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Prefeasibility Economic and Sensitivity Assessment of Hybrid Renewable Energy System

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ABSTRACT Nowadays, microgrids with hybrid renewable energy sources are increasing, and it is a promising solution to electrify remote areas where distribution network expansion is not feasible or economical. This study aims to find an ideal hybrid system grounded on solar, wind, diesel, biomass, hydro, and battery. This study utilizes the hybrid optimization model for electric renewable (HOMER) software to size the important components, perform technical, financial evaluation, renewable factor, estimate the harmful emissions, and sensitivity analysis. For optimum system selection, the lowest cost of energy is used as the criteria. Four different configurations of renewable energy sources are analyzed and found PV-WT-MH-CT-BT-DG-BG is the most feasible hybrid system amongst all configurations. The proposed PV-WT-MH-CT-BT-DG-BG hybrid system is more economic as the lowest cost of energy 0.196$, low operating cost 36,184$, low net present cost 831,217$. Also, this hybrid system is more environmentally friendly as it has less emission and a high renewable factor of 81.2%.

INDEX TERMS Microgrid, hybrid renewable energy sources, wind turbines, solar radiation, battery energy storage, biomass, micro hydro.

NOMENCLATURE

BG	Biodiesel Generator
BT	Battery Storage
COE	Cost of Energy
CT	Converter
DG	Diesel Generator
GW	Giga-Watt
HES	Hybrid Energy System
HRES	Hybrid renewable energy system
IRENA	International renewable energy agency
kWh/yr	kilowatt-hour/year
MH	Micro Hydro
Mt	Mega-tonne
Mtoe	Million tons
NASA	National aeronautics and space administration
NPC	Net Present Cost
O&M	Operations and Management
OC	Operating Costs
PL	Peak Load
PV	Photovoltaic
SR	Solar Radiation
STC	Standard Test Condition
WS	Wind Speed
WT	Wind Turbine

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I. INTRODUCTION

Electricity has turned out to be an essential criterion for the country's socio-economic development. Due to technological and other developments, developing countries like India require more energy than what is generated, to meet the ever-growing energy demand. In short, these countries are facing an energy deficit and in order to achieve the energy deficit, they require economical solutions.

Moreover, decline in the usage of non-renewable sources for generation of electricity. It has prompted developing countries to turn their attention towards environmentally-friendly solutions to meet the energy deficit. India possesses an increasing demand for electricity to fulfill the economic development initiatives that are being initiated.

The availability of growing sources of energy is essential for a country's economic development. As claimed by the world resource institute report 2017, India ranks fourth in total global carbon emissions, accounting for nearly 6.65% [1]. India is one of the most significant coal users in the world and imports expensive fossil fuel. Coal and oil cover around 76% of India's energy consumption. India purchased 182 Megatonnes (Mt) of coal in 2013-2014, 221 Mt in 2014-2015, 210 Mt in 2015-2016, 185 Mt in 2016-2017, and 220 Mt in 2017-2018, as reported by a survey from the center for monitoring the Indian economy. Hence, there is now an immediate requirement to replace the existing power generation sources. Fig. 1 displays the current and predicted worldwide power usage between the years 2010 to 2040. Based on the reports of BP energy outlook 2018 [1], [24]. India consumed 724 million tons of energy in 2016 and is expected to increase to 1921 million by 2040. Energy consumption includes market traded fuels and advanced non-conventional energy sources which is used to generate electricity in major countries.

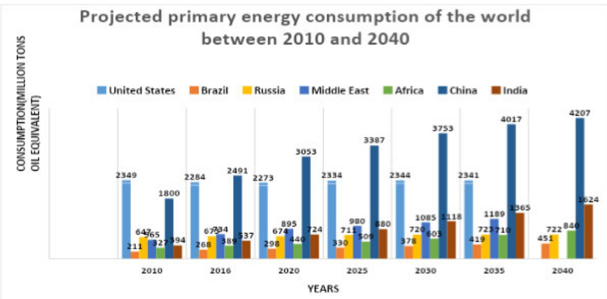

FIGURE 1. Worldwide power usage between years 2010 to 2040.

Power demand is considerably influenced by the size and the development of the population of a country. India is the second-largest populated nation globally, with 1,368 billion people, and is growing at a rate of 1.18 % per annum, which is higher than any other nation in the world. It represents almost 17.74% of the total pollution in this world. By the end of 2030, India is predicted to have more than 1512 billion inhabitants. By 2040, the growth in India's energy usage will be the highest of all major economies, where most of the demand will be met by coal, followed by renewable sources of energy. Now, Renewable energy sources are the second most important source for the production of domestic power. The Renewable energy demand in India will have considerable growth from 17 million tons of oil (Mtoe) in 2016 to 256 Mtoe in 2040, as shown in Fig. 2.

The International Renewable Energy Agency (IRENA) describes that non-conventional energy will meet one-fourth of India's energy demand. By 2030, Renewable energy production share can be increased to one-third of the total power generated. India aims to produce 180 GigaWatt (GW) of non-conventional energy that comprises 110 GW of solar energy, 12 GW of biomass energy, 62 GW of wind energy 7 GW of micro-hydro energy by the year 2022.

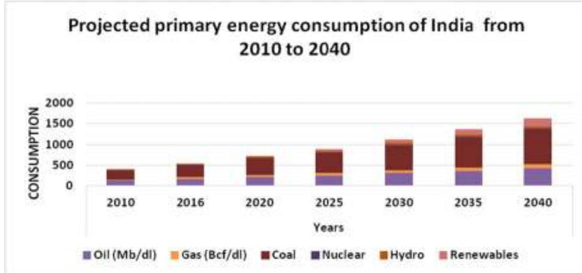

FIGURE 2. Projected primary energy consumption of India from 2010 to 2040.

