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Comparative Investigation of On-Grid and Off-Grid Hybrid Energy System for a Remote Area in District Jamshoro of Sindh, Pakistan

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Abstract: To meet electricity requirements and provide a long-term, sustainable existence, remote areas need to promote renewable projects. Most of the time, wind and solar power sources are selected as renewable energy technologies to help satisfy some of the power requirements. Alternative approaches should be employed, considering the inconsistent characteristics among those resources, to offer efficient and long-lasting responses. Electricity production needs to be conducted with the help of a wide range of energy sources to be productive and efficient. As a result, the current research concentrates on feasible analyses of interconnected hybrid energy systems for such remote residential electricity supply. To help a remote area's establishment decide whether to adopt renewable electricity technology, this paper evaluates the techno-economic effectiveness of grid-connected and standalone integrated hybrid energy systems. The electricity requirements for the entire selected remote area were determined first. Furthermore, the National Aeronautics and Space Administration, a national renewable energy laboratory, was used to evaluate the possibilities of green energy supplies. A thorough survey was performed to determine which parts were needed to simulate the interconnected hybrid energy systems. Employing the HOMER program, we conducted a simulation, optimizations, and economic research. Considering the net present cost, cost of energy, and compensation time, an economic comparison was made between the evaluated integrated hybrid systems. The assessment reveals that perhaps the grid-connected hybrid energy system is the best option for reliably satisfying remote areas' energy needs.

Keywords: on-grid; off-grid hybrid; HOMER; techno-economic analysis

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1. Introduction

The degrading state of the world's atmosphere, growing costs of fossil resources, and increased energy use all contribute to [1] a quick tendency towards renewable power production technologies including the fuel cell [2–5]. It is observed that wind energy has increased in recent decades [6,7] as well as solar energy [8,9]. Renewable sources of electricity that are being used have increased, and because of their higher efficiency and lack of poisonous gas emissions, wind and solar energy are seen to be the most essential contributors [10–13]. The provision of electrical supplies for some places also ranks among the top priorities of the world's rural areas, including off-grid regions. It would be an unaffordable plus and, under certain circumstances, technically not possible to interconnect these locations towards the grid [14–16]. Therefore, depending on the features of the region of the installation (radiation intensity, ambient temperature, wind speed, etc.), multiple hybrid energy system (HES) methods may be chosen for that kind of location [17–20]. Various renewable technologies including wind turbines, fuel cells, and photovoltaics [21–23] could be combined to create a hybrid power system. Consequently, the wind, photovoltaic, and fuel-cell hybrid combination is a brand-new renewable resource. Numerous countries and organizations have been interested in employing these resources because of their purity as well as renewability; therefore, studies are being conducted in this field [24–26]. A few current projects in the domain of fuel-cell power production and utilizing it in collaboration with renewable energy resources both within and outside of Pakistan are shown in Table 1.

Table 1. Latest studies on the use of renewable power sources and fuel cells to deliver power.

Purpose	Renewable Energy Used	Connection Mode	Electricity Demand (kWh/Day)	Location	Sensitivity Analysis	LCOE ($/kWh)	Reference Year
Electricity supply to Gwadar	PV, WT	On-grid and off-grid	1,680,000	Pakistan	No	0.0347	2022 [1]
Electricity supply to the Hunza district of Gilgit-Baltistan	PV, WT	On-grid and off-grid	372.09	Pakistan	Yes	0.0388	2022 [2]
Electric vehicle	PV, wind	Off-grid	11.27	Turkey	Yes	0.685	2021 [27]
Co-generation of electricity, heat, and hydrogen	PV, WT	Off-grid	15	Pakistan	Yes	0.965	2021 [28]
Remote application	PV, WT, tidal	Off-grid	20–40	Iran	No	0.45–11	2021 [29]
Desalinate seawater	PV	Off-grid	522	Saudi Arabia	No	0.124	2020 [30]
Rural electrification	PV, WT, biomass	On-grid and off-grid	361	Iran	No	0.096–0.164	2020 [31]
Residential house	WT	Off-grid	10	China	Yes	1.278	2020 [32]
Small tourist village	Biomass	Off-grid	92.2	Egypt	Yes	0.335	2020 [33]
Reverse osmosis desalination	PV	Off-grid	110	Egypt	Yes	0.062	2019 [34]

According to the findings of the current study's writers' numerous different studies and the outcomes of the results presented in Table 1, it is clear that relatively little research has been performed regarding technical analysis of Pakistan's fuel-cell-based hybrid renewable systems, and inconsistencies have not been investigated. Harnessing off-grid and grid-connected wind–solar–fuel cell systems to provide energy to a domestic residence in a dry and hot environment in Pakistan (city of Jamshoro) has been explored throughout the current study, which utilizes the HOMER Pro 3.11.2 software. The characteristics of wind speed and solar radiation were subjected to sensitivity analysis, and the results seem to determine the lowest price for every kilowatt hour of electricity or hydrogen generated. Various situations were matched, and the refund on the investment period for the best economic system was determined. Additionally, for the initial time, the functionality of an optimum fuel-cell-based hybrid system with battery backup was assessed. It needs to be highlighted that some other countries around the world having comparable climate circumstances may utilize the findings of the current investigation. The methods and research utilized can also be applied to certain other places featuring varied climate circumstances, even though the current research is a case study. Additional benefits of such a current study are comparable to those of earlier efforts, including utilizing current yearly interest rates to conduct economic analyses, performing sensitivity analyses, handling the topic of uncertainty, and using current costs for the equipment utilized. This research focuses on mixed rural and urban sustainability, as it aims to help generate standalone power via renewable energy sources, and it is a case study of one mixed urban and rural population district.

