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Research article

Exploring synergistic ecological and economic energy solutions for low-urbanized areas through simulation-based analysis

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Abstract: In this study, we assess the feasibility of a Hybrid Renewable Energy System (HRES) for the residential area of Hengam Island, Iran. The optimal system design, based on the analysis of minimum CO_2 emissions, unmet electric load and capacity shortage, reveals that a hybrid system consisting of 12,779,267 kW (55.8% of production) of solar PV panels and 10,141,978 kW (44.2% of production) of wind turbines is the most suitable for this case study. This configuration ensures zero CO_2 emissions and high reliability over a 25-year project lifetime, with an unmet electric load of 164 kWh per year and a capacity shortage of 5245 kWh per year. However, this case has a high initial cost of equipment, with a Total Net Present Cost (TNPC) of $54,493,590. If the power grid is also used for energy exchange with the island, TNPC can be significantly reduced by 76.95%, and battery losses can be reduced by 96.44%. The proposed system on the grid can reduce carbon emissions to zero, making it highly environmentally compatible. The sale of excess electricity produced to the power grid creates an energy market for the island. Given the weather conditions and the intensity of the sun in the studied area, the area has very suitable conditions for the exploitation of renewable energies. Transitioning the residential sector towards renewable energies is crucial to overcome energy crises and increasing carbon emissions. Increasing renewable equipment production and improving technology can address the challenge of high prices for renewable energy production.

Keywords: energy hub optimization; economic analysis; CO_2 emission; TNPC; HRES

Nomenclature: TNPC: Total net present cost ($); LCOE: Levelized cost of energy ($/kWh); TAC: Total annualized cost ($/year); PV: Photovoltaic; WT: Wind turbine; BESS: Battery energy storage system; RESs: Renewable energy sources; HOMER: Hybrid optimization of multiple energy resources; AES: Annual energy served (kWh/year); f_{PV}: Derating factor (%); G_T: Solar radiation incident on the PV array (kW/m^2); $G_{T,STC}$: The incident radiation at standard test conditions (1 kW/m^2); K_p: Temperature coefficient of power (%/°C); T_C: PV cell temperature (°C); $T_{C,STC}$: PV cell temperature under standard test conditions (25 °C); $PV_{poweroutput}$: PV electricity generated from the solar system (kW); $P_{pv,STC}$: The output power of the PV panels in the standard conditions (kW); U_{hub}: Wind speed at the wind turbine hub height (m); U_{wsah}: Wind speed at anemometer height (m/s); Z_{hub}: Wind turbine hub height (m); Z_{wsah}: Anemometer height (m); α: Power-Law exponent; P_{WT}: Output power of wind turbine (kW); $P_{WT,STP}$: Wind power output at standard temperature and pressure (kW); ρ: Actual air density (kg/m^3); ρ_0: Air density at standard temperature and pressure (1.225 kg/m^3); $\frac{\rho}{\rho_0}$: Density ratio; $P_{BESS,\mathrm{cmax}}$: The maximum amount of power that can be absorbed by the battery system (kW); $P_{BESS,cmax,kbm}$: The maximum power that can be stored based on kinetic battery model (kW); $P_{BESS,dmax,kbm}$: The maximum discharge power of the battery (kW); $P_{BESS,cmax,mcr}$: The storage charge power corresponding to the maximum charge rate (kW); $P_{BESS,cmax,mcc}$: The storage charge power corresponding to the maximum charge current (kW); η_{BESS}: The battery efficiency (%); k: The storage rate constant $(h)^{-1}$; Q_1: The available energy in storage at the beginning of the time-step (kWh); Δt: The length of the time-step (h); Q: The total amount of energy in storage at the beginning of the time-step (kWh); C: The storage capacity ratio; Q_{max}: The total capacity of the storage system (kWh); α_c: The battery maximum charge rate (A/Ah); N_{BESS}: The number of batteries in the storage bank; I_{max}: The storage maximum charge current (A); V_{nom}: The storage nominal voltage (V); $P_{inv,out}$: The power output of the inverter (kW); η_{inv}: The inverter efficiency (%); P_{DC}: DC power input (kW); $P_{rec,out}$: The power output of the rectifier (kW); η_{rec}: The rectifier efficiency (%); P_{AC}: AC power input (kW); $CRF(i,n)$: The capital recovery factor; i: Real interest rate (%); i': Real nominal rate (%); n: The project life-time (year); f: The inflation rate (%)

1. Introduction

On-grid energy systems are connected to the utility power grid, allowing surplus energy to be fed back into the grid and reducing energy costs through net metering. Off-grid energy systems are self-sufficient and not connected to the grid, relying on RESs and battery storage. Hybrid power systems combine multiple RESs with or without backup Diesel Generator (DG), aiming to increase reliability, reduce pollution and optimize energy consumption. Energy storage systems are commonly used in off-grid systems to enhance reliability. Due to difficult geographical terrain, the spread of carbon dioxide emissions, fast exhaustion of fossil fuels and high costs of electricity transmission, off-grid electricity generation and hybrid power networks containing some RESs such as biomass, wind and PV have been considered as methods for energy supply in remote or rural areas [1–13]. Under these conditions, the development of these remote areas will be accelerated using RESs, with or without DG.

Additionally, battery banks and DG are employed to enhance reliability in such systems. Since determining the optimal size of HRES is a crucial challenge in designing such a hybrid system, HOMER is used for cost-effective modeling of HRES [14]. When most countries around the world decided to generate their required electricity using fossil fuels in power plants, it led to an increase in annual CO_2 emissions [15–27]. However, the implementation of RESs in many countries will help reduce the level of this gas and enhance the reliability of the local grid [28–30]. The utilization of HRES has gained popularity and proven to be a fitting choice for interconnected power networks to cope with fossil fuel depletion and emissions [31]. While determining the optimal size of this type of system is considered a critical challenge in its design and modeling, it is addressed by HOMER [32]. Many researchers have investigated HRES using HOMER for the design and techno-economic analysis of such systems. Singh, Nagendra et al. [33] have simulated a combination of PV/WT/DG hybrid systems using HOMER to cater to the load profile of an Indian telecommunication place. This research presents how a hybrid power network can be created using different combinations to meet the required load demand. Salehin, Sayedus et al. [34] have modeled two RESs, namely PV/DG and WT/DG systems, using HOMER modeling framework as a proposed solution for a small area in Kutubdia Island, Bangladesh. Khosravani, Ali et al. [35] have conducted technical-economic feasibility studies of HRES for determining the Levelized Cost of Energy (LCOE) and the social cost of electricity (SCOE) for four sample locations in the United States. They considered different carbon tax levels, assessed the economic worth of health advantages derived from reduced emissions, and examined the proportion of renewables dependent on solar and wind energy combined with battery storage at an operational scale as a backup for providing hourly load using HOMER for simulation purposes. Jyoti Ranjan Baral et al. [36] simulated economic modeling and analysis of an islanded micro-grid for Bhubaneswar, India, comprising PV/DG/BES, was conducted to evaluate the current net cost using HOMER Pro software. Makbul A.M. Ramli et al. [37] simulated the configuration of three different systems containing DG, energy storage, PV and flywheel using HOMER. The findings indicate that the hybrid system combining PV, diesel, battery and flywheel technologies possesses the most favorable combination of low COE and reduced CO_2 emissions. Bortolini, Marco et al. [38] conducted a study using HOMER to simulate the integration of a PV power plant and a BES with conventional DG for off-grid applications. In the Caribbean region of Colombia, Antonio Barrozo Budes, Farid, et al. [39] proposed a HRES plant using HOMER. The plant incorporates parallel-connected PV systems and grid-connected WT. This hybrid power plant is capable of meeting a portion of the overall electricity requirement while mitigating the environmental impacts associated with traditional energy production. Sreenath et al. [40] used HOMER Pro designing a HRES for a campsite in Royal Belum State Park, Malaysia. The aim was to assess the viability of various arrangements of the systems. For economic performance, the PV/DG/BES demonstrated superior results compared to other arrangements, exhibiting the minimum cost of electricity, maximum profit and shortest payback duration. Guelleh, Houssein et al. [41] proposed the optimal combination of a HRES for a residential building in Tadjoura. They utilized HOMER to find the suitable economically viable HRES by incorporating actual data of solar radiation and wind speed. The output of this study presented that the best economically viable mixture for the HRES is a grid-connected PV/WT system. Balachander et al. [42] conducted a research study to optimize and simulate a hybrid power grid and provide electricity demand of a residential complex located in India. They considered the household load pattern with energy consumption supplied for different electricity consumptions by a combination of WT/DG/PV systems. Various analyses, such as net present value, energy cost, surplus energy generated by individual system components and pollution generated, were evaluated and analyzed. Halabi, Laith et al. [43] simulated power plants in Subang with various mixture of DG/PV/BES using HOMER. They analyzed the operational behaviors of various levels of PV penetration to determine the quantitative impacts of PV integration, technical and economic constraints, environmental considerations and load profile results with the least LCOE and net present cost. Iman Rahimi et al. [44] evaluated the feasibility of utilizing solar and wind energy in different cities. They compared ten types of buildings, including hospitals, hotels, offices, shopping centers, standalone clinics, independent retail stores, apartments, supermarkets, schools and warehouses, using HOMER. The study promoted the use of HRES in the studied locations, which led to a reduction in the effect of Australia on global warming. Laura Tribioli et al. [45] have designed a multi-generational solar-based micro-grid with multiple storage technologies for an isolated system. They evaluated the effectiveness of an energy management strategy using HOMER in eight different climatic regions in the United States. Increasing prices, depletion, pollution and global warming are among the problems associated with fossil fuels. Therefore, the use of RESs for energy production is of paramount importance. RESs are clean and cause minimal damage to the environment. Moreover, they are inexhaustible and can be utilized for generations to come. One of the challenges facing RESs is their intermittency and their unavailability in all regions. Solutions to address the energy intermittency challenge in RESs include hybridizing different sources with each other and combining them with high-reliability backup systems such as the power grid and batteries. In this research, the main purpose to provide electricity through a hybrid system of hybrid battery, wind and solar and sell surplus energy to the grid by promoting the implementation of a HRES in Hengam Island. The motivation for this study is to evaluate the financial benefits of hybrid systems, pollution emissions and power quality. In this study, not only is the electricity consumed by consumers supplied by RESs such as wind and solar but also the excess electricity is sold to the grid. The HOMER software is used to assess the feasibility of installing a HRES. An economically viable and optimally sized energy source that has the lowest emissions and the highest reliability will fill a crucial gap. Therefore, we aim to perform a technical-economic analysis of a hybrid system to ensure pod reliability, minimum emissions and supply of the island's electric load.