Financers have guaranteed to gain greater than 280 GW, which is a lot more than the decided goal. Most recent estimates predict that the energy from PV will be greater than 759 GW and that the energy from wind will be 419 GW by the year 2047.

The world, including India, is suffering from energy deficit. India needs to boost its energy production to three to four times higher than present energy production. Remote areas in India do not get an adequate power supply. For such areas, an off-grid hybrid energy system (HES) can supply electricity to such remote areas [2]. The usage of diesel generators reduces the dependence on solar and winds energy components by reducing the system's operation hours and running costs. Battery storage also restricts diesel generators' maximum start/stop cycles, decreasing fuel consumption [1].

Optimally designed microgrid systems provide many benefits that include energy security, lower electricity rate, as well as the system reliability. It incorporates surplus renewable power generation to the microgrid and it also ensures economic development of rural areas through the supply of electricity to remote locations which reduces emission [3]. However, the optimal energy management in a microgrid is a challenging task for microgrid operators with the optimal energy utilization of hybrid renewable energy sources.

A. RELATED WORK

Much work was performed on the design of HES, utilizing energy management and sizing methods on HOMER Software, given in table 1. Present literature review indicates insufficient research on the viability of distributed renewable electricity with integrated techno-economic and environmental solutions for rural communities in India. This analysis explores such a feasible solution, where an energy source is not technically or financially feasible, or problems related to transportation to rural areas etc occurs, a fusion of two optimized systems minimizes fossil fuel consumption [4]. Four locally available non-conventional energy sources such as wind, solar, biomass, and hydro are best hybridized for the economic and environmental index to fulfill the village load demand. All these sources of energy are irregular. Energy can be produced from these sources, which require a short transmission line and can be installed even in remote sites. This research's primary goal is to model a microgrid using

TABLE 1. Different research studies with HOMER software.

Authors	Design place	Type of load	Technology	Findings
Li et al. 2010 [7]	Malaysia	Rural load	PV/diesel	Round the clock service but a considerable demand profile for a rural sector
Nandi et al. 2010 [8]	Bangladesh	Community load	PV/wind/battery	Solar and wind hybrid; no profitable requirement
Hiendro et al. 2013 [9]	Indonesia	Remote load	PV/wind/battery	Wind turbine and battery are the major components of this system
Pavlovic et al. 2013 [10]	Serbia	Specific load	PV	Regular simulation of solar radiation for producing electricity for particular locations in Serbia.
Sen and Bhattacharya. 2014 [11]	Palari, Chhattisgarh	Residential load	PV-wind-biodiesel	I. The combination of technology increases system reliability. II. Sites where the hydro potential is available should be studied to benefit from this source.
Sagani et al. 2017 [12]	Northwest Greece	Household applications load	PV/diesel /battery	A hybrid power and heat system is suggested; a low-cost substitute to the traditional type is obtained.
Aly et al. 2019 [13]	Egypt	University load	PV/diesel	Micro-grid model simulations with a flywheel energy storage system
Jahangiri et al. 2019 [14]	Iran	City load	PV/diesel	Design for optimizing the micro-power system compared to a system based on hydrogen
Miao et al. 2020 [4]	Northeast united Kingdom	Household load	PV/wind/battery/biogas	Both heating and electrification loads are taken into account. Of the eight cases, the optimal off-grid choice is determined.

the existing hydro, photovoltaic, wind, and biogas which is available at that location and perform a cost optimization analysis to find the best system based on minimum NPC.

B. NOVELEITES OF PROPOSED MODEL

Following the analysis of the literature review, the synopsis are-

- The hybrid renewable energy system prototypes are the finest choice regarding dependability as well as practicable selections with little poisonous gases ejection.
- The key fact in the literature review is the size development with a practicable strategy with respect to finances or on energy management systems.

The key influences beside with the purposes and opportunity of the proposed study are as follows:

- To fulfil the growing energy requirement around the globe, the identified rural area in India is chosen to scrutinize feasible hybrid renewable energy system models with PV, WT, MH, BG.
- The feasible model plan is found with the help of comprehensive analysis in terms of cost minimization with low emission and high reliability of the model is incorporated as an objective.
- Transient state from grid-connected to disconnected mode is completely analyzed.

C. ADVANTAGES OF PROPOSED MODEL

The advantages of the proposed model are as below:

- The suggested model can be employed more effectively for multi-variable models to spread out subsequently.
- The proposed model is valid for real as well as on-line Hybrid renewable energy system with non-linear system.
- The proposed plan is with a broad result including optimized architecture as well as management for the chosen location is not implemented before.
- The suggested model picks the most feasible hybrid renewable energy system design by confronting the points and challenges of the system. Thus, this model satisfies the demand of the users in terms of the economic benefits with fast performance.
- The proposed Hybrid renewable energy system deals with comprehensive study including the integration of sensitivity analysis.

D. ORGANIZATION OF THE MANUSCRIPT

The rest of the paper is organized as follows: Section two discuss about the hybrid optimization model for electric renewable (HOMER) software. Section three presents the methodology, utilized in this work. Section four discusses the results, computed in this work, followed by the conclusion.