Novelty and Motivation of the Study

This research on the comparative investigation of on-grid and off-grid hybrid energy systems for a remote location in District Jamshoro of Sindh, Pakistan, including solar, wind, and fuel-cell technology, is an important innovation in renewable energy. The goal of this study is to investigate the viability and effectiveness of combining different sources of energy to meet the energy requirements of remote areas.

Utilizing solar, wind, and fuel-cell energy, which are plentiful in the research location, is one of the major innovations. A special potential to capture clean as well as sustainable energy is provided by the incorporation of various renewable resources. This research aims to provide consideration of the technical aspect and the financial and ecological implications of on-grid and off-grid systems by comparing how they perform.

Furthermore, this inquiry is made even more innovative by the inclusion of a fuel cell. When solar and wind power output is low, fuel cells act as an additional source of power to maintain a steady flow of electricity. Incorporating fuel-cell technology within the hybrid system promotes the environment while simultaneously reducing dependability on conventional energy sources.

Overall, a comparison of hybrid energy systems that use solar, wind, and fuel cells to produce electricity that is both on-grid and off-grid has never been seen in the selected area of study. With the results of this study, the researchers want to advance environmentally friendly growth and offer insightful information to populations, legislators, and power coordinators who are working to satisfy their energy demands effectively and reliably.

2. Material and Methods

Throughout the whole proposed study, the wind-energy opportunities in Jamshoro were examined. Afterward, gathering other necessary data such as solar energy as well as electrical potential in the preferred location using the HOMER software, the most affordable framework, was completed by taking the reliability of the hybrid power system into account. The sensitivity evaluation has been carried out to compensate for modifications in the price of various components as well as variations in the wind speed and solar irradiance.

2.1. Specifications of the Studied Site

The NASA (National Aeronautics and Space Administration) satellites provided estimated solar irradiance strength for such periods, and the HOMER program also used this data as input. Predicated upon the data, the HOMER calculated the estimated yearly solar irradiance to be 5.27 kWh/m^2/d; the diagram is displayed in Figure 1. The NASA satellites also gathered information on wind throughout the seasons, and thus the HOMER program used this information as input. Predicated upon the data, HOMER calculated that the estimated yearly wind speed is 4.45 m/s, as shown in Figure 2. Remote areas in Jamshoro needed electricity consumption for such a residential unit to be considered. Figure 3 illustrates a daily electricity use of 262.62 kWh/d and even the peak electrical load of 34.08 kW.

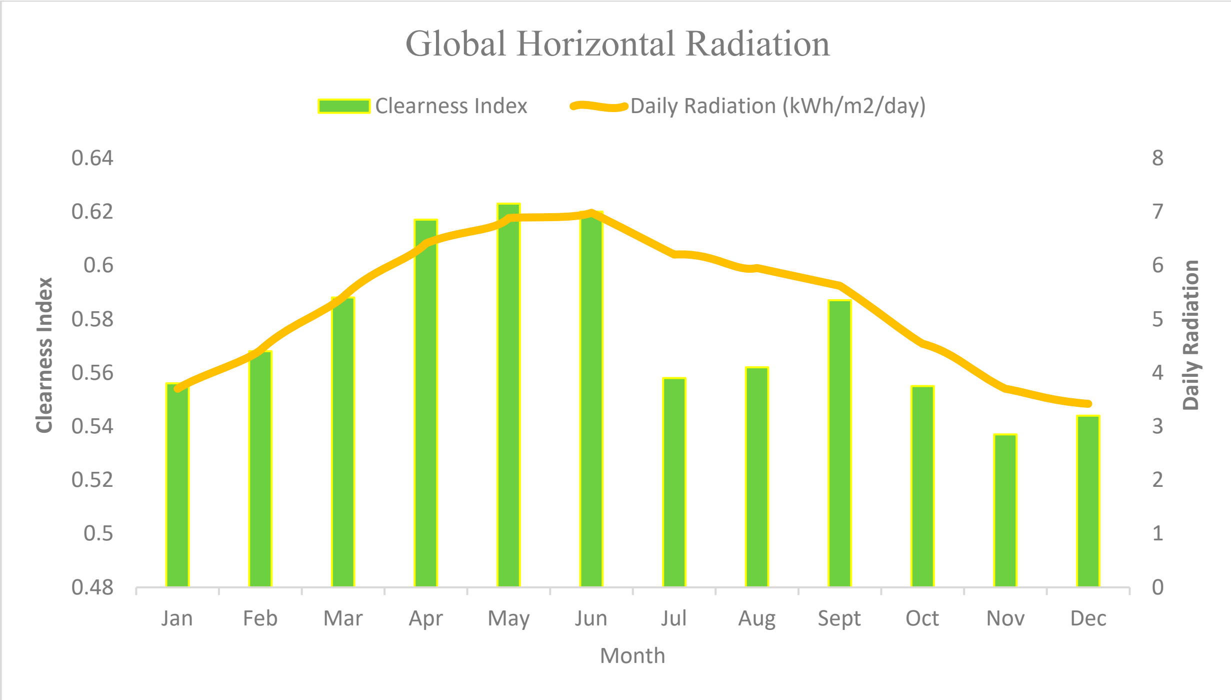

Figure 1. Solar radiation levels every month.

