diesel generator (100 KW), battery (540 no's), and converter (58.0 KW).
- The best cost-effective option of Case 3 is that the COE is \$0.347 per kWh with a net present cost of \$1710000,

- which is 72% less than Case 6 of the PV-WT-BGG-DG HRES configuration.
- Cases 1 and 2 with 100% renewable penetration do not have any carbon dioxide emissions, whereas the energy produced by diesel generators has significant emissions. The winning case 3 emission was more than half carbon monoxide compared with case 6.

The suggested hybrid system has proven technical and economic feasibility for electrifying rural communities in Bihar. The practical application of underutilized resources to accomplish India's renewable energy objective while also providing jobs for local populations. Furthermore, such studies include broad recommendations for best practices or proposals for future biomass-based study plans/projects in Bihar. Further simulations can be performed with sensitivity scenarios to determine the cost variance concerning the inflation rate of all the components.

NOMENCLATURE

HOMER	Hybrid Optimization Model for Electric Renewable
IRENA	International Renewable Energy Agency
HRES	Hybrid Renewable Energy System
NEPRA	National Electric Power Regulatory Authority
NPC	Net Present Cost
SWERA	Solar and Wind Energy Resource Assessment
MSW	Municipal Solid Waste
COE	Cost of Electricity
SIF	Solar Irradiance Factor
PV	Photo Voltaic
WT	Wind Turbine
DG	Diesel Generator
BGG	Biogas/ Biomass Generator
LAB	Battery
C	Converter
RET	Renewable Energy Technology
RES	Renewable Energy Sources
HES	Hybrid Energy System
TNPC	Total Net Present Cost
RF	Renewable Fraction

REFERENCES

Ahmad, J., Imran, M., Khalid, A., Iqbal, W., Ashraf, S. R., Adnan, M. and Khokhar, K. S. 2018. Techno economic analysis of a wind-photovoltaicbiomass hybrid renewable energy system for rural electrification: A case study of Kallar Kahar. Energy, 148: 208-234. doi: 10.1016/j. energy.2018.01.133.

Ajlan, A., Tan, C. W. and Abdilahi, A. M. 2017. Assessment of environmental and economic perspectives for renewable-based