II. HYBRID OPTIMIZATION MODEL FOR ELECTRIC RENEWABLE (HOMER)

This research utilizes Hybrid Optimization Model for Electric Renewable (HOMER) to assist with a micro-grid. In the Pre-HOMER assessment, an in-depth analysis of the area and accessible resources in that location are collected [5]. To compare various configurations based on operational and economical rates, HOMER calculates the numerical data and generates output from possible configurations arranged by NPC, as shown in Fig 3. The best feasible system configurations can be achieved from optimization and sensitivity analysis of HOMER. Simulation, optimization, and sensitivity analysis are the key functions of HOMER [6]. The following costs can be determined through the simulation process:

- Net Present Cost (NPC)
- Cost of Energy (COE)
- Operations and Management (O&M)
- Operating Costs (OC)

III. METHODOLOGY

Fig 4 portrays the steps to implement the suggested HES in HOMER. Primarily procedure starts with determining the load profile of the location we selected, followed by acquiring

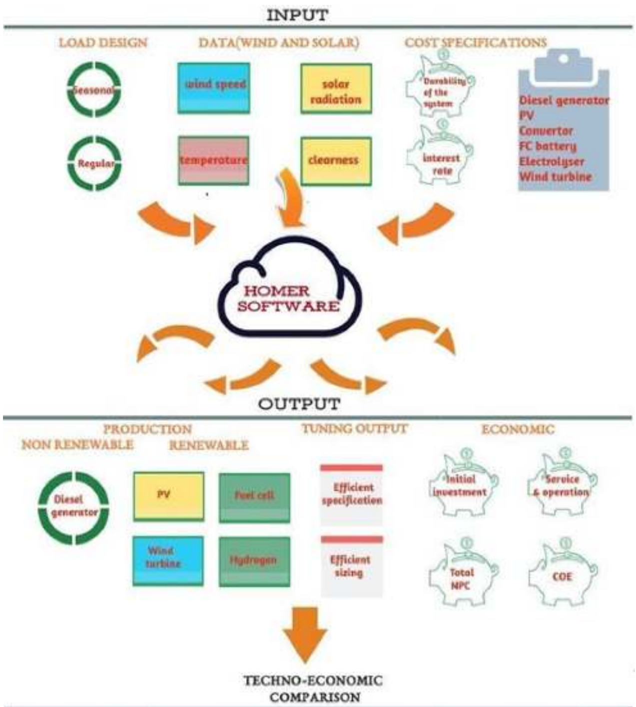

FIGURE 3. Steps of the model in HOMER.

FIGURE 4. The methodology used in HOMER.

the solar, wind potential. Then, we use different elements to model the system [15]. The economic parameters, as well as the sizing of the components, are added. Optimization is done to carry out the cost optimization evaluation of our model. To determine whether the selected outcome satisfies the study's aim, the overall simulated results are analyzed by COE to obtain satisfactory results [16]. HOMER classifies its outcome based on a minimal cost alliance.

A. STUDY AREA

Ukai is a town located in the Tapi district in Gujarat, India. The coordinates for this town are 21.2342°N, 73.5786°E. Many services like colleges, primary schools, banks, supermarkets, hospitals, and offices are available here. Ukai is a Census Town city in the district of Tapi, Gujarat. The geographical location of Ukai is shown in fig 5, and general information of the town is given in Table 2

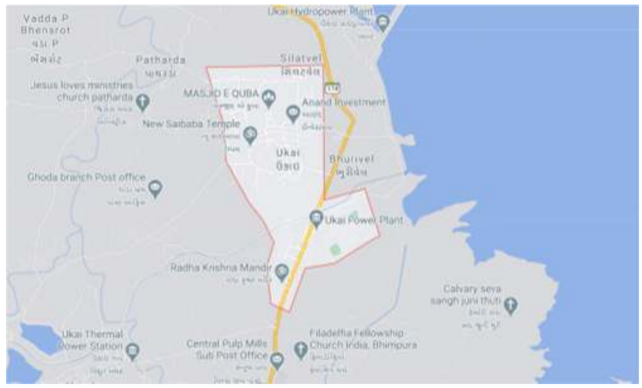

FIGURE 5. Geographical map of Ukai.

TABLE 2. General information of town.

Country	India
State	Gujarat
District Name	Tapi
Name of Town	Ukai
Latitude	21.2342° N
Longitude	73.5786° E
Pin Code	394680
Sex Ratio	1000/972

B. LOAD PROFILE

Load modeling measures the level of fuel that needs to be generated and retained. The load demand (kW) and the period (h) of the loading process will be given attention to assessing energy consumption. The energy demand in kWh is calculated using equations (1) and (2) [22].

$$\text{Energy Demand (kWh)} = \text{Load demand (kW)} \times \text{Duration (h)} \tag{1}$$

$$\text{Total Energy Demand (kWh)} = \sum\nolimits_{i=1} n \times (\text{Energy Demand (kWh)}) \tag{2}$$

The regular load profile is centered on the typical daily load of the residence in Ukai Town. Fig 6 displays a comprehensive load profile for a residential unit in the village on one day. This load usage situation in one remote community is presumed to have 1,000 houses with typical load requirements. The load profile in HOMER is then improved by a factor of 100. The average load demand is 898 kWh/day as well as the PL is 90.97 kW [17]. A leap day-to-day and time-to-step HOMER is set at 2% to evaluate the implications of randomness. Random variables are percentages to achieve more accurate load results [21]. The average monthly average daily load criteria stay the same as reported from Fig. 7.

FIGURE 6. Daily load profile of load data.

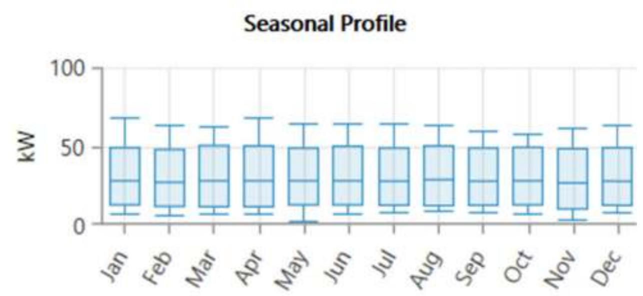

FIGURE 7. Seasonal profile of load data.