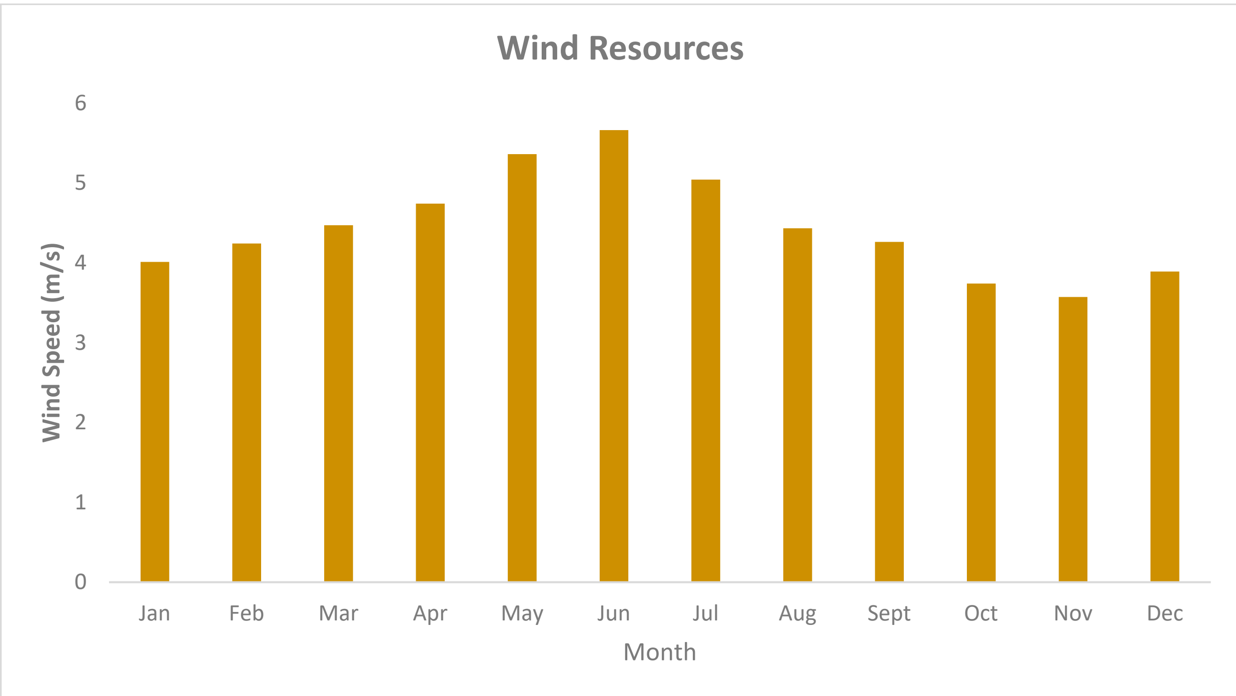

Figure 2. The investigated region's monthly average wind speed.

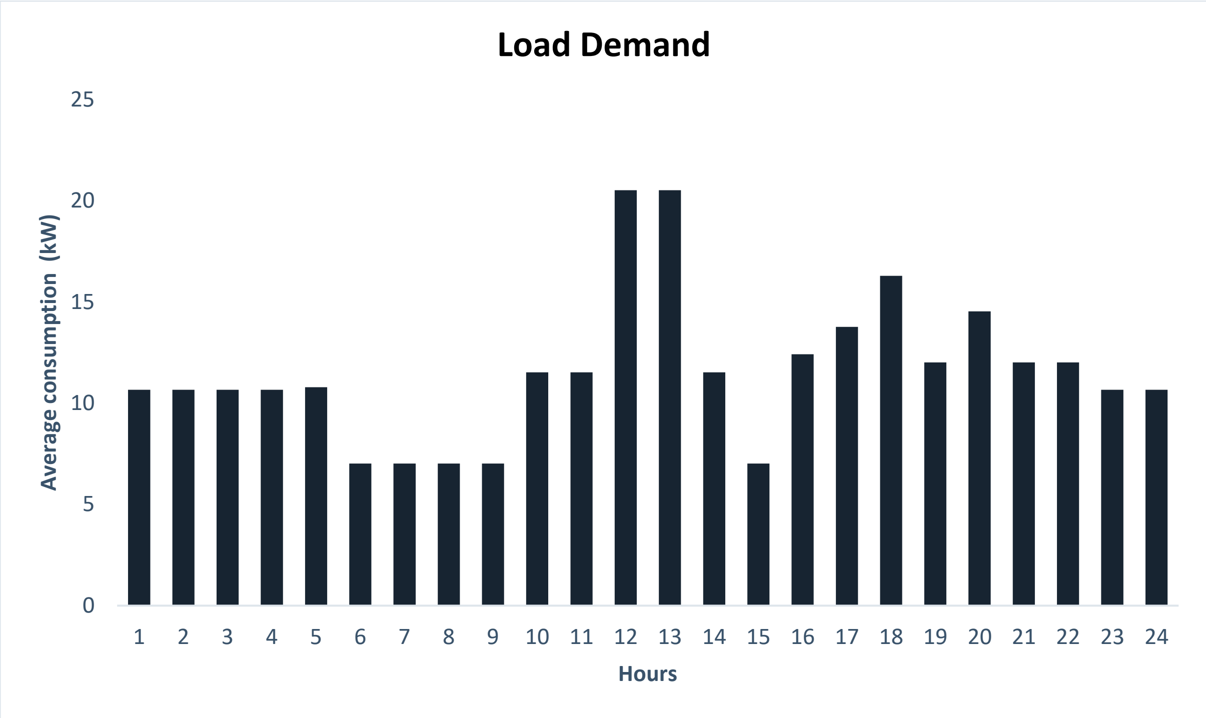

Figure 3. The required remote area electrical demand.

2.2. Details on Costs and Characteristics of Hybrid Energy System Components

2.2.1. Photovoltaic Cells

Proposed power models of the photovoltaic (PV) array, models of solar irradiance on the surfaces of the photovoltaic system, and the temperature of the photovoltaic modules make up the electricity-production simulation system for a solar system. These components are neglected because the photovoltaic module's temperatures have a minimal impact on the outcome of the modeling [35].