The integration of smart communities with renewable energy resources, smart homes and electric vehicles plays a crucial role in providing ancillary services and enhancing the overall efficiency of power systems. A tri-stage optimization mechanism has been proposed to explore the potential of smart communities in delivering ancillary services, utilizing the capabilities of renewable energy resources, smart homes and electric vehicles. This mechanism optimizes the coordination and utilization of these assets, enabling the provision of valuable grid services while ensuring the reliability and sustainability of the power system. Moreover, the resilience of hydrogen fuel station-integrated power systems with a high penetration of photovoltaics has been investigated, highlighting the importance of incorporating renewable energy sources into the power infrastructure to enhance system robustness and reduce dependency on conventional energy sources [46,47].

Effective home energy management is critical in achieving optimal utilization of resources in smart homes. A fully robust home energy management model has been developed, considering real-time price signals and leveraging on-board vehicle batteries to optimize energy consumption. This model maximizes the use of renewable energy, minimizes electricity costs and ensures efficient utilization of available energy resources. Additionally, a tri-layer stochastic framework has been proposed to manage the electricity market within a smart community, considering the presence of energy storage systems. This framework optimizes energy trading and consumption decisions, taking into account uncertainties in renewable energy generation, demand patterns and market dynamics [48–50] .

The optimal scheduling and management of microgrids are crucial for maximizing their potential in leveraging smart buildings and electric vehicle fleets. A three-layer game-theoretic-based strategy has been introduced to enable optimal scheduling of microgrids by harnessing a dynamic demand response program designer. This strategy optimizes the coordination among microgrid participants, taking into account their preferences, objectives and constraints. Furthermore, a three-stage mechanism has been proposed for flexibility-oriented energy management in renewable-based community microgrids with a high penetration of smart homes and electric vehicles. This mechanism optimizes energy generation, storage and consumption, ensuring flexible and reliable operation of the microgrid while accommodating the varying demands and availability of renewable energy [51,52].

Achieving eco-environmental management of the electricity market in the presence of microgrids with high penetration of smart homes, plug-in electric vehicles and energy storage devices is a significant research area. A multi-level multi-objective strategy has been developed to address this challenge, considering the economic, environmental and social dimensions of electricity market management. This strategy optimizes the allocation of energy resources, maximizes renewable energy utilization and minimizes environmental impacts, fostering sustainable and eco-friendly energy practices within microgrids. Additionally, an interval-based nested optimization framework has been proposed to derive flexibility from smart buildings and electric vehicle fleets in the coordination between transmission system operators (TSOs) and distribution system operators (DSOs). This framework optimizes the utilization of flexible energy resources, ensuring reliable and efficient coordination between the TSO and DSO, and enhancing the overall flexibility and resilience of the power system [53–57] .

Managing the electricity market by actively involving smart buildings and electric vehicles is essential for the development of smart cities with active end-users. A four-stage stochastic framework has been introduced to enable effective electricity market management, considering the participation of smart buildings and electric vehicles. This framework integrates demand response programs, market dynamics and uncertainties in renewable energy generation, enabling efficient resource allocation, price determination and demand response activation. By involving end-users in the electricity market, this approach promotes energy efficiency, grid stability and active involvement of consumers in shaping the future energy landscape of smart cities [58].

Paper [59] presents a particle swarm optimization (PSO) algorithm for the optimal design of grid-connected photovoltaic-wind hybrid energy systems. This algorithm uses real hourly data of wind speed, solar radiation, temperature and electricity demand at a specific location. The PSO algorithm has been used to obtain the minimum cost of the generated energy while matching the electricity supply with the local demand with a specific reliability index.

In [60], HRES measurement is done by dividing the load into high and low priority segments. The proposed system is composed of a photovoltaic array, wind turbines, batteries, fuel cells and a diesel generator as a backup energy source. A smart particle swarm optimization (PSO) algorithm using MATLAB is introduced to determine the optimal size of HRES. Simulations with and without load sharing was done to compare these concepts. Also, HOMER software was used to simulate the proposed system without dividing loads to confirm the results obtained from the proposed PSO algorithm.

The paper [61] introduces an optimal metering algorithm for a hybrid renewable energy system using a smart grid load management program based on available generation. The goal of this algorithm is to maximize system energy production and meet load demand with minimum cost and highest reliability. This system consists of photovoltaic array, wind turbines, storage batteries and diesel generator as a backup source of energy.

The paper [62] uses a new proposed design and optimization program for techno-economic measurement of PV/wind/diesel/battery hybrid energy systems under smart grid theory for the lowest cost of energy produced with the highest reliability.

A very important issue in reducing the consumption of electricity, including that from fossil fuels and the emission of harmful substances into the air, is the use of low-emission energy generation technologies and devices enabling, among others, energy transmission over long distances. Increasing the usability, operating time and reliability of devices used in industry is also a very important problem for world economies. Also, from the point of view of sustainable development of less urbanized areas where access to conventional energy sources is difficult, it is important that the new energy generation systems from renewable sources installed are reliable and their operation time can be extended. The use of low-emission technologies with high energy efficiency is becoming a need on a global scale and requires an interdisciplinary and innovative approach to the process of designing technologies enabling the production, transmission and consumption of electricity. This approach to the design and implementation process gives good results not only financially, but also makes it possible to minimize the costs of generating electricity itself, as well as to minimize the emission of harmful substances into the environment. An innovative and interdisciplinary approach to design and implementation processes should provide, and in many cases already does, the possibility of diversification in obtaining new sources of electricity with a significant reduction in pollution to the natural environment. It should be noted that the analyses conducted in this article may (taking into account local conditions) be used in other places in the world, e.g. in Poland [63–78].

There are certain potential limitations associated with modeling and simulation that should be considered. These limitations can impact the feasibility of applying the proposed approach in practical engineering.

1. Assumptions: Modeling and simulation often rely on simplifying assumptions to make the problem computationally tractable. However, these assumptions may not always hold in real-world scenarios. It is crucial to assess the impact of these assumptions on the accuracy and applicability of the results obtained from the simulations.
2. Model Validity: The accuracy of any simulation heavily depends on the validity of the underlying mathematical model. If the model does not accurately represent the real system, the simulation results may not reflect the actual behavior. Therefore, it is important to validate the model against empirical data or experimental results to ensure its reliability.
3. Parameter Estimation: Simulation models often require input parameters, which may not be known precisely in practice. Estimating these parameters can introduce uncertainties that propagate through the simulation, potentially affecting the reliability of the results. Robust methods for parameter estimation and sensitivity analysis should be employed to address this limitation.
4. Computational Resources: Complex simulations can be computationally intensive and require significant computational resources. This may limit the feasibility of applying the proposed approach in practical engineering, especially when real-time or near-real-time simulations are required. Efficient algorithms and hardware resources need to be considered to overcome this limitation.

5. Model Complexity: As the complexity of the system increases, modeling and simulating all aspects accurately can become challenging. Simplifications and abstractions may be necessary, but they can introduce potential inaccuracies. Proper validation and verification processes should be followed to ensure that the simplified model is suitable for addressing the engineering problem at hand.

Feasibility in practical engineering relies on mitigating these limitations. It is crucial to carefully assess the validity and accuracy of the simulation model by comparing its results with real-world data or experimental measurements. Sensitivity analyses and uncertainty quantification techniques can help evaluate the robustness of the simulation results. Furthermore, the computational efficiency of the simulations should be considered to ensure that they can be executed within practical timeframes.

This research makes the following key contributions:

1) Addressing Electricity Shortage Challenges: The study proposes a novel HRES connected to the grid to tackle the electricity shortage challenges faced by Hengam Island. By integrating renewable energy sources with the grid, the HRES provides a reliable and sustainable solution to meet the island's electricity demand.

2) Sizing of Interconnected HRES Components: The research focuses on determining the optimal sizing of interconnected components within the HRES, including PV panels, BES and WT. By accurately sizing these components, the HRES can effectively harness renewable energy resources and meet the electricity demand of the island.

3) Consideration of Economic, Technical and Environmental Aspects: The study takes into account various factors, such as economic feasibility, technical viability and environmental sustainability, when determining the optimal hybrid system configuration. This comprehensive analysis ensures that the chosen HRES design is not only economically viable but also technically efficient and environmentally friendly.

Utilization of Batteries for Enhanced Reliability: The research emphasizes the use of BES within the HRES to improve system reliability. By incorporating BES, the HRES can store excess energy generated during peak production periods and utilize it during periods of low renewable energy generation. This enhances the reliability of the system and ensures a consistent power supply for the residents of Hengam Island. These contributions collectively highlight the significance of the research in addressing electricity shortage challenges, optimizing renewable energy system design and considering economic, technical and environmental factors for the development of a sustainable energy solution on Hengam Island.

2. Motivation

The provision of dependable, high-caliber electricity is an indispensable element for any geographical region or island. In this milieu, power systems are pivotal in the energy supply chain, with renewable energy surfacing as a compelling prospect for attaining zero carbon dioxide emissions. In this research, we are not merely focused on fulfilling all electricity requirements through an absolute dependence on renewable energy, but also aims to construct a resilient energy market by capitalizing on the excess production of renewable energy. In the absence of a power grid, the implementation of battery energy backup systems becomes imperative to cater to the electrical load. The capacity of the battery is meticulously selected to optimize the storage of surplus renewable energy production, thereby ensuring both reliability and economic feasibility. The excess electricity is then lucratively sold to the power grid, thereby generating an additional revenue stream for the island. One of the cardinal objectives of this research is to promote environmental sustainability by eradicating carbon dioxide emissions. Concurrently, it aspires to inaugurate a novel energy market by vending the excess load generated to the grid, thus creating a revenue stream for the island. To augment reliability, this study advocates for the amplification of renewable systems production, which not only bolsters environmental sustainability but also entices new investors in this domain. In conclusion, the advancement of renewable energy for energy supply emerges as one of the quintessential solutions for fostering environmental sustainability and economic growth.