It is related to why the typical weather patterns are very constant, i.e., small fluctuations

C. RESOURCE ASSESSMENT

The primary non-conventional energy sources are solar, wind, hydro, and biomass in the present research. Monthly, as well as annual solar radiation and wind speed are obtained. Accessible biomass and hydro statistics are incorporated for 12 months. The optimal sizing of the hybrid renewable energy system (HRES) is depended on various modeling parameters such as technical, economic and social parameters. [25].

1) PV

Solar radiation and the temperature at 21.2342°N, 73.5786°E, are obtained from the national aeronautics and space administration (NASA) surface meteorology. The estimated yearly SR is expected as 5.30kWh/m^2/day. From Fig. 8, it is clear that a large amount of solar energy can be used nearly during the year in the chosen village. Dependent on the SR and the atmospheric temperature recorded, performance of PV panels at every hour can be determined using the below mentioned equation [18].

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{G_T}{G_{T,STC}}\right) \left[1 + \alpha_P \left(T_C - T_{c,STC}\right)\right] \quad (3)$$

where, Y_{PV} is the relevant capacity of the PV in kW. It represents energy outcome at STC (STC that is the emission of 1 kW/m^2, 25°C is the cell temperature), f_{PV} is the derating factor of Photovoltaic in %, G_T is SR incident on PV in the present timeframe in kW/m^2, $G_{T,STC}$ is incident radiation at STC in kW/m^2, α_p is the temperature coefficient of power,

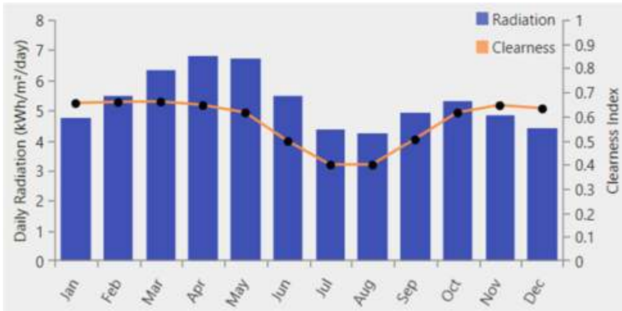

FIGURE 8. Monthly average solar radiation.

considered as −0.5 in %/°C, T_C is PV cell temperature in the present timeframe in %/°C and $T_{c,STC}$ is the temperature of PV cell at STC, considered as 25°C.

2) WIND

Annually wind energy information is obtained for the study site from the NASA resource website, as shown in Fig 9. The average annual velocity is 5.63 m/s.

FIGURE 9. Monthly average wind speed.

The evaluation of the energy production of the windmill at every time frame is calculated as follows [19]. Initially, the WS at the center of the windmill is obtained from equation 4 [18]:

$$U_{hub} = U_{anem} \frac{ln\left(\frac{z_{hub}}{z_0}\right)}{ln\left(\frac{z_{anem}}{z_0}\right)} \quad (4)$$

where, U_{hub} represents WS at the center of the windmill (m/s), U_{anem} represents WS at the anemometer height (m/s), Z_{hub} is Hub height of windmill (m), Z_{anem} is Anemometer height (m), and Z_0 is surface roughness (m).

Suppose the wind mill's height has been evaluated, then the windmill's demand curve is used to assess the windmill's predictable functioning at that WS under normal atmospheric conditions. Equation 5 measures the required outcome of the actual air pressure:

$$P_{WTG} = P_{WTG,STP} \left(\frac{\rho}{\rho_0}\right) \quad (5)$$

where, P_{WTG} is windmill power outcome in kW, $P_{WTG,STP}$ is windmill power outcome at STC in kW, ρ is real wind density in kg/m^3 and ρ_0 is the wind density at STC, which is equal to 1.225 kg/m^3.

3) BIOMASS

Biomass is primarily of the major energy resources a Biomass is primarily the major energy resource among non-conventional energy. Diverse categories of bio trash are accessible in Ukai town such as cow manure, rice straw, and other wastages. Rice husk is utilized for energy production [28]. The yearly average (t/d) is 0.43. Fig 10 displays the monthly average of biomass accessible at Ukai.

FIGURE 10. Monthly average biomass recourse.

4) MICRO-HYDRO

A dam is built near Ukai called a Ukai dam. Specification of the dam is given below [20]:

- Capacity of the dam = 46,269 m^3/s
- Gross height of the dam = 345 ft.

The discharge necessity for energy production per month is determined based on direct runoff production using rainfall distribution outcomes. Fig.11 indicates the monthly water discharge. The annual average (L/sec) is 222.92 [20].

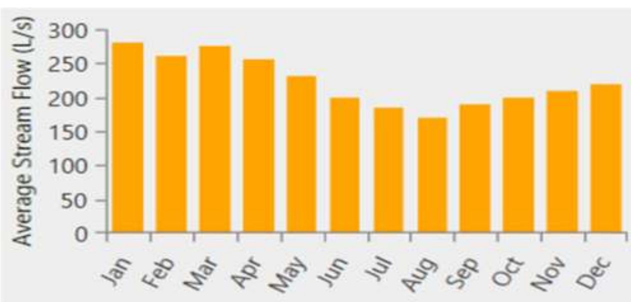

FIGURE 11. Monthly average micro-hydro recourse.