Climate factors, particularly solar irradiance as well as module temperatures, have a significant impact on the photovoltaic module's functionality. Temperatures, radiation strength, radiation inclination, and radiation period seem to be four non-linear climate conditions that have an impact on how well a solar module performs. The maximum amount of output power provided by the photovoltaic panels may be expressed as follows utilizing the scatter factor concept [36]:

$$P_{pv} = V_{oc} \times I_{SCV} \times \eta_{MPPT} \quad (1)$$

where V_{oc} is the open-circuit voltage, I_{sc} is the short-circuit current, and η_{MPPT} is the photovoltaic cell's maximum output tracking efficiency because solar panels are typically fitted with one to optimize the output power.

2.2.2. Wind Turbine

Wind-turbine modeling necessitates designing several factors that have an impact on the wind turbine's output [37]. In order to reproduce the intrinsic features of wind resources, an appropriate model must first include the unpredictable features of the site's resources. The relationship seen between the wind resources and electricity production comes afterward. Wind-turbine operating variables according to the manufacturer's instructions can be used to demonstrate the correlation [38]. According to one such formula, the wind-turbine generator begins to produce electricity somewhere at cut-in wind velocity (V_c). The generated power grows linearly until it reaches the specified power P_{wtr} even as wind velocity v climbs to the optimum wind velocity (V_r) [39]. The estimated power is produced whenever v changes from the running velocity (V_r) to the cut-off velocity (V_f). Regarding safety reasons, the wind turbine might be shut down whenever $v < V_c$ and $v > V_f$.

$$P_{wt} = \begin{cases} 0 & v < V_c \text{ or } v > V_f \\ P_{wtr} \times \frac{v - V_c}{V_r - V_c} & V_c \le v < V_r \\ P_{wtr} & V_r \le v < V_f \end{cases} \tag{2}$$

Any wind turbine must usually be located over the average usage area and in keeping with the minimum or maximum wind velocity in an area because the wind turbine's power production is heavily dependent on wind velocity. As a result, it is able to provide part of the essential load. A Bergey Excel 10-R 10 kW AC wind turbine was used in this study [40,41].

2.2.3. Electrolyzer

Calculated as the greater heating value divided by the quantity of electricity spent, an electrolyzer's efficacy is the rate at which electricity is converted to hydrogen and is equivalent to the energy contents of hydrogen.

2.2.4. Hydrogen Tank

The power capability of said hydrogen storage tank toward the electrical load is measured as hydrogen tank independence. The following given equation is used by HOMER to compute the independence of a hydrogen tank [42]:

$$A_{htank} = \frac{Y_{htank} LHV_{H2} \left(24 \frac{h}{d}\right)}{L_{prim,avg} \left(3.6 \frac{Mj}{kWh}\right)} \tag{3}$$

where Y_{htank} is the hydrogen tank's weight in kilograms; LHV_{H2} is hydrogen power content (lower heating value), which is 120 MJ per kilogram; and $L_{prim,ave}$ is the average main load in kilowatt hours per day.

2.2.5. Fuel Cell

The electrical efficiency of a fuel cell (η_{FC}) is calculated using the HOMER program as the resultant electric power divided by that of the chemical energy of such fuel intake, as shown below [43].

$$\eta_{FC} = \frac{3.6 E_{FC}}{M_{H2} \cdot LHV_{H2}} \tag{4}$$

In the equation given, E_{FC} stands for the fuel cell's yearly total electricity generation in kWh, m_{H2} for its total yearly hydrogen consumption in kilograms, and LHV_{H2} for its lower heating value (megajoules per kg).

2.2.6. Battery

A battery bank stores DC power generated by fuel cells, wind turbines, and solar modules. Whenever the producing energy systems are not producing enough electricity, this energy supplies the remote area's basic electrical needs. When determining the battery bank's capacity, the independence and duration of the batteries become crucial factors. The steps HOMER employs to assess battery performance over time are described below [44]:

$$R_{batt} = \begin{cases} \frac{N_{batt} \times Q_{lifetime}}{Q_{thrpt}} & \text{if limited by throughput} \\ R_{batt,f} & \text{if limited by time} \\ \text{MIM}\left(\frac{N_{batt} \times Q_{lifetime}}{Q_{thrpt}} \times R_{batt,f}\right) & \text{if limited by throughput and time} \end{cases} \tag{5}$$

The terms N_{batt}, $Q_{lifetime}$, Q_{thrpt}, and R_{batt} relate to the number of batteries in storage banks, the lifetime production of a unit stored (kWh), the annual output of storage (kWh/yr), and the reserves' floating life (year), respectively. The battery type with string voltage employed in this investigation is Li-ion batteries having a string size of 40 v.

2.2.7. Bi-Directional Converter

Because all renewable energy (RE) resources provide DC power rather than the AC power that is required, bi-directional converters are required for converting AC to DC as well as for DC to AC transformation. Because the power transfer is dependent on solar, wind, and fuel-cell energy sources with varying demand times, HOMER modifies the bi-directional converter size.

2.2.8. Economic Analysis

The HOMER program outputs a range of possibilities depending on the overall net present cost (NPC) after simulating various system setups [45]:

$$\text{TOTAL NPC} = \frac{C_{ann,tot}}{\frac{i(1+i)^N}{(1+i)^N-1}} \quad (6)$$

Throughout the relationship mentioned earlier, $C_{ann,tot}$ stands for the total annual cost, I for the yearly interest rate, and N for the project's expected lifetime. The following calculation is used by the HOMER program to determine the levelized cost of energy (LCOE) in dollars per kWh [46]:

$$\text{LCOE} = \frac{C_{ann,tot}}{R_{prim} + R_{tot,grid,sale}} \quad (7)$$

In the relationship above, R_{Prim} stands for the starting loads in kWh/year and $R_{tot,grid,sales}$ for the total power sold to the grid in kWh/year.