The structure of this research study is arranged as follows: Chapter 3 describes the energy demands of the island. Chapter 4 discusses the methodology used in this study. Sections 5 and 6 present the results and compare the outcomes. Finally, chapter 7 provides the conclusion of the paper.

3. Energy demand on Hengam Island

The solar, wind and temperature data used in this study were obtained using HOMER. Input information about the longitude and latitude of the study area is given to HOMER, and then the information is downloaded from the World Energy Source (POWER) using the NASA forecast. Thus, solar data (monthly average for the global horizon over a 22-year period July 1983–June 2005), wind data (monthly average wind speed at 50 m above ground over a 30-year period January 1984–December 2013) and temperature data (monthly average air temperature over a 30-year period January 1984–December 2013) have been downloaded which are shown in Table 1.

Table 1. Average radiation, speed and temperature of Hengam Island, Iran.

Month	Daily radiation (kW/m^2/day)	Wind speed (m/s)	Temperature (c)
Jan.	3.640	5.170	18.510
Feb.	4.470	5.860	19.640
March	5.180	5.660	22.910
Apr.	6.430	5.730	27.780
May	7.360	6.320	32.470
June	7.510	6.120	34.520
July	6.940	5.880	35.340
Aug.	6.580	5.670	34.580
Sep.	6.160	5.490	32.550
Oct.	5.130	5.050	29.130
Nov.	3.980	4.580	24.820
Dec.	3.390	5.150	20.520

According to the energy status of Hemgan Island and the potential of renewable energy production, some studies have evaluated the potential of solar and wind energy to optimize the hybrid system. The location of the study and the average data of radiation, wind and temperature in the island of Heng are shown in Figure 1 and Table 1.

The temperature of the island ranges from 18.5 degrees Celsius in January to 35.34 degrees Celsius in July. The hottest months are from May to September, with temperatures consistently above 30 °C. The coldest months are January and December with temperatures below 20 degrees Celsius. The temperature gradually increases from January to July and then starts to decrease by December. The wind speed on this island varies from 4.58 m/s in November to 6.32 m/s in May. The highest wind speed occurs from April to June with an average speed of 6.04 m/s. The lowest wind speed occurs from October to December with an average speed of 5.29 m/s. Daily radiation on the island ranges from 3.39 kW/m^2/day in December to 7.51 kW/m^2/day in June. The highest radiation occurs from May to July with an average of 7.27 kilowatts per square meter per day. The lowest radiation occurs from November to February with an average of 4.13 kW/m^2 per day. In general, the climate of the island is hot and dry, and during the summer months the temperature and radiation are high. Wind speed is moderate throughout the year and is faster in spring and slower in autumn and winter.

Figure 1. Geolocation of Hengam Island, Iran regarding HOMER software.

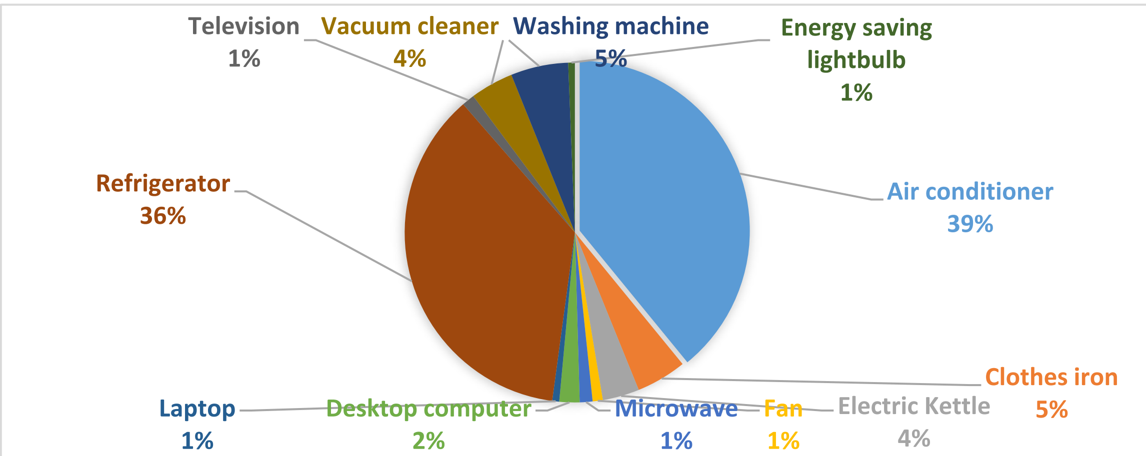

Figure 2. Electricity consumption of household devices: understanding energy usage on Hengam Island [79,80].

The energy demand for residential houses on Hengam Island is highest during the spring and summer seasons due to the hot weather. In July, August and September, the energy demand exceeds the supply, leading to power outages on the island. however, in the winter and autumn seasons, the energy demand is lower due to lower temperatures. The lowest energy demand is in January, February and December, with a consumption of 8486.385 kWh per day. The demand increases by 23.91% in September, October and November, with a consumption of 10515.885 kWh per day. In March and April, the energy demand reaches 14205.885 kWh per day, and in May, June, July and August, it peaks at 23430.885 kWh per day. The electric load profile of household appliances on Hengam Island is evaluated based on the energy consumption of appliances, with air conditioning systems (water coolers) and refrigerators accounting for the highest energy consumption during hot months [81]. Washing machines also consume significant amounts of energy. Meeting the energy demand cost-effectively can allow the island's population of 615 people in 141 households to maintain their traditional lifestyle without compromising their living standards [82]. However, due to the insufficient supply of energy during the summer season, the residents of Hengam Island are forced to adapt to changes in their traditional lifestyle. The table shows the power ratings, hours used and energy consumed per day for various household devices in four different seasons. Figure 2 shows electricity consumption of household devices in Hengam Island.

Table 2. Household energy consumption: Understanding seasonal variations and device usage for efficient energy management [79,80].

		Jan-Feb-Dec		May-Jun-Jan-Aug		Nov-Oct-Sep		Apr-	Mar
Device	Power rating (w)	Hours used (h/day)	Energy consumed (kwh/day)	Hours used (h/day)	Energy consumed (kwh/day)	Hours used (h/day)	Energy consumed (kwh/day)	Hours used (h/day)	Energy consumed (kwh/day)
Air conditioner	3000	0	0	8	14760	1	1845	3	5535
Clothes iron	1100	1	676.5	1	676.5	1	676.5	1	676.5
Electric kettle	1200	0.67	494.46	0.67	494.46	0.67	494.46	0.67	494.46
Fan	75	0	0	4	184.5	4	184.5	4	184.5
Microwave	1000	0.28	172.2	0.28	172.2	0.28	172.2	0.28	172.2
Desktop computer	200	2.21	271.83	2.21	271.83	2.21	271.83	2.21	271.83
Laptop	50	3	92.25	3	92.25	3	92.25	3	92.25
Refrigerator	350	24	5166	24	5166	24	5166	24	5166
Television	70	4	172.2	4	172.2	4	172.2	4	172.2
Vacuum cleaner	2200	0.4285	579.33	0.4285	579.33	0.4285	579.33	0.428	579.33
Washing machine	2200	0.5714	773.055	0.5714	773.055	0.5714	773.055	0.5714	773.055
Energy saving lightbulb	18	8	88.56	8	88.56	8	88.56	8	88.56

The devices include air conditioners, clothes irons, electric kettles, fans, microwaves, desktop computers, laptops, refrigerators, televisions, vacuum cleaners, washing machines and energy-saving light bulbs. In terms of energy consumption, the refrigerator is the highest consumer of energy, followed by the air conditioner and the washing machine. On the other hand, the energy-saving light bulb consumes the least amount of energy. The air conditioner is used more frequently in the summer months, with an average of 8 hours per day, whereas it is not used at all in the winter months. similarly, the fan is used more during the summer and less during the winter months. The clothes iron, electric kettle, microwave, desktop computer, laptop, refrigerator, television, vacuum cleaner and washing machine are used for similar hours and consume similar amounts of energy throughout the year. Overall, the table highlights the seasonal variations in energy consumption for different household devices. It also emphasizes the importance of using energy-efficient devices and managing energy consumption to reduce electricity bills and carbon footprint. Table 2 compares energy consumption in different sectors in the Island.

The energy demand on the island is highest during the summer months, from May to August, with a constant demand of 23430.885 kWh per day. This is likely due to the hot weather during this time, which requires the use of air conditioning and other cooling appliances. The energy demand in spring is high, with a demand of 14205.885 kWh per day. This is likely due to the weather beginning to warm up during this time, which also requires the use of cooling appliances. The energy demand during the fall months, from September to November, is lower than during the summer and spring months, with a constant demand of 10515.885 kWh per day. This is likely due to the weather beginning to cool down during this time, which reduces the need for cooling appliances. The minimum energy demand is in winter and the beginning two months of the spring, with a demand of 8486.385 kWh per day. This is likely due to the cooler weather during this time, which reduces the need for both cooling and heating appliances. Figure 3 shows energy demand variation in different seasons in the Island [79,80].