- hybrid power system in Yemen. Renewable and Sustainable Energy Reviews, 75: 559-570. doi: 10.1016/j.rser.2016.11.024.
- Akinyele, D. 2017. Techno-economic design and performance analysis of nanogrid systems for households in energy-poor villages. Sustainable Cities and Society, 34: 335-357. doi: 10.1016/j.scs.2017.07.004.
- Baghdadi, F., Mohammedi, K., Diaf, S. and Behar, O. 2015. Feasibility study and energy conversion analysis of stand-alone hybrid renewable energy system. Energy Conversion and Management, 105: 471-479.
- Balamurugan, P., Ashok, S. and Jose, T. L. 2009. Optimal operation of biomass/wind/PV hybrid energy system for rural areas. International Journal of Green Energy, 6(1): 104-116. doi: 10.1080/15435070802701892.
- Balamurugan, P., Ashok, S. and Jose, T. L. 2011. An optimal hybrid wind-biomass gasifier system for rural areas. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 33(9): 823-832. oi: 10.1080/15567030903117646.
- Balcombe, P., Rigby, D. and Azapagic, A. 2013. Motivations and barriers associated with adopting microgeneration energy technologies in the UK. Renewable and Sustainable Energy Reviews, 22: 655-666. doi: 10.1016/j.rser.2013.02.012.
- Bandara, K., Sweet, T. and Ekanayake, J. 2012. Photovoltaic applications for off-grid electrification using novel multi-level inverter technology with energy storage. Renewable Energy, 37(1): 82-88. doi: 10.1016/j. renene.2011.05.036.
- Bansal, M., Saini, R. P. and Khatod, D. K. 2013. Development of cooking sector in rural areas in India-A review. Renewable and Sustainable Energy Reviews, 17: 44-53. doi: 10.1016/j.renene.2011.05.036.
- Bhatt, A., Sharma, M. P. and Saini, R. P. 2016. Feasibility and sensitivity analysis of an off-grid micro hydro–photovoltaic–biomass and biogas–diesel–battery hybrid energy system for a remote area in Uttarakhand state, India. Renewable and Sustainable Energy Reviews, 61: 53-69. doi: 10.1016/j.rser.2016.03.030.
- Bhuvan 2024. Gateway to Indian Earth Observation. Accessed: Jan. 20, 2024. [Online]. Available: https://bhuvan-app1.nrsc.gov.in/bioenergy/home/
- Castellanos, J. G., Walker, M., Poggio, D., Pourkashanian, M. and Nimmo, W. 2015. Modelling an off-grid integrated renewable energy system for rural electrification in India using photovoltaics and anaerobic digestion. Renewable Energy, 74: 390-398. doi: 10.1016/j. renene.2014.08.055.
- Census 2011 India. Accessed: Jan. 20, 2024. [Online]. Available: https://www.census2011.co.in/
- Chambon, C. L., Karia, T., Sandwell, P. and Hallett, J. P. 2020. Technoeconomic assessment of biomass gasification-based mini-grids for productive energy applications: The case of rural India. Renewable Energy, 154: 432-444. doi: 10.1016/j.renene.2020.03.002.
- Chandel, S. S., Shrivastva, R., Sharma, V. and Ramasamy, P. 2016. Overview of the initiatives in renewable energy sector under the national action plan on climate change in India. Renewable and Sustainable Energy Reviews, 54: 866-873. doi: 10.1016/j. rser.2015.10.057.
- Chauhan, A. and Saini, R. P. 2016. Discrete harmony search based size optimization of Integrated Renewable Energy System for remote rural areas of Uttarakhand state in India. Renewable Energy, 94: 587-604. doi: 10.1016/j.renene.2016.03.079.
- Dawoud, S. M., Lin, X. N., Sun, J. W., Okba, M. I., Khalid, M. S. and Waqar, A. 2015. Feasibility study of isolated PV-wind hybrid system in Egypt. Advanced Materials Research, 1092: 145-151. doi: 10.4028/ www.scientific.net/AMR.1092-1093.145.
- Elhadidy, M. A. and Shaahid, S. M. 2000. Parametric study of hybrid (wind+ solar+ diesel) power generating systems. Renewable energy, 21(2): 129-139.
- Elhadidy, M. A. and Shaahid, S. M. 2004. Promoting applications of