3. Modeling of the Studied System

Figure 4 displays hybrid energy systems without a grid-connected overall design.

Solar panels, battery units, fuel cells, hydrogen tanks, and electrolyzers are all linked to the DC bus bar because of the DC power production, and the wind turbine is connected to the AC bus bar side because of AC power production, as shown in the upper figure. The entire power generation of all these modules is converted into AC power with a DC/AC bi-directional converter, which is connected to an AC bus bar for consumer usage.

A grid-connected hybrid energy system with a photovoltaic system, a fuel cell, and battery packs that are linked to a DC bus and additional side wind turbines that are connected to an AC bus is another similar approach that is being designed. The above systems could significantly lower the price of electricity. In the absence of wind energy and solar energy, conditions can always be powered with the fuel cell and battery backup, and additional power may be supplied to the grid as can be seen in Figure 5.

The program is processed and the advanced optimization processes are carried out using the data of the program as well as the price of the instruments utilized in the hybrid energy system.

Table 2 mainly includes details on the cost, expected longevity, model, and dimensions of the equipment utilized in the simulations. This table contains some helpful details regarding the tools utilized. The flowchart depicted in Figure 6 illustrates how the HOMER program performs, whether to solve problems or demonstrate the various steps of simulations. As can be seen, a renewable energy system is suggested after first evaluating the solar and wind statistics in addition to the necessary electricity demand. Next, the suggested system is examined on the basis of its elements, power source, economics, and statistics on the utilization of renewable energy sources. The simulations for this situation finish whether this system is capable of the load requirement and is economically feasible; alternatively, a different solution is suggested and evaluated. The procedure is then repeated as the program looks at a different situation for a different set of renewable energy suppliers.

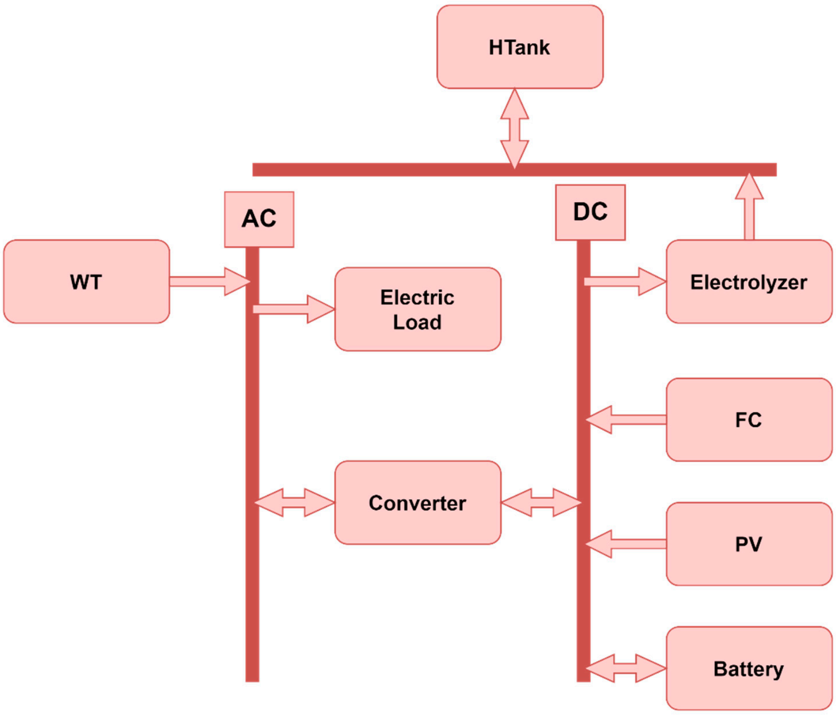

Figure 4. A generalized design of a wind, solar, and fuel-cell power system including backup batteries and a hydrogen tank.