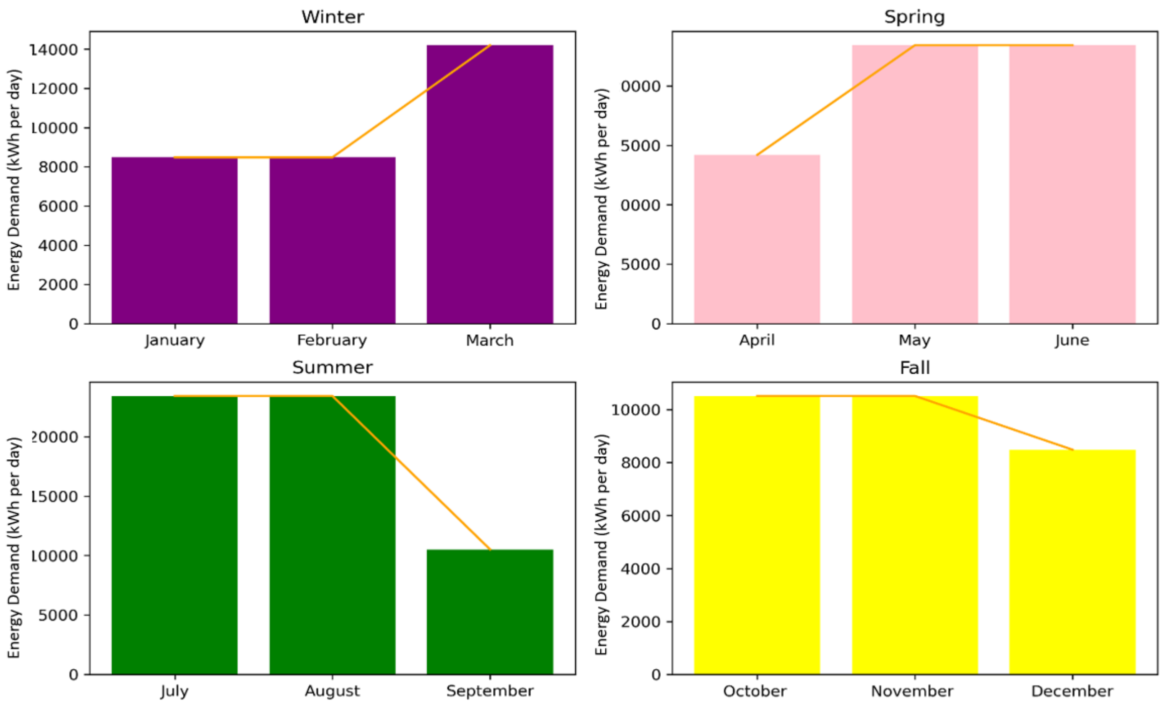

Figure 3. Energy demand fluctuations throughout in the year 2022 in Hengam Island.

4. Methodology

The first step of this research is the evaluation of RES and the power grid. The second step is to estimate the load of the island. In this research, it has been tried to supply the load of the island from renewable systems and networks in order to have the least amount of excess electricity and load without service. Also, batteries are used as the power grid to increase the reliability of the island system and have the least load shortage in the island. Optimization in HOMER Pro x64 has been simulated for 25 years using hourly steps to meet electricity demand with the lowest TNPC, emissions and increased reliability in different scenarios.

The methodology employed in this study is centered around HOMER, a software that determines the optimal size of each component within a HRES. The simulation framework, as depicted in Figure 4, utilizes two optimization algorithms within HOMER Pro: the original grid search algorithm, which simulates all applicable system configurations defined by the search space, and the HOMER Optimizer, which employs a proprietary derivative-free algorithm to search for a cost-effective system. For an in-depth understanding, one may refer to the HOMER technical documentation. The primary objective of this study is to conduct a comparative analysis of all potential HRESs to ascertain the optimal configuration. Figure 5 delineates the various factors employed for comparing HRESs. These factors encompass location, renewable sector, cost parameters (including capital, replacement, operating and maintenance costs), constraints and outcomes. The outcomes are further categorized into cost, emissions, contribution of each energy component, excess electricity produced, unmet electric load, capacity shortage and battery condition (including battery losses). It is noteworthy that upon identifying the various factors, the methodology adheres to the process outlined in Figure 4 to obtain and compare the results. This comprehensive approach ensures a thorough evaluation of the HRESs, thereby facilitating the identification of the most efficient and sustainable configuration.

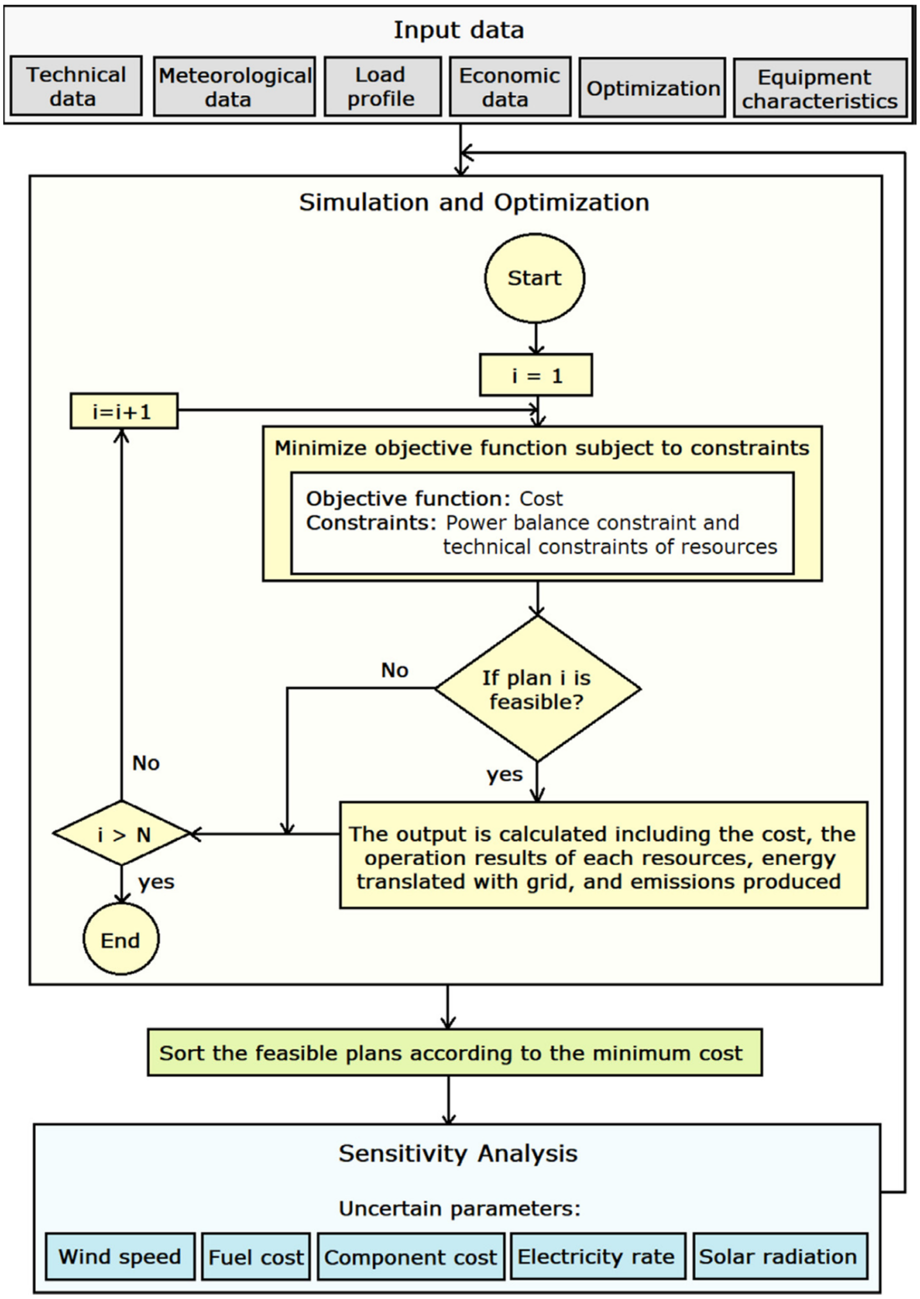

Figure 4. The comprehensive framework of the HOMER simulation procedure [35].

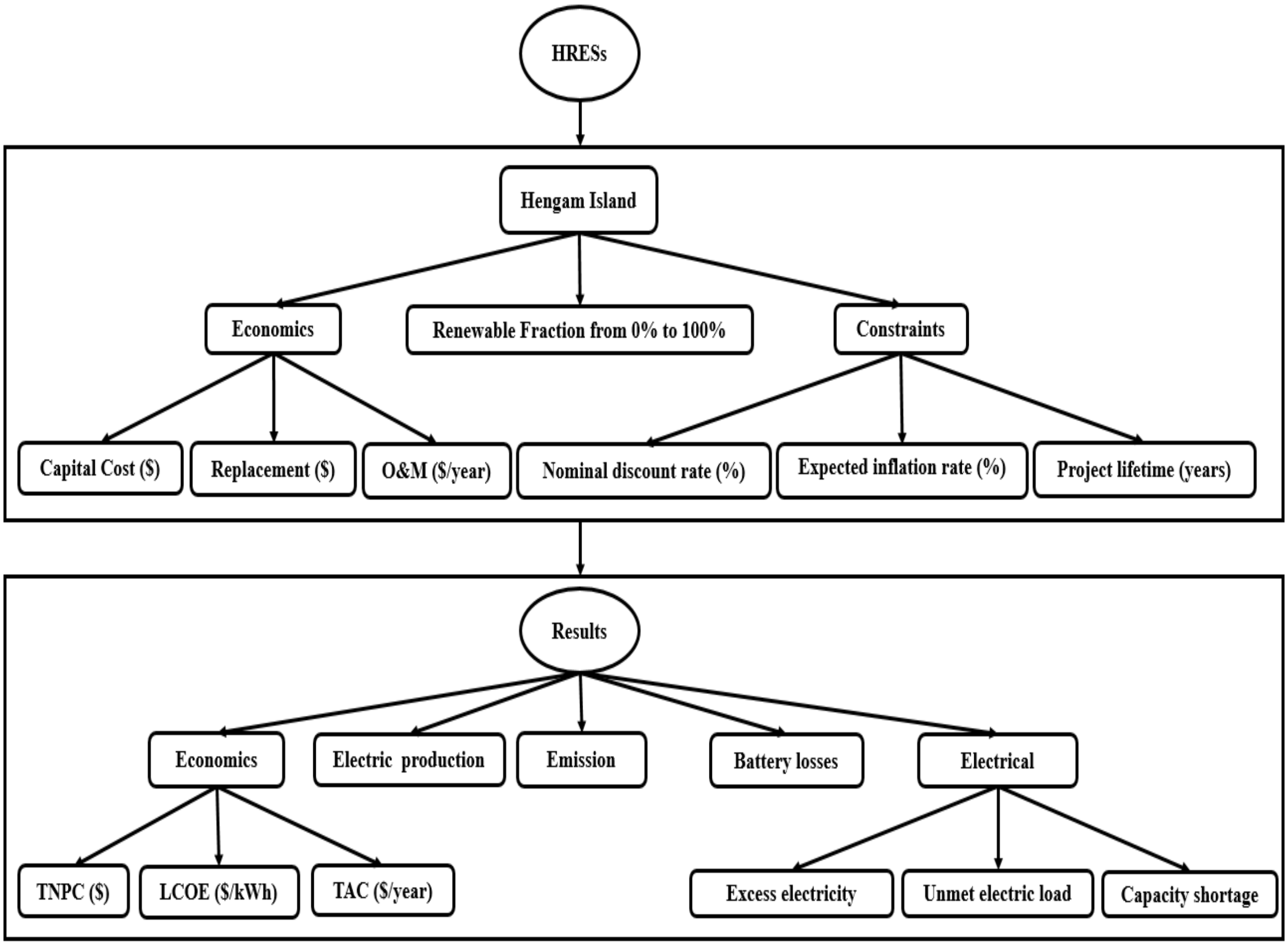

Figure 5. The factors that HRESs are compared to each other based on.