- hybrid (wind+ photovoltaic+ diesel+ battery) power systems in hot regions. Renewable Energy, 29(4): 517-528.
- Forough, A. B. and Roshandel, R. 2017. Multi objective receding horizon optimization for optimal scheduling of hybrid renewable energy system. Energy and Buildings, 150: 583-597. doi: 10.1016/j. enbuild.2017.06.031.
- Gan, L. K., Shek, J. K. and Mueller, M. A. 2015. Hybrid wind–photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland. Energy Conversion and Management, 106: 479-494. doi: 10.1016/j.enconman.2015.09.029.
- Google Maps 2024. Tola Dhumnadih Google Maps. Accessed: Jan. 21, 2024. [Online]. Available: https://maps.app.goo.gl/ PcdaZjLD4Sbb5VQE9
- Gupta, S. K. and Purohit, P. 2013. Renewable energy certificate mechanism in India: A preliminary assessment. Renewable and Sustainable Energy Reviews, 22: 380-392. doi: 10.1016/j.rser.2013.01.044.
- Harish, V. S. K. V. and Kumar, A. 2014. Demand side management in India: action plan, policies and regulations. Renewable and Sustainable Energy Reviews, 33: 613-624. doi: 10.1016/j. rser.2014.02.021.
- Hoicka, C. E. and Rowlands, I. H. 2011. Solar and wind resource complementarity: Advancing options for renewable electricity integration in Ontario, Canada. Renewable energy, 36(1): 97-107. doi: 10.1016/j.renene.2010.06.004.
- HOMER Pro Microgrid Software for Designing Optimized Hybrid Microgrids. Accessed: Jan. 21, 2024. [Online]. Available: https:// www.homerenergy.com/products/pro/index.html
- Indian Village Directory 2024. Indian Village Directory. Accessed: Jan. 21, 2024. [Online]. Available: https://villageinfo.in/
- Ismail, M. S., Moghavvemi, M. and Mahlia, T. M. I. 2013. Energy trends in Palestinian territories of West Bank and Gaza Strip: Possibilities for reducing the reliance on external energy sources. Renewable and Sustainable Energy Reviews, 28: 117-129. doi: 10.1016/j. rser.2013.07.047.
- Kanase-Patil, A. B., Saini, R. P. and Sharma, M. P. 2010. Integrated renewable energy systems for off grid rural electrification of remote area. Renewable Energy, 35(6): 1342-1349. doi: 10.1016/j. renene.2009.10.005.
- Karki, S., Mann, M. D. and Salehfar, H. 2008. Environmental implications of renewable distributed generation technologies in rural electrification. Energy Sources, Part B, 3(2): 186-195. doi: 10.1080/15567240601057057.
- Khan, M. J., Yadav, A. K. and Mathew, L. 2017. Techno economic feasibility analysis of different combinations of PV-Wind-Diesel-Battery hybrid system for telecommunication applications in different cities of Punjab, India. Renewable and Sustainable Energy Reviews, 76: 577-607.
- Khare, V., Nema, S. and Baredar, P. 2013. Status of solar wind renewable energy in India. Renewable and Sustainable Energy Reviews, 27: 1-10. doi: 10.1016/j.rser.2013.06.018.
- Kumaravel, S. and Ashok, S. 2015. Optimal power management controller for a stand-alone solar PV/wind/battery hybrid energy system. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 37(4): 407-415. doi: 10.1080/15567036.2011.576414.
- Lau, K. Y., Yousof, M. F. M., Arshad, S. N. M., Anwari, M. and Yatim, A. H. M. 2010. Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. Energy, 35(8): 3245-3255. doi: 10.1016/j.energy.2010.04.008.
- Li, C., Zhou, D., Wang, H., Lu, Y. and Li, D. 2020. Techno-economic performance study of stand-alone wind/diesel/battery hybrid system with different battery technologies in the cold region of China. Energy, 192: 116702. doi: 10.1016/j.energy.2019.116702.