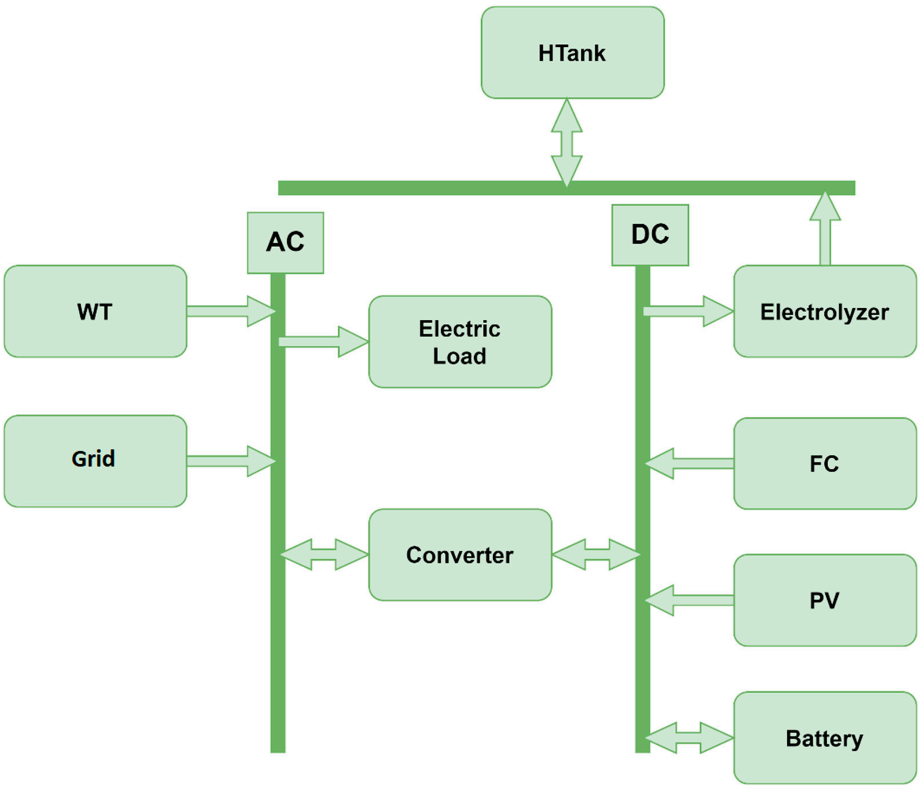

Figure 5. A generalized design of a grid-connected, wind–solar, and fuel-cell power system including backup batteries and a hydrogen tank.

Table 2. Information from a potential hybrid energy system.

S.NO	Components	Capital Cost ($)	Replacement Cost ($)	O & M Cost ($)	Lifetime	Other Information
1	PV [47]	400	400	10	25 years	Derating factor 80%
2	Wind turbine [41]	3200	3000	120	25 years	Bergey Excel 10-R, Hub height, 80 m
3	Electrolyzer [47]	1100	850	10	15 years	Efficiency 85%
4	HTank [47]	600	600	10	25 years	Initial tank level, 10%
5	Fuel cell [47]	2000	2000	0.030	15,000 h	Max. efficiency, 51.3%
6	Battery [48]	320	300	15	10 years	Li-ion battery
7	Converter [41]	800	750	20	15 years	Efficiency, 90%

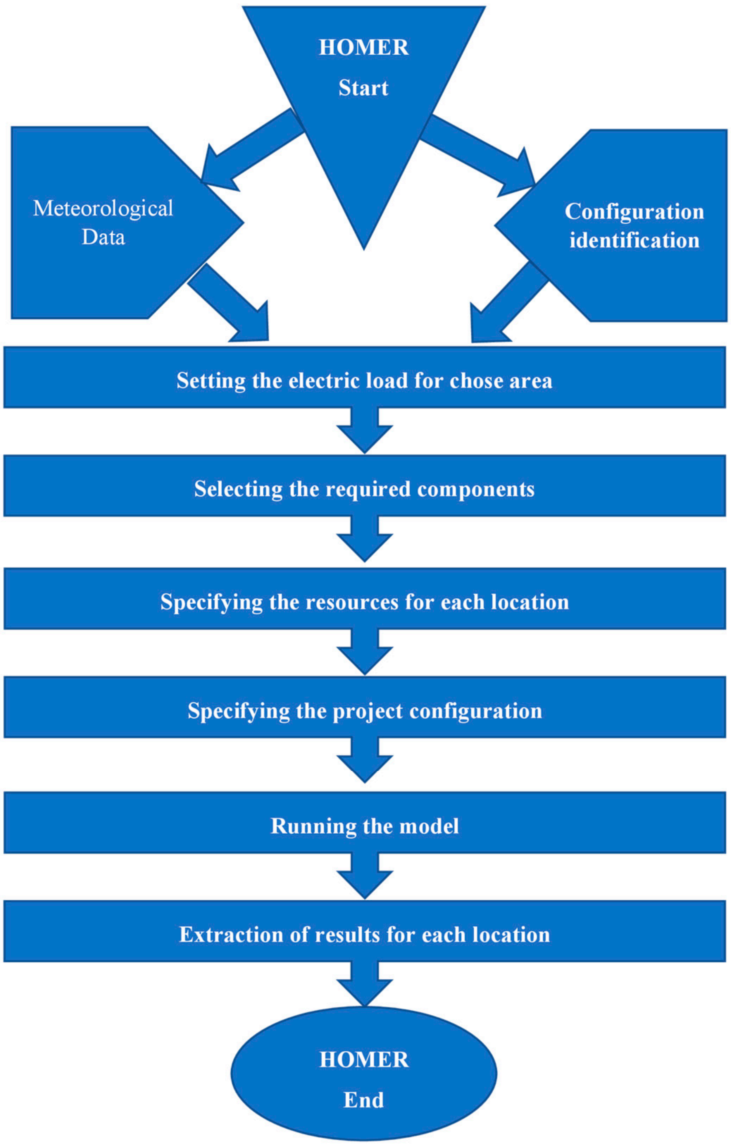

Figure 6. HOMER performance flow chart.

HOMER Pro 3.11.2 Software

Hybrid Optimizations Systems for Electric Renewables is referred to as HOMER (). It is among the most popular software. In 1993, Mistaya Engineering of Canada created HOMER for the National Renewable Energy Laboratory (NREL) of the United States. To evaluate designs of both without-grid and grid-connected hybrid systems for a variety of purposes, a micropower optimization model is used. Optimizing and sensitivity testing are both performed by HOMER. The framework calculates the power balance while considering various element counts and configurations with the aid of HOMER. The program presents an ordered collection of configuration results in accordance with Total Net Present Cost (TNPC). The system computes expenses for fuel, interest, replacements, operation, and maintenance charges, among others. The use of sensitivity analysis quantifies a variety of variables, including wind speed and fuel price. The way that HOMER presents simulations results in various graphs and tables, which makes it easier to distinguish between setups and assess their financial sustainability.

4. Results and Discussion

Employing HOMER, we performed simulations for every scenario involving interconnected energy infrastructure. According to the net present cost (NPC) and cost of energy (COE), the best option for such techno-economic analysis of power production in each scenario is determined. This classification is assigned to different design parameters using the net present cost. The smallest NPC statistic is used to determine the best course of action. In upcoming subsections, the optimizing outcomes including the economic characteristics of the two models are covered.