D. COMPONENTS AND MATHEMATICAL MODELING

1) PV ARRAY

PV array is a method that alters solar power into electrical power. The energy delivered by the photovoltaic is calculated on the sources of solar emissions and the temperature of the air as defined in Equation 6 [22].

$$P_{pv} = P_{Npv} \times \frac{G}{G_{ref}} \times \left[1 + K_t \times \left(\left[T_{amb} + \frac{NOCT - 20}{800}\right] \times G - T_{ref}\right)\right] \quad (6)$$

where, P_{pv} is rated power of photovoltaic array, G, G_{ref} are solar emissions at time t and standard situations, T_{amb}, T_{ref} are Ambient temperature at time t and standard conditions, K_t is the temperature coefficient of power, and its value depends on the photovoltaic panel technology.

2) WIND MILL

The windmill is employed for the production of kinetic energy resources accessible as wind. The power production of the windmill P_{wt} is calculated using Equations (7)–(9) [28].

$$P_{wt} = 0 \; if \; V < Vcut_{in} \; orV > Vcut_{out} \quad (7)$$

$$P_{wt} = V^3 \left(\frac{P_r}{Vr^3 - Vcut_{in}^3}\right) - \left(\frac{Vcut_{in}^3}{Vr^3 - Vcut_{in}^3}\right) \times P_r \quad if \; V > Vcut_{in} \; and \; V < V_r \quad (8)$$

$$P_{wt} = P_r \; if \; V < Vcut_{out} \; and \; V > V_r \quad (9)$$

where, P_r is rated power of windmill, V is WS at the studied area, $Vcut_{in}$ is cut in of WS of the windmill, $Vcut_{out}$ is cut out of WS of windmill and V_r is rated WS of windmill respectively.

3) DIESEL GENERATOR (DG)

DG is utilized as a united power system to fulfill the load requirements if the total electricity generated by non-conventional energy and storage cells is insufficient. Equation (10) communicates the volume of gas used up by diesel generators rely on its generation of power at every period [22].

$$F_{cons} = a \cdot P_{DG} + b \cdot P_{DG\_r} \quad (10)$$

where, $P_{DG}(t)$ is power produced by diesel generator (kW) at hourly (t), F_{cons} is Fuel consumption (Litre/hour), P_{DG_r} is rated power of diesel generator produced at hourly (t), a and b are coefficients (liter/kW).

4) CONVERTER

A converter is an apparatus that transforms the electrical energy from alternating current into direct current or vice versa. Equation (11) calculates peak load determines the rated power. The converter efficiency is given by [22], [27].

$$\eta_{cnv} = \frac{P_{output}}{P_{input}} \quad (11)$$

where, P_{output} is output power from/to converter, and P_{input} is input power from/to converter.

TABLE 3. A complete description of components.

Parameters	Value	Parameters	Value
PV System		**Wind System**	
Rated capacity (kWp)	1	Rated capacity (kWp)	1
Slope or tilt angle (degree)	37.5	Hub Height (m)	17
Capital cost ($)	1000	Capital cost ($)	1200
Replacement cost ($)	820	Replacement cost ($)	850
O&M cost ($/year)	10	O&M cost ($/year)	20
Lifetime (years)	25	Lifetime (years)	20
Diesel Generator System	**Value**	**Biodiesel Generator System**	**Value**
Rated capacity (kW)	10	Rated capacity (kW)	100
Minimum load ratio (%)	25	Minimum load ratio (%)	25
Capital cost ($)	1,000	Capital cost ($)	500
Replacement cost ($)	800	Replacement cost ($)	250
O&M cost ($/year)	0.300	O&M cost ($/year)	0.030
Lifetime (hrs)	15,000	Lifetime (hrs)	15,000 hrs
Fuel Price ($/L)	0.8	Fuel Price ($/L)	0.6
Battery	**Value**	**Converter**	**Value**
Nominal Voltage (V)	12	Rated capacity (kW)	1
Nominal Capacity (kWh)	1	Efficiency (%)	95
Initial State of Charge (%)	100	Capital cost ($)	300
Minimum State of Charge (%)	40	Replacement cost ($)	300
Quantity	1	O&M cost ($/year)	0
Capital cost ($)	300	Lifetime (years)	15
Replacement cost ($)	300	-	-
O&M cost ($/year)	10	-	-
Lifetime (years)	10	-	-
Throughput(kWh)	800	-	-
Hydro System	**Value**	**Other economic inputs**	**Value**
Rated capacity (kW)	10	Discount Rate (%)	8
Capital cost ($)	80,000	Inflation Rate (%)	2
Replacement cost ($)	40,000	Annual Capacity Shortage (%)	0
O&M cost ($/year)	2,400	Project lifetime (years)	25
Lifetime (years)	25	-	-
Nominal capacity (kW)	10.987	-	-
Available Head (m)	20	-	-
Design Flow Rate (L/s)	70	-	-
Minimum Flow Ratio (%)	50	-	-
Maximum Flow Ratio (%)	150	-	-
Efficiency (%)	80	-	-

5) STORAGE AGENT

In this research, the storage agent comprises batteries undemanding to link and have well energy productivity.

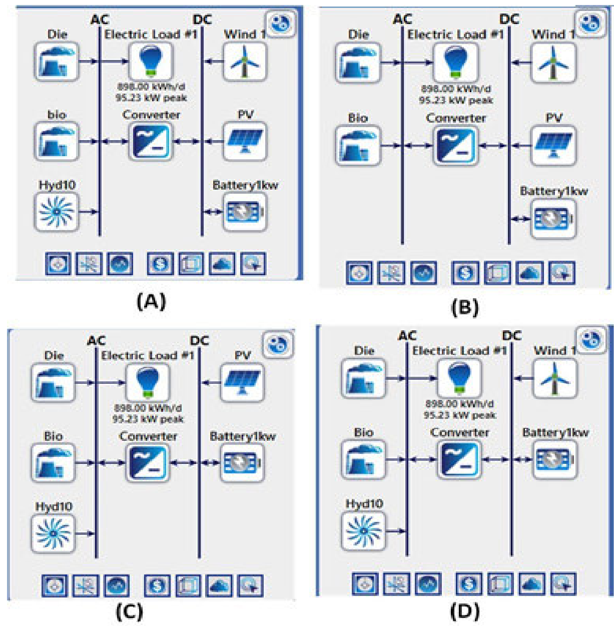

FIGURE 12. HOMER simulated models for area.