4.1. PV modeling

The sun is one of the most potent sources of light. Photovoltaic (PV) systems can harness solar energy and convert it into electrical energy. The power output of a PV system depends on factors such as global solar radiation, PV panel temperature and the PV rating factor. The PV rating factor is a scaling factor that considers the impact of various losses on the output power of the PV module, relative to the ideal expected output. These losses account for factors that reduce the efficiency of the PV system. In this study, a generic flat panel PV with a capacity of 1 kW and a reduction factor of 80% was used. The reason for using this type of specification for PV is its ease of access in the study area. The average solar radiation of the island in kilowatt hours per square meter per day is shown in Figure 6. The following equation is used to evaluate the output of PV panels [82].

$$PV_{poweroutput} = P_{pv,STC} f_{pv} \frac{G_T}{G_{T,STC}} \left[1 + K_p \left(T_C - T_{C,STC}\right)\right] \tag{1}$$

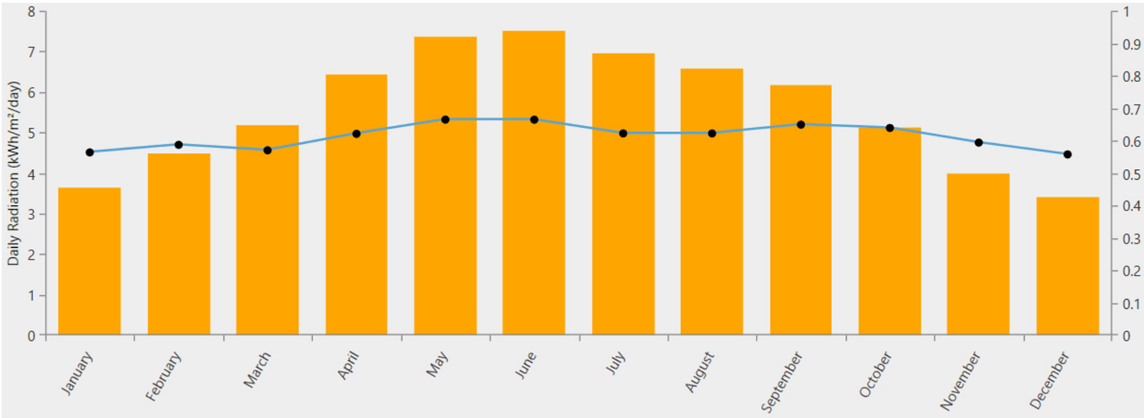

Figure 6. Shining bright: Daily solar radiation on Hengam Island, Iran.

Also, the capital cost and replacement cost of solar panels are considered to be 1420.7 and 1420.7 dollars per kilowatt, respectively. The cost of operating and maintaining the panels is $30.2 per kilowatt per year. 20 years is considered as the lifespan of solar panels.

4.2. Wind turbine modeling

WT converts wind energy into electricity. The power produced by WT depends on factors such as wind direction, air density, local topography, altitude, roughness coefficient of the ground and the temperature of the place where the turbine is installed. Figure 7 shows the average wind speed on the island when outputting from the Homer software. In this simulation, an ideal WT is considered. Electricity losses and repairs are not considered. According to the information downloaded from the NASA website, the speed that gives us the power to produce WT is 4 meters per second. In this case, the output power is 0.06 kW. The critical speed preferred for the WT to produce no power is 24 m/s. This comparison of power generation speed and WT risk speed is shown in Figure 8. HOMER software for WT modeling first converts the kinetic energy of the wind into electricity through the power curve, which is the graph of the output power against the wind speed. At the hub height, the wind source data is first used to determine the average wind speed per hour and uses the height of the anemometer, and then calculates the correlation of the wind speed at the height of the turbine hub using the power. Then, using Laws or logarithms, the turbine power curve must be completed to use the turbine output power for the desired wind speed based on the air density. Finally, there is the air density ratio, which is the ratio of the actual air density to the standard multiplied by the total power output. Power curves generally describe WT performance at standard temperature and pressure (STP) conditions. Then, the HOMER software calculates the output power of the WT by multiplying the air density ratio by the power value estimated by the power curve with air density at standard temperature and pressure (1.225 kg/m^3). The WT used in this study is Generic 1 kW and the hub height is 17 m. Extrapolation of wind speed data (from power law) and wind output power at standard temperature and pressure (PWT, STP) can be calculated as follows [82].

$$U_{hub} = U_{wsah} \left(\frac{Z_{hub}}{Z_{wsah}}\right)^{\alpha} \tag{2}$$

$$P_{WT} = \left(\frac{\rho}{\rho_0}\right) P_{WT,STP} \tag{3}$$

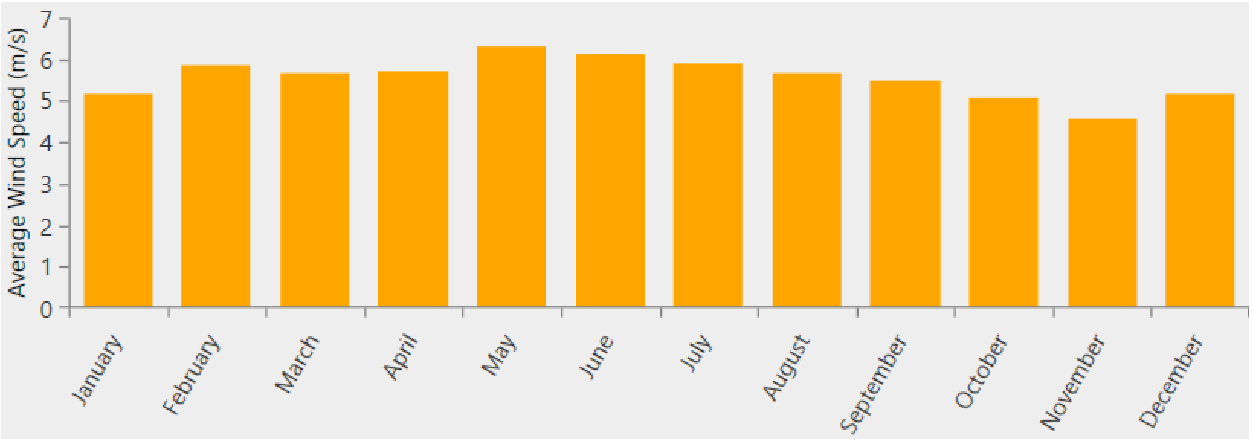

Figure 7. Blowing in the wind: Average wind speed on Hengam Island, Iran.

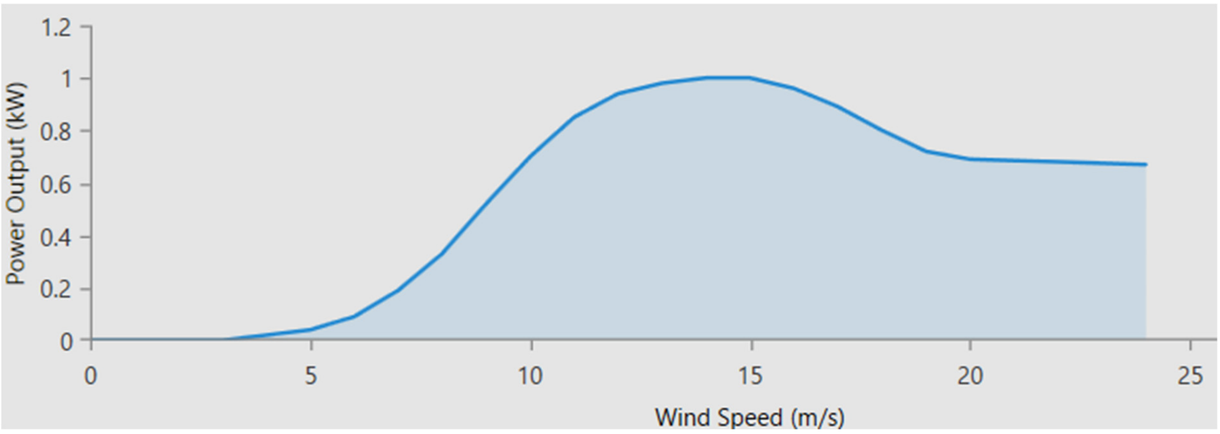

Figure 8. Harvesting wind energy: Power curve analysis for WT on Hengam Island, Iran.

The cost of a WT in this study is $1097 per kilowatt, and the replacement cost is also 1097 dollars per kilowatt. The operation and maintenance cost is $10.97 per year [20]. The WT's lifetime is supposed to be 20 years.