- Ma, T., Yang, H. and Lu, L. 2013. Performance evaluation of a stand-alone photovoltaic system on an isolated island in Hong Kong. Applied Energy, 112: 663-672. doi: 10.1016/j.apenergy.2012.12.004.
- Maherchandani, J. K., Agarwal, C. and Sahi, M. 2012. Economic feasibility of hybrid biomass/PV/wind system for remote villages using HOMER. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 1(2): 49-53.
- Malik, P., Awasthi, M. and Sinha, S. 2019. Analysis of sensitive parameters influencing a SPV/WT/Biomass/Battery based hybrid system. In 2019 8th International Conference on Power Systems
- Malik, P., Awasthi, M. and Sinha, S. 2020. Study on an existing PV/wind hybrid system using biomass gasifier for energy generation. Pollution, 6(2): 325-336. doi: 10.22059/poll.2020.293034.719.
- Malik, P., Awasthi, M. and Sinha, S. 2021. Biomass based gaseous fuel for hybrid renewable energy systems: An overview and future research opportunities. International Journal of Energy Research, 45(3): 3464-3494. doi: 10.1002/er.6061.
- Malik, P., Awasthi, M. and Sinha, S. 2021. Techno-economic and environmental analysis of biomass-based hybrid energy systems: A case study of a Western Himalayan state in India. Sustainable Energy Technologies and Assessments, 45: 101189.
- Mandal, S., Das, B. K. and Hoque, N. 2018. Optimum sizing of a stand-alone hybrid energy system for rural electrification in Bangladesh. Journal of Cleaner Production, 200: 12-27. doi: 10.1016/j.jclepro.2018.07.257.
- Mekhilef, S., Faramarzi, S. Z., Saidur, R. and Salam, Z. 2013. The application of solar technologies for sustainable development of agricultural sector. Renewable and sustainable energy reviews, 18: 583-594. doi: 10.1016/j.rser.2012.10.049.
- Mekhilef, S., Saidur, R. and Kamalisarvestani, M. 2012. Effect of dust, humidity and air velocity on efficiency of photovoltaic cells. Renewable and sustainable energy reviews, 16(5): 2920-2925. doi: 10.1016/j.rser.2012.02.012.
- Meyar-Naimi, H. and Vaez-Zadeh, S. 2012. Sustainable development-based energy policy making frameworks, a critical review. Energy Policy, 43: 351-361. doi: 10.1016/j.enpol.2012.01.012.
- Moghavvemi, M., Ismail, M. S., Murali, B., Yang, S. S., Attaran, A. and Moghavvemi, S. 2013. Development and optimization of a PV/diesel hybrid supply system for remote controlled commercial large scale FM transmitters. Energy Conversion and Management, 75: 542-551. doi: 10.1016/j.enconman.2013.07.011.
- Nema, S., Nema, R. K. and Agnihotri, G. 2010. Matlab/simulink based study of photovoltaic cells/modules/array and their experimental verification. International journal of Energy and Environment, 1(3): 487-500.
- Neves, D., Silva, C. A. and Connors, S. 2014. Design and implementation of hybrid renewable energy systems on micro-communities: A review on case studies. Renewable and Sustainable Energy. doi: 10.1016/j. rser.2013.12.047.
- Notton, G., Muselli, M. and Louche, A. 1996. Autonomous hybrid photovoltaic power plant using a back-up generator: a case study in a Mediterranean Island. Renewable Energy, 7(4): 371-391.
- NSRDB 2024. NSRDB. Accessed: Jan. 20, 2024. [Online]. Available: https://nsrdb.nrel.gov/
- Ozden, E. and Tari, I. 2016. Energy-exergy and economic analyses of a hybrid solar-hydrogen renewable energy system in Ankara, Turkey. Applied Thermal Engineering, 99: 169-178.
- Padrón, I., Avila, D., Marichal, G. N. and Rodríguez, J. A. 2019. Assessment of Hybrid Renewable Energy Systems to supplied energy to Autonomous Desalination Systems in two islands of the Canary Archipelago. Renewable and Sustainable Energy Reviews, 101: 221-230. doi: 10.1016/j.rser.2018.11.009.