TABLE 4. Information on sensitivity parameters.

Sensitivity Parameters	Specifications
Project Life Time (Years)	15,25
Electrical load Demand (kWh/day)	898,929,940

Additional energy from non-conventional sources is utilized in the situation of energy deficit. Equations (11) and (12) evaluate the state of charge of the battery in the discharge and the setting of the charge [22].

$$E_b(t+1) = E_b(t) \times (1-\sigma) - \left(\frac{E_l(t)}{\eta_{cnv}} - E_g(t)\right) \times \eta_{BD} \tag{12}$$

$$E_b(t+1) = E_b(t) \times (1-\sigma) + \left(E_g(t) - \frac{E_l(t)}{\eta_{cnv}}\right) \times \eta_{BC} \tag{13}$$

where, $E_l(t)$, $E_g(t)$ are energy demand and produced power, η_{BD}, η_{BC} are discharge and charge efficiencies of the battery, σ is self-discharge of the battery, which is set to be zero in this research, η_{cnv} is the converter's efficiency, $E_b(t)$ is restricted by the minimum and the maximum storage capacities. Eb_{min}, Eb_{max} are stated in Equation (14):

$$Eb_{min} \leq Eb(t) \leq Eb_{max} \text{ where } Eb_{min} = (1 - DOD) \times Eb_{max} \tag{14}$$

where, DOD is the depth of discharge of battery, which relies on the battery's technology [34].

E. SYSTEM STRUCTURE AND ITS SPECIFICATIONS

As we can see from Fig. 12, the suggested HES is put into the simulation. The proposed system transfers electric current to

TABLE 5. Simulation results of different arrangements.

Case	System Configuration	Components size							Cost			RF (%)
		PV (kW)	WT	DG (kW)	BG (kW)	BT (kW)	MH (kW)	CT (kW)	NPC ($)	COE ($)	OC ($/yr)	
1	PV-WT-MH-BT-CT-DG- BG	75.8	73	10	110	158	11	55.6	831,217	0.196	36,184	81.2
2	PV-MH-BT-CT-DG-BG	256	-	10	110	510	11	110	848,385	0.265	27,640	88.8
3	PV-WT-BT-CT-DG-BG	205	157	10	110	707	-	82.2	981,350	0.306	30,139	90.7
4	WT-MH-BT-CT-BG-DG	-	622	10	110	151	11	84.5	1.16M	0.360	20,689	96.7

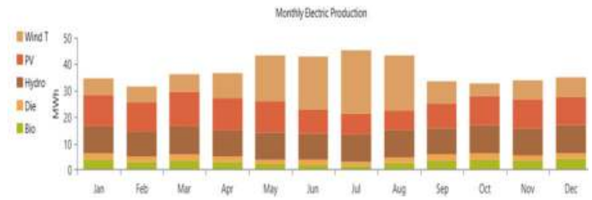

FIGURE 13. Monthly average electric share of each renewable source.

the grid and withdraw electric current from the grid whenever necessary to achieve continuous power flow [23], [26]. Table 3 displays the complete description of components.

F. SENSITIVITY PARAMETERS

Sensitivity analysis supervises the impact of specific variables. Distinct data are allocated to these parameters for a specified order to evaluate its impact on the microgrid. Table 4 tabulates the sensitivity parameters reviewed in this study.

IV. RESULTS AND DISCUSSION

In this research, the non-conventional energy sources with storage cells as a support are evaluated to search for a convenient solution that will fulfill the local load demand and concurrently reduce cost variables (COE, NPC, and O&M) and emissions. Rarely diesel generator has to function when the non-conventional resources assisted by storage cells are not adequate to meet the peak load.

A. TECHNO-ECONOMIC STUDY SCENARIOS AND OPTIMAL POWER FLOW STUDY CASES

The preliminary optimization criteria of the research are: scaled yearly average electric load demand is 898 kWh/day. The yearly average wind potential is 5.63 meters/second, the yearly average solar potential is 5.30 kWh/m^2/day, yearly average biomass (t/d) is 0.43, and yearly average streamflow (liter/second) is 222.92. Nominal discount rate is 8%, and project lifetime years is 25. In this research, the non-conventional energy sources with storage cells as a support are evaluated to search for a convenient solution that will fulfill the local load demand and concurrently reduce cost variables (COE, NPC, and O&M) and emissions. Rarely diesel generator has to function when the non-conventional resources assisted by storage cells are not adequate to meet the peak load. In this research, HOMER carries out

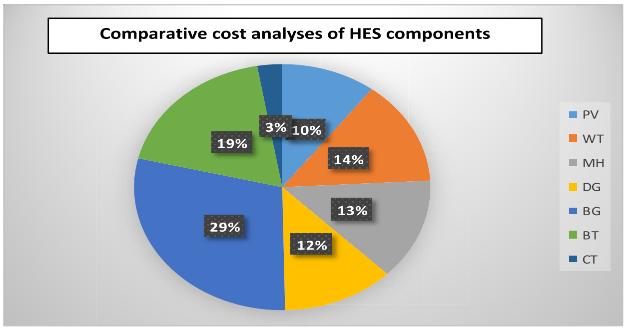

FIGURE 14. Comparative cost analyses of HES components.