4.3. Battery modeling

A battery is modeled by HOMER as a device that can store a certain amount of DC power with constant energy efficiency. HOMER states that battery characteristics remain constant over time and are not affected by environmental influences such as temperature. Also, the integration of an energy storage system increases reliability during off-grid operation and simplifies the integration of renewable resources into the primary system. In this research, a lead-acid BESS with a nominal voltage of 12 V and an energy capacity of 1kWh has been used. The maximum charging power of BESS can be calculated using the formula presented in the study. Each BESS has a price tag of $800, with replacement costs of $800 and annual operating and maintenance costs of $16. The maximum charge power of the battery, total storage capacity and maximum discharge power of the battery can be calculated as follows [83].

$$P_{BESS,\text{cmax}} = \frac{Min(P_{BESS,cmax,kbm}, P_{BESS,cmax,mcr}, P_{BESS,cmax,mcc})}{\eta_{BESS}} \tag{4}$$

$$P_{BESS,dmax,kbm} = \frac{-kcQ_{max} + KQ_1 e^{-k\Delta t} + QKc(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \tag{5}$$

$$P_{BESS,cmax,kbm} = \frac{KQ_1 e^{-k\Delta t} + QKc(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \tag{6}$$

$$P_{BESS,cmax,mcr} = \frac{(Q_{max} - Q)(1-e^{-\alpha_c \Delta t})}{\Delta t} \tag{7}$$

$$P_{BESS,cmax,mcc} = \frac{N_{BESS} \times I_{max} \times V_{nom}}{1000} \tag{8}$$

4.4. Converter modeling

In an HRES, a converter is necessary to manage and convert the flow of electrical energy between alternating current (AC) and direct current (DC) systems. The output power of the converter can be calculated using the formula presented in the study [82]. The DC output of the PV panel is converted through an inverter. In this research, an inverter is used to convert the DC output of PV panels. The inverter costs $600, the replacement cost is $600 and the maintenance cost is $30 per year. Equations related to the converter are given below [83]. The selection of the photovoltaic converter is a crucial aspect in ensuring the proper functioning of a solar photovoltaic energy production system. To meet the technical requirements of the entire system, the following considerations should be taken into account:

1. Rated Output Power:
   The rated output power represents the capacity of the photovoltaic converter to supply energy to the load. A high-output power PV inverter can handle larger loads. When choosing a PV converter, it is essential to ensure that it has sufficient rated power to meet the electrical demands of the equipment under high loads, accommodate system expansion and support temporary loads.
2. Output Voltage Adjustment Function:
   The output voltage adjustment function refers to the ability to regulate the output voltage of the photovoltaic converter. Typically, PV converters specify the percentage variation in output voltage when the DC input voltage fluctuates within the allowable range, known as voltage regulation speed. Additionally, a high-performance photovoltaic converter should indicate the percentage deviation in the output voltage when the load changes from zero to 100%, which is commonly referred to as load regulation.
3. Overall Efficiency:
   The overall efficiency indicates the power loss within the PV inverter itself. Larger PV inverters provide efficiency values for both full-load and low-load operation. It is desirable to select a photovoltaic converter with high overall efficiency to minimize energy losses during the conversion process.

4. Start Function:
   The PV inverter should reliably start at the rated load. High-performance photovoltaic converters can endure multiple full-time startups without damaging power switching devices and other circuits. Smaller converters sometimes incorporate safety starting mechanisms or current limiting circuits to ensure safe operation.

$$P_{inv,out} = \eta_{inv} P_{DC} \tag{9}$$

$$P_{rec,out} = \eta_{rec} P_{AC} \tag{10}$$

4.5. Economy modeling

Techno-Economic Evaluation of a Hybrid PV-Wind-BESS System for Sustainable Energy Supply. Therefore, the economic analysis of the designed hybrid system deals with the importance of this issue. Simulations performed by HOMER software can provide optimal sizing of renewable components to minimize potential energy source losses as well as minimize TNPC and LCOE. The parameters considered for the calculations are the annual interest rate, the annual inflation rate and the life of the project. NPC is the sum of initial cost, replacement cost, operation and maintenance (O&M) cost and fuel cost. A key element in comparing different scenarios is the LCOE, which depends on the Total Annualized Cost (TAC) and the Annual Energy Served (AES). The following relationship is used to evaluate the techno-economic output of the hybrid system [84].

$$LCOE = \frac{TAC}{AES} \tag{11}$$

$$TAC = CRF(i, n) \times TNPC \tag{12}$$

$$i = \frac{i' - f}{1 + f} \tag{13}$$

$$CRF(i, n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{14}$$

To simulate the renewable energy system, it is important to first design the system architecture. In this case, the system architecture includes various energy sources such as utility, photovoltaic (PV), wind turbine (WT), lithium battery, converter and load, as mentioned earlier. Hengam Island experiences an average daily electric load of 14840.26 kWh and a peak electric load of 1236.92 kW. Figure 9 presents a schematic representation of the proposed system design.

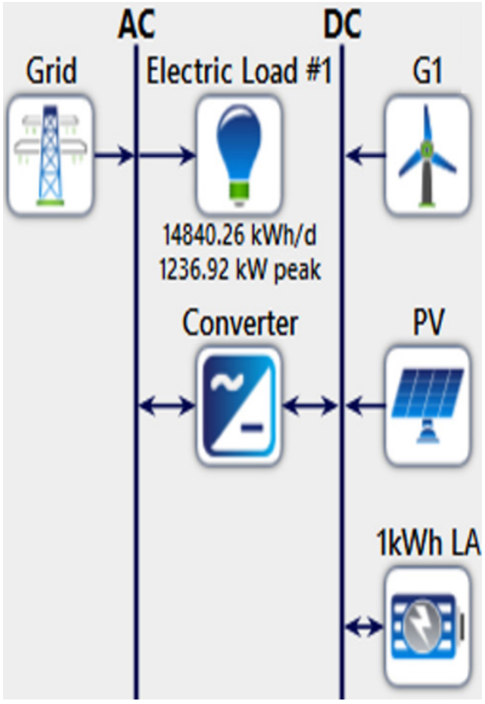

Figure 9. Harvesting wind energy: Power curve analysis for WT on Hengam Island, Iran.

This chapter presents a case study of real data from residential houses on Hengam Island. The first objective is to determine the optimal combination of renewable sources that can minimize the cost of energy supply, reduce emissions, minimize excess electricity and meet the energy demand on the island. Figure 10 shows that the mean outage frequency in 2022 is 2 times per year, with a repair time of 12 hours per outage [85]. The chapter also discusses the effects of operational parameters, particularly the maximum annual capacity shortage and annual purchase capacity, on the system cost, emissions and network reliability. Sensitivity analysis is performed at different levels to allow users to choose the best combination of solutions. For choosing the best mix of system elements and analyzing the impact of storage, four distinct scenarios are under scrutiny. The input for the HOMER software assumes solar power output at 80 percent and wind power output at 50%.

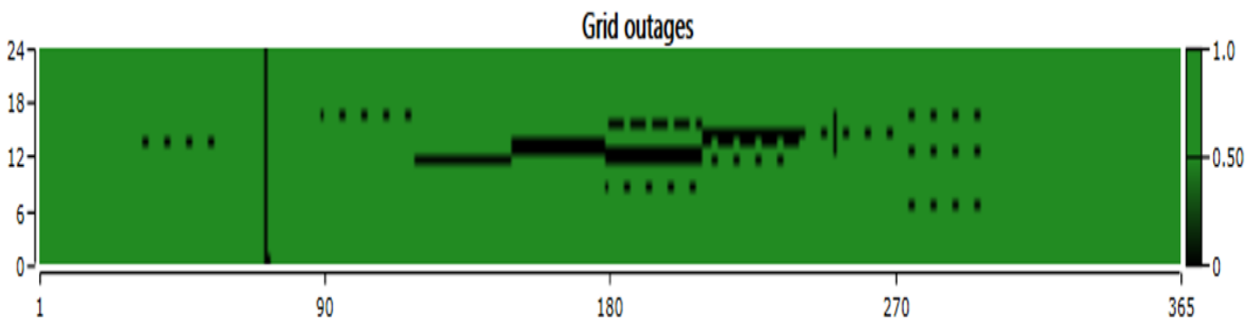

Figure 10. Grid power outage from January 1st, 2022 to December 31st, 2022 on Hengam Island, Hormozgan, Iran.

5. Case studies and modeling

5.1. Base case

In this scenario, the island's electricity demand is entirely met by renewable hybrid systems, which consist of WT and solar panels. The connection between the main power grid and the hybrid systems is used only to sell excess electricity to the grid. The total installation cost in this scenario is $54,493,590 and the LCOE is $0.4867 per kWh, with a TAC of $2,134,535. The renewable hybrid system produces a total of 22,921,245 kWh of electricity per year. Solar panels account for 12,779,267 kWh per year (55.8%), while WT produce 10,141,978 kWh per year (44.2%). In this scenario, the extra electricity generation is 4,347,166 kWh per year (19%), with an unmet electric load of only 164 kWh per year (0.003%), and a capacity shortage of 5,245 kWh per year (0.0968%). This scenario also results in negative carbon dioxide emissions, with a total of 7,521,816 kWh per year. This indicates that the island is not only using renewable energy to meet its energy demand, but also making a conscious effort to purchase renewable energy, thus preventing carbon dioxide emissions and encouraging others to do the same. The annual revenue generated by selling extra energy to the power network in this scenario is $123,776. The lifetime throughput of the battery is 7,713,307 kWh, with an energy loss of 344,898 kWh per year due to the difference between input and output energy to the battery. Overall, this scenario demonstrates that it is possible to meet 100% of the island's electricity demand with renewable hybrid systems, which not only reduces carbon dioxide emissions but also lowers the cost of electricity production. By relying on RESs, the island can contribute to a cleaner environment and encourage the use of renewable energy by others. The Figure 11 shows the monthly electricity production in this scenario.

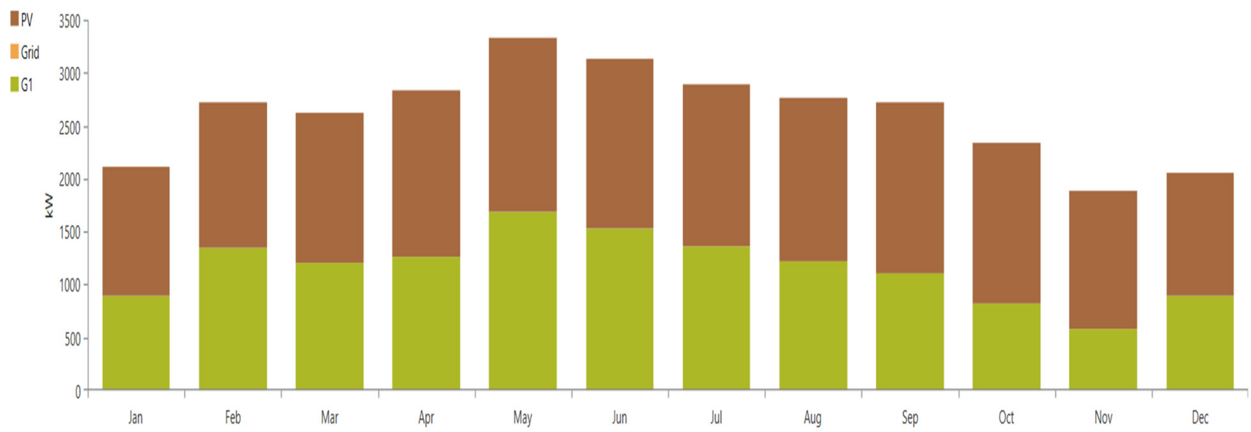

Figure 11. Going green and profitable: monthly average electric production for Base case, achieving 100% renewable energy reliance with profitable excess electricity sales on Hengam Island, Iran.