- Patil, A. A., Arora, R., Arora, R. and Sridhara, S. N. 2023. Performance analysis of hybrid renewable energy using homer software. Tuijin Jishu/Journal Propuls. Technol., 44(3): 2832-2853.
- Perera, A. T. D., Attalage, R. A., Perera, K. K. C. K. and Dassanayake, V. P. C. 2013. Designing standalone hybrid energy systems minimizing initial investment, life cycle cost and pollutant emission. Energy, 54: 220-230. doi: 10.1016/j.energy.2013.03.028
- Rad, M. A. V., Ghasempour, R., Rahdan, P., Mousavi, S. and Arastounia, M. 2020. Techno-economic analysis of a hybrid power system based on the cost-effective hydrogen production method for rural electrification, a case study in Iran. Energy, 190: 116421. doi: 10.1016/j.energy.2019.116421.
- Rahman, M. M., Hasan, M. M., Paatero, J. V. and Lahdelma, R. 2014. Hybrid application of biogas and solar resources to fulfill household energy needs: A potentially viable option in rural areas of developing countries. Renewable Energy, 68: 35-45.
- Salehin, S., Islam, A. S., Hoque, R., Rahman, M., Hoque, A. and Manna, E. 2014. Optimized model of a solar PV-biogas-diesel hybrid energy system for Adorsho Char Island, Bangladesh. In 2014 3rd International Conference on the Developments in Renewable Energy Technology (ICDRET) (1-6). IEEE.
- Saubhagya Dashboard. Accessed: Jan. 20, 2024. [Online]. Available: https://saubhagya.gov.in/
- Sawle, Y., Gupta, S. C. and Bohre, A. K. 2018. Socio-techno-economic design of hybrid renewable energy system using optimization techniques. Renewable energy, 119: 459-472. doi: 10.1016/j. renene.2017.11.058.
- Sawle, Y., Jain, S., Babu, S., Nair, A. R. and Khan, B. 2021. Prefeasibility economic and sensitivity assessment of hybrid renewable energy system. Ieee Access, 9: 28260-28271. doi: 10.1109/ ACCESS.2021.3058517
- Shaahid, S. M. and El-Amin, I. 2009. Techno-economic evaluation of off-grid hybrid photovoltaic-diesel-battery power systems for rural electrification in Saudi Arabia-A way forward for sustainable development. Renewable and sustainable energy reviews, 13(3): 625-633. doi: 10.1016/j.rser.2007.11.017.
- Shahzad, M. K., Zahid, A., ur Rashid, T., Rehan, M. A., Ali, M. and Ahmad, M. 2017. Techno-economic feasibility analysis of a solarbiomass off grid system for the electrification of remote rural areas in Pakistan using HOMER software. Renewable energy, 106: 264-273. doi: 10.1016/j.renene.2017.01.033.
- Shi, Z., Wang, R. and Zhang, T. 2015. Multi-objective optimal design of hybrid renewable energy systems using preference-inspired coevolutionary approach. Solar energy, 118: 96-106. doi: 10.1016/j. solener.2015.03.052.
- Sigarchian, S. G., Paleta, R., Malmquist, A. and Pina, A. 2015. Feasibility study of using a biogas engine as backup in a decentralzed hybrid (PV/wind/battery) power generation system-Case study Kenya. Energy, 90: 1830-1841. doi: 10.1016/j.energy.2015.07.008.
- Taele, B. M., Mokhutšoane, L., Hapazari, I., Tlali, S. B. and Senatla, M. 2012. Grid electrification challenges, photovoltaic electrification progress and energy sustainability in Lesotho. Renewable and Sustainable Energy Reviews, 16(1): 973-980. doi: 10.1016/j. rser.2011.09.019.
- Vendoti, S., Muralidhar, M. and Kiranmayi, R. 2021. Techno-economic analysis of off-grid solar/wind/biogas/biomass/fuel cell/battery system for electrification in a cluster of villages by HOMER software. Environment, Development and Sustainability, 23(1): 351-372. doi: 10.1007/s10668-019-00583-2.
- Verma, A., Biswas, S. and Ahmad, S. Y. 2015. Techno-financial analysis of energy access through hybrid system with solar PV under the various rural community models for State of Uttarakhand, India. Smart Grid and Renewable Energy, 6(4): 75-94.

- Wikipedia 2024. File:Mean Wind Speed Map India.png Wikipedia. Accessed: Jan. 20, 2024. [Online]. Available: https://en.m.wikipedia.org/wiki/File:Mean_Wind_Speed_Map_India.png
- Yılmaz, S. and Selim, H. 2013. A review on the methods for biomass to energy conversion systems design. Renewable and Sustainable Energy Reviews, 25: 420-430. doi: 10.1016/j.rser.2013.05.015.
- Yimen, N., Hamandjoda, O., Meva'a, L., Ndzana, B. and Nganhou, J. 2018.
 Analyzing of a photovoltaic/wind/biogas/pumped-hydro off-grid hybrid system for rural electrification in Sub-Saharan Africa—Case

study of Djoundé in Northern Cameroon. Energies, 11(10): 2644. doi: 10.3390/en11102644.

ORCID DETAILS OF THE AUTHORS

Anant Arun Patil https://orcid.org/0009-0004-2339-736X Rajesh Arora https://orcid.org/0000-0001-9234-4115 Ranjana Arora https://orcid.org/0000-0002-8912-9067 S. N. Sridhara https://orcid.org/0000-0002-4393-6314