TABLE 6. Energy generation of HREs.

Source	kWh/yr	%
PV	125,692	28
DG	24,327	5.43
BG	37,325	8.32
WT	138,343	30.9
MH	122,716	27.4
TOTAL	448,403	100

TABLE 7. Energy consumption of HREs.

Load	kWh/yr	%
Capacity Shortage	0	0
Unmet Load	0	0
Excess Electricity	107,941	24.1

1,983,995 simulations, whereas 14,725 simulation outcomes and 198 sensitivity outcomes are measured. In this division, the simulation outcomes are introduced, which are continued by the sensitivity parameters' findings and further elaborate analysis of the optimization outcomes of the efficient HES.

Scenario 1: PV-WT-MH-BT-CT-DG- BG
Scenario 2: PV-WT-BT-CT-DG-BG
Scenario 3: PV-MH-BT-CT-DG-BG
Scenario 4: WT-MH-BT-CT-BG-DG

B. OPTIMAL CONFIGURATION PLAN OF THE HYBRID GRID CONNECTED SYSTEM OF UKAI

Table 5 gives the full simulation results of different arrangements scenarios with the help of the HOMER PRO software package. In all scenarios, the electricity production satisfy required load within the permissible rating of various system

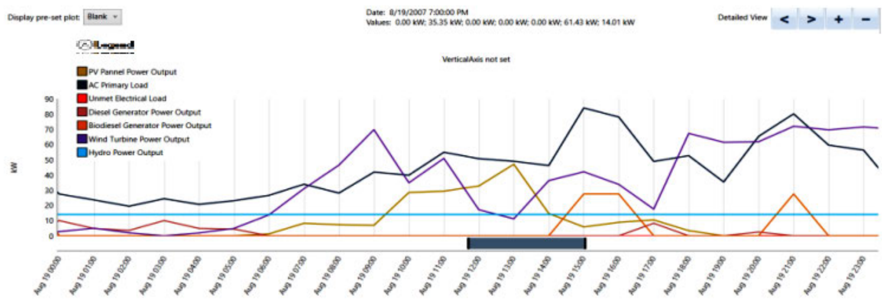

FIGURE 15. On-line energy-scheduling scheme including generation and load profiles.

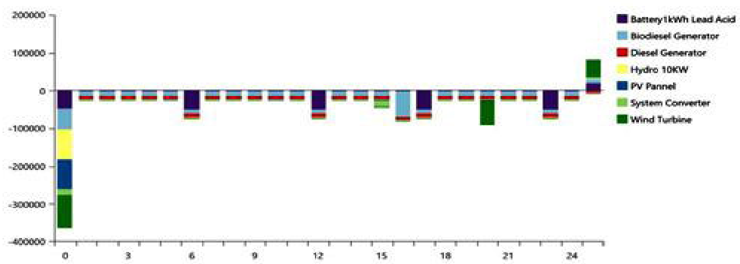

FIGURE 16. Cash flow HES components.

TABLE 8. Overall economic assessment of HES components.

Component	Capital	Replacement	O & M	Fuel	Salvage	Total
PV	$75,774.75	$0.00	$9,795.79	$0.00	$0.00	$85,570.54
WT	$87,600.00	$19,782.00	$18,874.17	$0.00	$11,148.42	$115,107.75
MH	$80,000.00	$0.00	$31,026.04	$0.00	$0.00	$111,026.04
DG	$1,000.00	$1,850.47	$11,739.48	$86,979.98	$183.02	$101,386.91
BG	$55,000.00	$22,368.93	$40,655.75	$129,182.93	$5,423.99	$241,783.24
BT	$47,400.00	$91,517.82	$20,425.48	$0.00	$5,422.17	$153,921.12
CT	$16,677.56	$7,075.85	$0.00	$0.00	$1,331.75	$22,421.67
System	$363,452.31	$142,595.07	$132,516.71	$216,162.53	$23,509.36	$831,217.26

components. Table 1 shows the optimal size of the system component at each configuration that gives the cost data including NPC ($) and COE ($/kWh) besides, the value of the total system emission (kg/yr.).

Some highlights on the HOMER techno-economic results in table 5.

- PV-WT-MH-CT-BT-DG-BG is the utmost feasible system with $830,997 NPC. The micro-grid comprises 1 PV of 76 kW, 1 Wind Mill of 73 kW, Diesel Generator of 10 kW, Bio Generator of 110 kW, and 155 Batteries of Generic 1kWh Lead Acid, Hydro of 11 kW and 57.2 kW converters. The NPC, COE, and operating cost of the PV-WT-MH-CT-BT-DG-BG HES are $830 997, $0.196, $363,209, respectively.
- Besides, PV-WT-MH-CT-BT-DG-BG HES, the second-best HES PV-MH-BT-CT-DG-BG is with an NPC, COE, and operating cost of $ 1.03M, $ 0.243, $ 563,670.
- The third-best HES PV-WT-BT-CT-DG-BG is with an NPC, COE and operating cost of $ 1.24M, $0.292, $707,592.
- The fourth-best HES WT-MH-BT-CT-BG-DG is with an NPC, COE, and operating cost of $ 1.55M, $ 0.366, and $859,133.
- After the above mentioned highlights, it is settled that the HRES of PV-WT-MH-CT-BT-DG-BG is the best setup plan for Ukai area as it gives a reasonable result regarding technical, economic and environmental aspects.