5.2. Case 1

In this Case, a combination of PV/ WT/BES and the power grid were used to meet the island's electricity demand. The TNPC is $12,559,100, the LCOE is $0.3048 and the TAC is $714,769. The total energy generated in this scenario is 6,818,722 kWh per year, with PV systems accounting for

3,048,576 kWh per year (44.7%), WT producing 1,177,450 kWh per year (17.3%) and the power grid supplying 2,592,697 kWh per year (38%). In this scenario, there is an excess electricity of 232,936 kWh per year (3.42%), an unmet electric load of 3,162 kWh per year (0.0584%) and a capacity shortage of 5,373 kWh per year (0.0992%). As the power grid is also used to meet the island's electricity demand in this scenario, carbon dioxide is produced. The CO_2 emissions in this scenario are 1,032,168 kg per year. The lifetime throughput of the battery in this scenario is 274,463 kWh, with an energy loss of 12,274 kWh per year due to the difference between input and output energy to the battery. The island's electricity demand is met by the power grid/PV/WT in this scenario. The monthly electricity production in this scenario is shown below Figure 12.

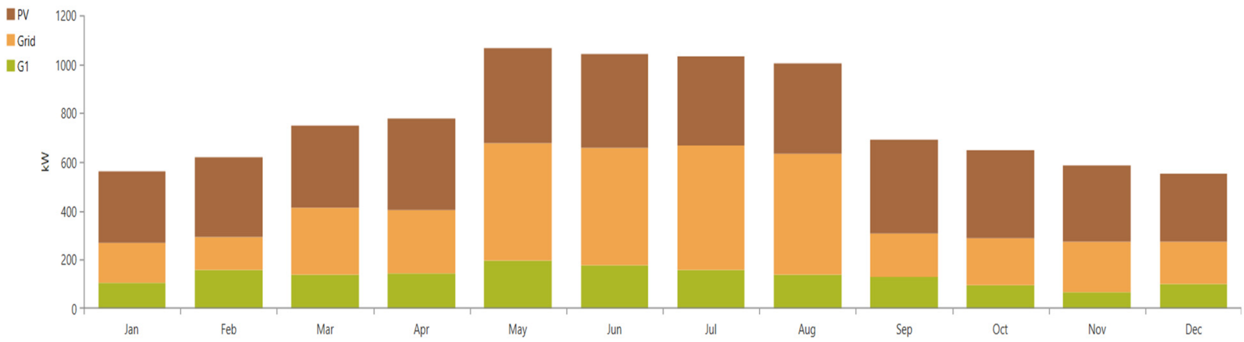

Figure 12. Going green and profitable: monthly average electric production for base Case, achieving 100% renewable energy reliance with profitable excess electricity sales on Hengam Island, Iran.

In this Case, a combination of PV/WT/BES and the power grid were used to meet the island's electricity demand. The TNPC is $12,559,100, the LCOE is $0.3048 and the TAC is $714,769. The total energy generated in this scenario is 6,818,722 kWh per year, with PV systems accounting for 3,048,576 kWh per year (44.7%), WT producing 1,177,450 kWh per year (17.3%) and the power grid supplying 2,592,697 kWh per year (38%). In this scenario, there is an excess electricity of 232,936 kWh per year (3.42%), an unmet electric load of 3,162 kWh per year (0.0584%) and a capacity shortage of 5,373 kWh per year (0.0992%). As the power grid is also used to meet the island's electricity demand in this scenario, carbon dioxide is produced. The carbon dioxide emissions in this scenario are 1,032,168 kg per year. The lifetime throughput of the battery in this scenario is 274,463 kWh, with an energy loss of 12,274 kWh per year due to the difference between input and output energy to the battery. The island's electricity demand is met by the power grid/PV/ WT in this scenario. The monthly electricity production in this scenario is shown in Figure 13.

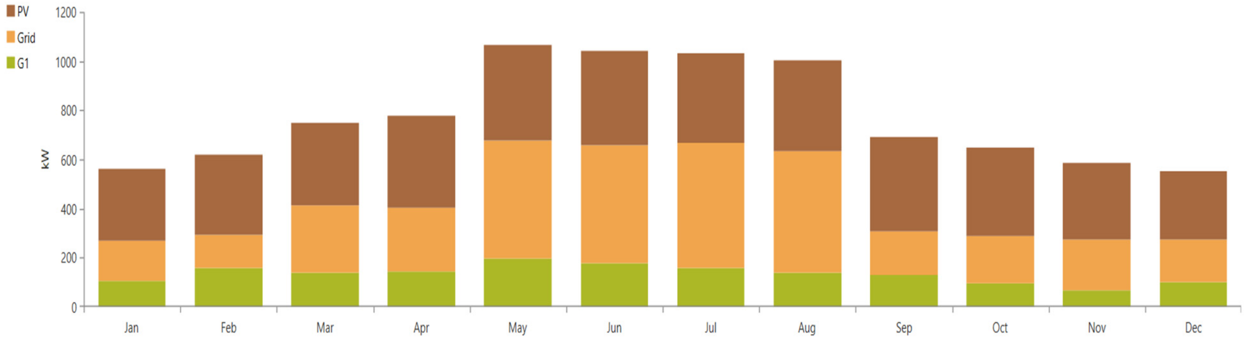

Figure 13. Powering up: Monthly average electric production for the Case 1 on Hengam Island, Iran.

5.3. *Case 2*

In this Case, there is no energy exchange between the HRES and the power network. All the island's electricity load is satisfied by renewable systems, and no extra electricity is sold to the grid. The TNPC is $55,297,470, the LCOE is $1.58 and the TAC is $3,262,323. All the electricity production and demand in this scenario are met by 100% renewable hybrid systems, and no energy exchange occurs with outside sources. The total energy generated in this scenario is 17,562,030 kWh per year, with PV systems and WT producing 10,461,266 kWh per year (59.6%) and 7,100,764 kWh per year (40.4%), respectively. As there is no energy exchange with the power grid in this scenario, there is a high excess electricity of 11,478,517 kWh per year (65.4%), an unmet electric load of 1,329 kWh per year (0.0245%) and a capacity shortage of 50,395 kWh per year (0.0996%). The carbon dioxide emissions in this scenario are zero. The lifetime throughput of the battery in this scenario is 8,596,601 kWh, with an energy loss of 384,312 kWh per year due to the difference between input and output energy to the battery. All the electricity demand in this scenario is met by renewable hybrid systems, and the monthly electricity generation is presented below Figure 14.

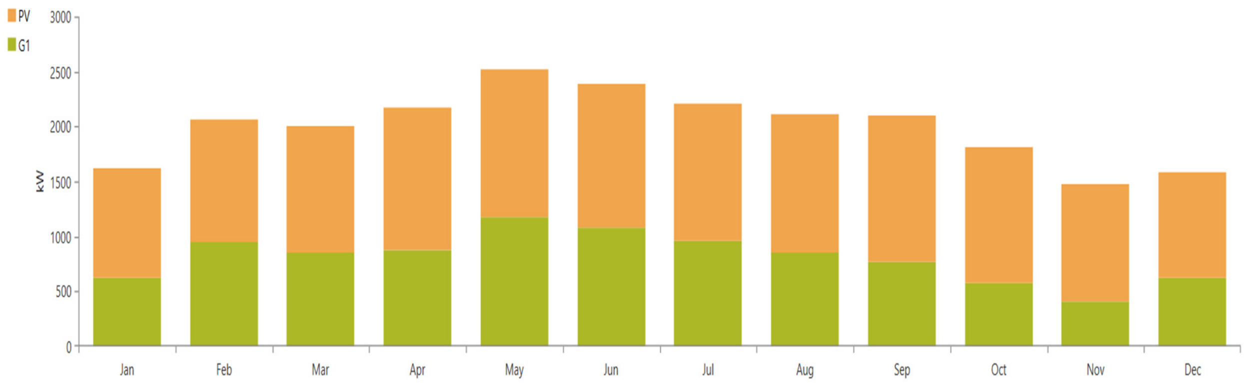

Figure 14. Zero emissions, maximum impact: Monthly average electric production for Case 2, achieving 100% renewable energy reliance with no grid exchange on Hengam Island, Iran.

5.4. Case 3

In this Case, only the power grid was used to meet the island's electricity demand. The TNPC is $1,449,589, the LCOE is $0.04419 and the TAC is $224,212.3. The total energy generated in this scenario is 5,073,873 kWh per year, with 100% of the island's electricity demand being met by the power grid. As there is no excess electricity in this scenario, the excess electricity is zero. The unmet electric load is 342,823 kWh per year (6.33%), and the capacity shortage is 342,823 kWh per year (6.33%). To make this system feasible in HOMER, we need to have a maximum annual capacity shortage of 10% of the load. As only the power grid was used to meet the island's electricity demand in this scenario, there is a high carbon dioxide emission. The carbon dioxide emissions in this scenario are 3,206,688 kg per year. The lifetime throughput of the battery in this scenario is zero kWh, with no energy loss. All the electricity demand in this scenario is met by the power grid, and the monthly electricity production is shown in Figure 15.

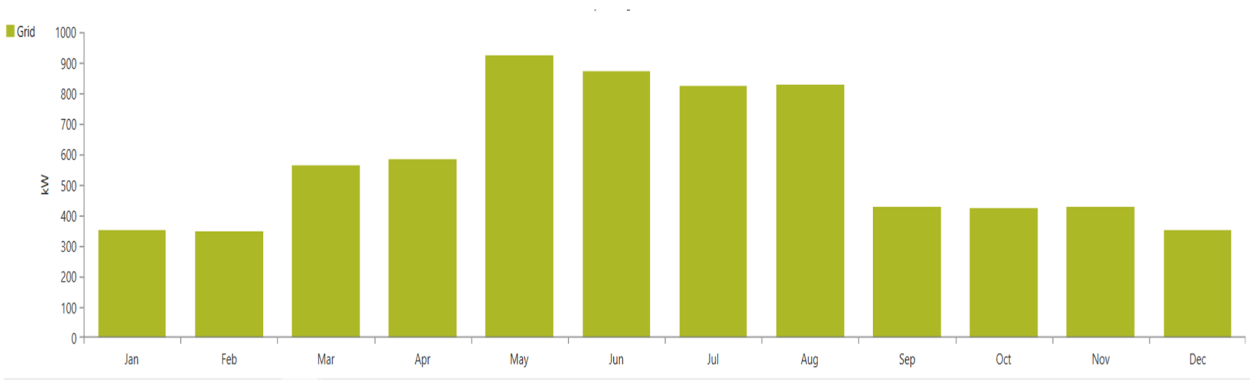

Figure 15. Monthly average electric production in Case 3.