4.1. Without Grid-Connected Hybrid Energy System

An economic analysis of the without grid-connected hybrid energy system optimization outcomes is displayed in Table 3. The top section in Table 3 shows the highest rating and is regarded as the system design that best satisfies the remote area in Jamshoro's need for electric power. The ideal hybridization configurations of NPC and COE are $410,000 and $0.294, respectively. The ideal configuration for an off-grid connected hybrid system is shown in Table 3. A total of 150 kW photovoltaic panels, 110 kW wind turbine, 60 kW of fuel cell, 240 Li-ion batteries, and 60 kW converters are all part of the system.

Table 3. Outcomes of PV/WT/FC optimization of off-grid system.

PV (kW)	WT (kW)	FC (kW)	EL (kW)	HTank (kg)	Battery	Converter (kW)	COE ($)	NPC (M$)	Disp
150	10	60	60	60	240	60	0.294	410,000	CC
150	10	60	60	60	240	60	0.298	410,010	LF

Table 4 displays the yearly electrical power production of each element of such an ideal hybrid energy setup. It shows that around 95,805 kWh of energy must be generated annually to meet the necessary demand. It must be believed that about 94.5% of the electricity consumption is satisfied by photovoltaic panels, 4.48 % by wind turbines, and 1.07% by the fuel cell. HOMER needs to take into consideration all elements in their most optimum design arrangement to consider their salvage value. Figure 7 displays the monthly mean electricity power generated from every element of such an ideal hybrid power system's architecture. Table 5 displays the expenses of various without grid-connected hybrid system components throughout the duration of the system's lifetime. It has been noted that perhaps the NPC of such a framework has the most impact on the overall cost of the batteries, photovoltaic panels, and fuel cells.

Table 4. The yearly electricity output of the best hybrid off-grid energy system.

Production	kWh/Year	%
Generic flat plate PV	244,792	94.5
Fuel cell	2763	1.07
Wind turbine	11,599	4.48
Total	259,154	100

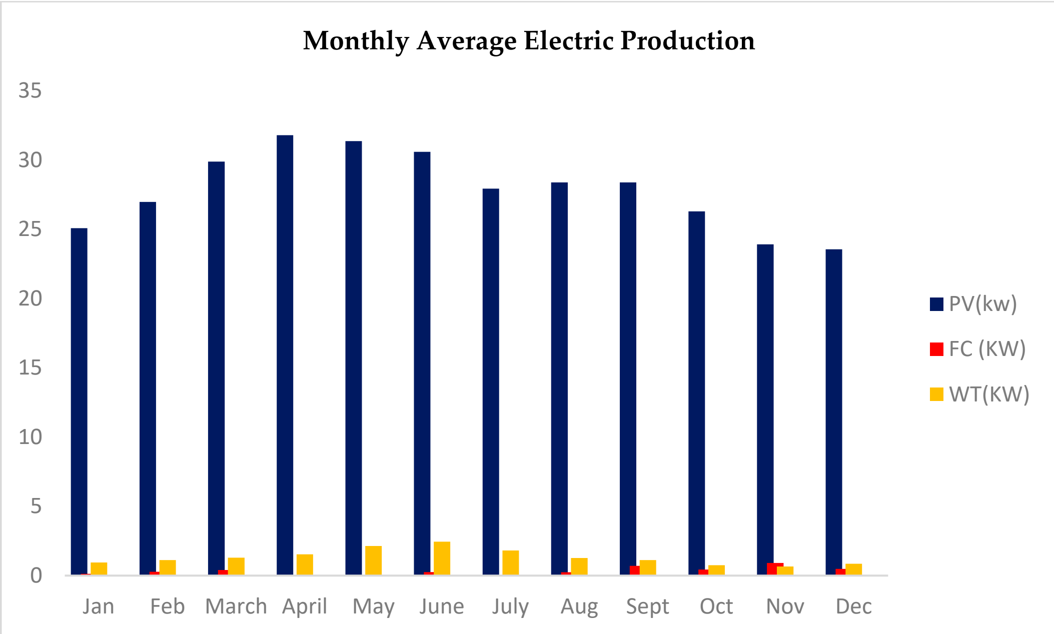

Figure 7. Estimated monthly electricity produced by each component of the off-grid hybrid system.

Table 5. Pricing description of the ideal hybrid off-grid energy systems.

Components	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Fuel cell	120,000	0.00	1710.34	0.00	69,260.56	52,449.78
Electrolyzer	66,000	38,554.97	11,877.37	0.00	10,665.12	105,767.21
PV panel	60,000	0.00	29,693.42	0.00	0.00	89,693.42
HTank	36,000	0.00	11,877.37	0.00	0.00	47,877.37
Battery	76,800	54,156.65	71,264.21	0.00	16,390.20	185,830.66
Converter	48,000	0.00	23,754.74	0.00	0.00	71,754.74
WT	3200	0.00	1583.65	0.00	0.00	4783.65
System	410,000	92,711.62	151,761.08	0.00	96,315.88	558,156.82

4.2. Grid-Connected Hybrid Energy System

Table 6 displays the optimizing outcomes for a grid-connected hybrid energy system when the whole surface was considered. The ideal hybrid energy system configurations have an NPC with COE costs of M$1.24 and $0.108, respectively. The ideal setup includes 600 kW photovoltaic panels, 610 kW wind turbines, a 300 kW fuel cell, a 600 batteries, and a 999,999 kW grid connection, as seen in Table 6.

Table 6. Outcomes of PV/WT/FC grid-connected optimization.