C. OPTIMAL HES SIMULATION OUTCOMES

The above evaluation shows that PV-WT-MH-CT-BT-DG-BG is the best HES to electrify the town over various analyze. The monthly average electric share of each renewable source for optimal HES plan is graphically illustrated in Fig 13.

TABLE 9. Emissions produced by the HES system.

Quantity	Value
Carbon Dioxide	54,669 (kg/yr)
Carbon Monoxide	372 (kg/yr)
Unburned Hydrocarbons	15 (kg/yr)
Particulate Matter	11.3 (kg/yr)
Sulphur Dioxide	134 (kg/yr)
Nitrogen Oxides	383 (kg/yr)

Table 6 presents energy generation of the optimal HREs plan, renewable resources (PV, WT, MH) are the main sources to supply load by 448,403 kWh/yr. As expected from the cheaper cost of PV besides the high, value of average PV in Ukai.

Total energy generation of PV array is 125,692kWh/yr with 4401 h/yr operating hours and COE of $0.0527/kWh. The wind turbine energy output is 138,343kWh/yr with 7332 operational hours/year, and the COE is $0.0644/kWh. The hydro energy output is 122,716kWh/yr with 8760h/yr operational hours and $0.0700/kWh as COE. The Bio-Diesel Generator runs 953 hours/year, which starts 536 times/year and has 15.7 years as operating lifetime; total electrical output from Bio-Diesel Generator is 37,325kWh/year. The DG functions 3027h/yr, which commence 1,363 times annually and has 4.96 years of operational lifetime, with a total electrical output of 24,327kWh/yr from the diesel generator. The converter operates 7891h/yr.

Regarding energy consumption, it is seen from table 7 that the optimal configuration plan succeeds to meet 24-hr load demand with zero capacity shortage, as well as a backup excess energy of 107,941 kWh/yr.

Regarding overall economic assessment, Table 8 includes capital, replacement, O&M, fuel, and salvage costs for system components and the overall system of the optimal configuration plan.

The expensive cost of BG, results in the higher total cost between system components with $241,738.24, this is because of high Capital cost and fuel cost. On the other hand, PV and CT comes with low total cost and is the cheapest components in HRES. Fig.14 summarizes table 7 as it shows in a comparative graph the total system costs distribution between different system components.

The on-line energy-scheduling scheme including generation and load profiles is displayed in Fig.15 for August 19. The critical analysis of Fig.15 reveals many important prospects for the suggested configuration plan. It is observed that solar energy generations is available from 06:00 onward and are not available after 18:00 and peak is at 13:00.Due to non-avaibility of PV before 06:00 onwards and after 18:00 all load is supplied by WT. It is also observed that power from the MH is constant. We could also see that DG operates for a limited amount of time when compared to other components in the system. BG only functions from 14:00 to 17:00 and from 20:00 to 22:00. Moreover, excess energy is used to charge the battery units. During this time, the battery remains in idle state and hence the life of the battery is improved.

TABLE 10. Results of sensitivity analysis.

1). Project Life= 15 years.

System	Load	NPC	COE	Operating Cost
PV-WT-MH-CT-BT-DG-BG	898	656659	0.205	31158
	920	675771	0.206	31803
	940	692849	0.206	32905
PV-MH-BT-CT-DG-BG	898	848385	0.265	27640
	920	870431	0.265	28059
	940	903081	0.269	29030
PV-WT-BT-CT-DG-BG	898	981350	0.306	30139
	920	1.02M	0.310	30276
	940	1.04M	0.311	31155
WT-MH-BT-CT-DG-BG	898	1.16M	0.360	20689
	920	1.31M	0.399	39720
	940	138M	0.410	40567

2.) Project Life= 25 years.

System	Load	NPC	COE	Operating Cost
PV-WT-MH-CT-BT-DG-BG	898	831236	0.196	36380
	920	855299	0.197	37140
	940	877401	0.198	38037
PV-MH-BT-CT-DG-BG	898	1.04M	0.245	36100
	920	1.08M	0.249	37542
	940	1.12M	0.254	39129
PV-WT-BT-CT-DG-BG	898	1.23M	0.290	40315
	920	1.28M	0.294	40320
	940	1.31M	0.296	43083
WT-MH-BT-CT-DG-BG	898	1.41M	0.332	35165
	920	1.65M	0.379	53355
	940	1.71M	0.386	56095

An overview of the cash flow HES components is presented in Fig. 16. Emissions produced by HES are presented in Table 9.

D. SENSITIVITY ANALYSIS

The system comprises two sensitivity parameters: project lifetime years and scaled annual average electric load. The sensitivity analysis outcomes are shown in Table 10.

As we could see that when project lifetime years is 15 Years in case 1 and when project lifetime is 25 Years in case 2, PV-WT-MH-CT-BT-DG-BG is the best optimal system in NPC, COE, and operating costs.

V. CONCLUSION

Our goal was to show the viability of HES for isolated urban electrification through this research, Ukai in Gujarat, India. After modeling, optimization, and other economic research, we derived the best possible HES, which consist of a PV array of 76 kW, 1 WT of 73 kW, DG of 10 kW, BG of 110 kW, 155 BT cells of generic 1kWh lead acid, MH of 11 kW and 57.2 kW CT. The solar, wind, biomass, hydro resources are abundantly available in this area. Also, the availability of various support policies through subsidies by the government reduces the assets and the cost of energy designed for the villagers. The urban electrification process is associated with economic, environmental phases.

Along with the current power network extension lead plans; this research endorses the HES for urban electrification. With additional improvements of India's urban locations, the design and magnitude of the electricity demand of numerous kinds of consumers alter accordingly. This trend shows a vital part of the exemplary architecture of HES throughout the project time.

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