PV (kW)	WT (kW)	FC (kW)	EL (kW)	HTank (kg)	Battery(s)	Grid (kW)	Converter (kW)	COE ($)	NPC (M$)	Disp
600	60	300	300	300	600	999,999	155	0.108	1.24	CC
600	60	300	300	300	600	999,999	155	0.109	1.25	LF

Table 7 displays the yearly electricity production by each element of the ideal hybrid power system's architecture. It can be observed that the solar (PV) system accounts for a larger portion (93.4%) of energy production, wind turbines produce 6.64%, and fuel cells produce 0% because of grid connection. The grid contribution, however, is 0% because the energy produced is sufficient and there is no need to purchase electricity from the grid; in fact, the excess electricity is sold to the grid. This demonstrates that, in contrast with the present circumstance, when electricity is purchased from the grid roughly at the rate of $0.080, the electricity purchased from the grid is $0.16, and electricity is preserved. Figure 8 displays the estimated monthly amount of electricity produced by each power source in its ideal arrangement. Table 8 displays the overall cost breakdown of several elements of the ideal design throughout its lifespan. Such a table gives the impression that perhaps the NPC of such infrastructure has the most share of the overall cost of the grid including the WT, FC, and PV modules.

Table 7. The yearly electricity output of the best hybrid grid-connected energy system.

Production	kWh/Year	%
Generic flat plate PV	979,167	93.4
Fuel cell	0	0
Wind turbine	69,594	6.64
Total	1,048,760	100

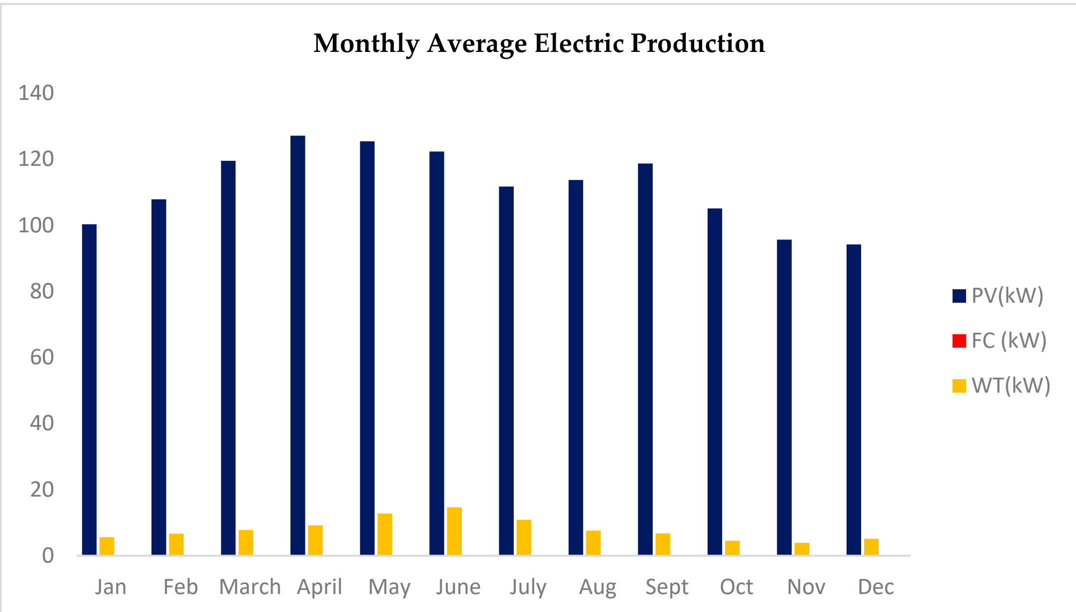

Figure 8. Estimated monthly electricity produced by each component of the grid-connected hybrid system.

Table 8. Pricing description of the ideal hybrid grid-connected energy systems.

Components	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Fuel cell	600,000.00	0.00	0.00	0.00	370,293.31	229,706.69
Electrolyzer	330,000.00	193,809.11	59,642.51	0.00	53,803.30	529,648.32
PV panel	240,000.00	0.00	119,285.02	0.00	0.00	359,285.02
Grid	0.00	0.00	771,216.12	0.00	0.00	771,216.12
HTank	180,000.00	0.00	59,642.51	0.00	0.00	239,642.51
Battery	192,000.00	0.00	178,927.53	0.00	0.00	370,927.53
Converter	124,800.00	88,924.18	62,028.21	0.00	24,686.22	251,066.17
WT	19,200.00	0.00	14,314.20	0.00	0.00	33,514.20
System	1,686,000.00	282,733.29	277,376.13	0.00	44,8782.84	1,242,574.32

5. Conclusions

In this study, HOMER was used to simulate interconnected hybrid energy systems for remote areas that are either grid-connected or standalone. The simulation findings indicate that grid-connected hybrid energy systems are significantly superior to standalone integrated hybrid energy systems in terms of performance. The PV, WT, and FC on-grid hybrid energy systems, which consist of 600 kW of PV panels, 610 kW wind turbines, a 300 kW fuel cell, a 155 kW converter, a 600 battery, and a 999,999 kW grid support, are demonstrated to be the most efficient and ideal design for meeting the remote area's energy demands. To satisfy the requirements, this hybrid renewable energy system optimization generates 95,805 kWh of electricity. Additionally, photovoltaic energy systems account for 93.4% of all electricity production, whispering wind turbines provide 6.64% of the required power, and fuel cells generate 0% because of grid connection. The optimum hybrid renewable energy systems' NPC and COE are determined to be M$1.24 and $0.108, respectively. Such findings may help electricity planners and those who make judgment calls and choose the best hybrid power generation systems for a remote area in Jamshoro with comparable power demand and topographical circumstances to conserve electricity and encourage the usage of renewable technology.

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