6. Discussions

RESs are vital for electricity generation, but their direct utilization can be costly for both investors and individuals. As a result, combining RESs is essential. This study investigates the best size for a hybrid PV/WT/BES to supply electricity on an island in southern Iran, using the HOMER software. The analysis examines different configurations of renewable hybrid systems, both with and without a power grid, across four distinct scenarios. The optimum size of the hybrid PV/WT/BES is determined, and the purchase and sale of electricity between renewable systems and the power grid are depicted in Figure 16. Scenario 3 involves no energy exchange between the power grid and the renewable system, while base scenario only sells excess electricity to the power grid. TNPC for generating electric power by renewable hybrid systems is significant, and environmentally friendly projects produce the least amount of carbon dioxide emissions. Figure 16 shows and compares the 4 scenarios in terms of buying/selling energy from/to the main grid on the Island.

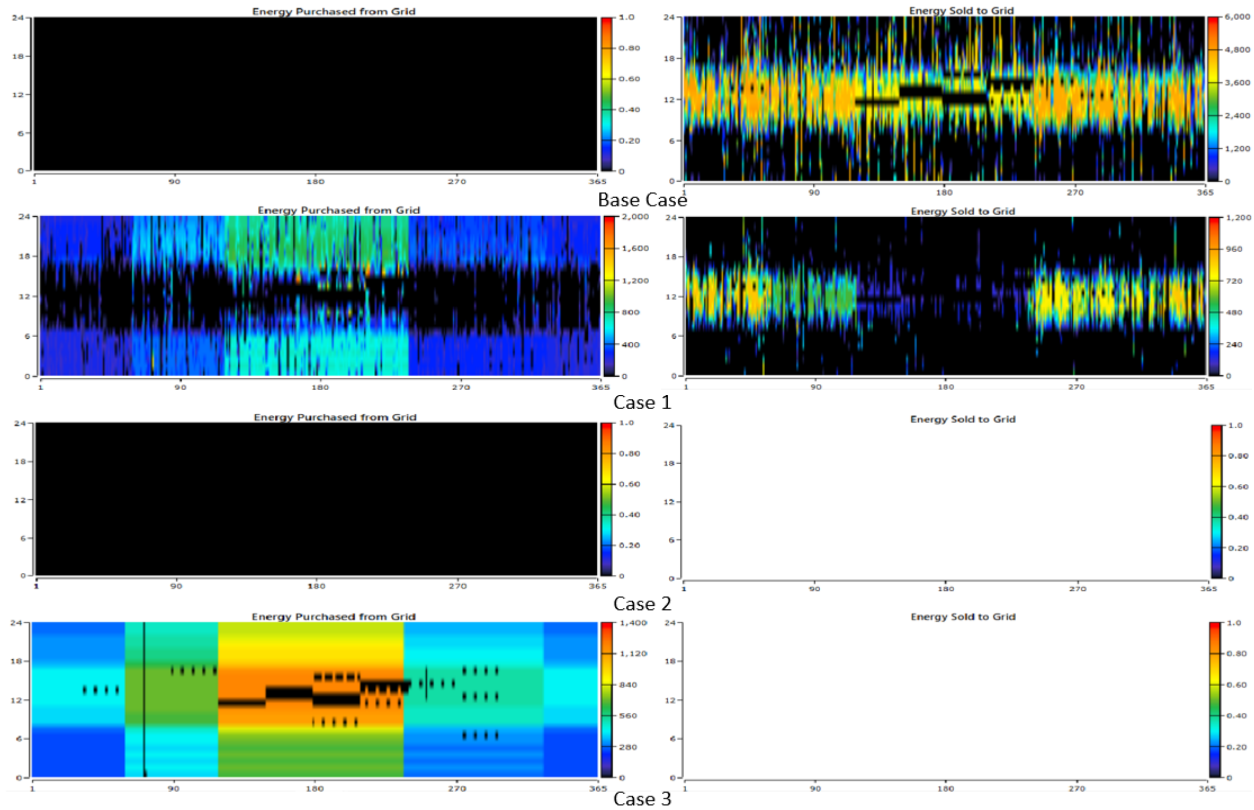

Figure 16. Hybrid system diagrams.

A challenge in meeting the island's electric load demand using renewable hybrid systems is handling excess electricity production. Storage systems are required to avoid excess electricity, but they increase the TNPC. Integrating renewable hybrid energies with the power grid reduces the TNPC and prevents excess electricity production. Relying solely on the power grid results in no excess electricity but significant carbon dioxide emissions. Scenario 3, which only involves energy exchange, has the lowest extra electricity, capacity shortage and unsatisfied electric demand, making it the most reliable scenario. Scenario 2 has the highest TNPC due to the need for larger batteries to store excess electricity, while scenario 3 has the largest unmet electric load due to annual outages, resulting in lower reliability than other scenarios. Figure 17 illustrates a comparison of four cases across 15 Key factors in different scenarios.

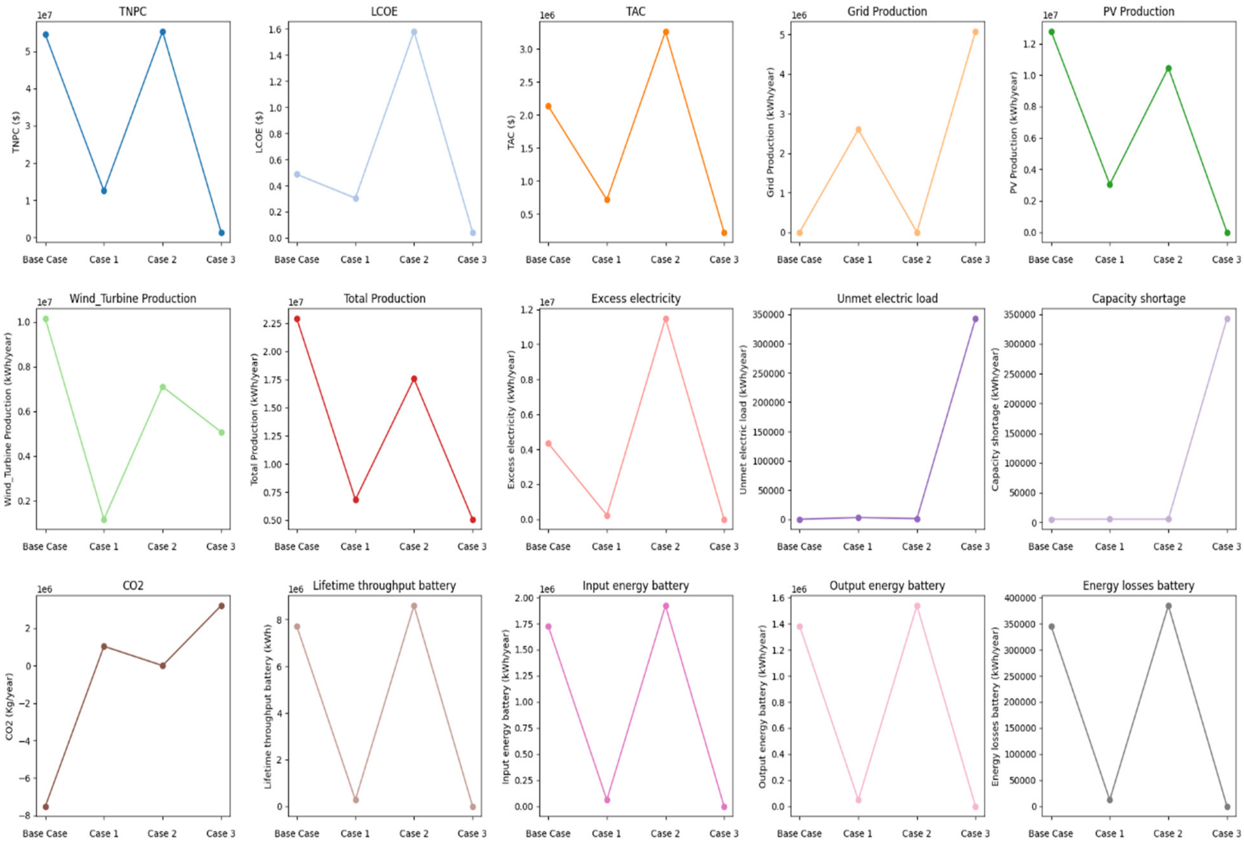

Figure 17. Powering Hengam Island: A captivating comparison of four cases across 15 key factors.

Here, we the performance and cost of four different scenarios for electricity production on an island in southern Iran. The scenarios are as follows:

Scenario 1: Utilizing only the power grid.

Scenario 2: Employing a hybrid system of Photovoltaic (PV)/Wind Turbine (WT)/Battery Energy Storage (BES) without grid integration.

Scenario 3 (Base case): Using a hybrid system of PV/WT/BES with energy exchange with the power grid.

Scenario 4: Implementing a hybrid system of PV/WT/BES without energy exchange with the power grid.

The power generation capacity of Renewable Energy Sources (RESs) using solar panels in each scenario is as follows: 55.8% in the base scenario, 44.7% in scenario 1, 59.6% in scenario 2 and 0% in scenario 3. On the other hand, the power generation capacity of WT systems in these scenarios is 44.2% in the base scenario, 17.3% in scenario 1, 40.4% in scenario 2 and 0% in scenario 3. These results indicate that solar energy production surpasses WT production in all scenarios due to the island's weather conditions and solar radiation, underscoring the island's high potential for harnessing solar energy.

If the power grid alone is used to meet the island's electric load demand, the minimum Total Net Present Cost (TNPC) is $1,449,589. However, this scenario results in the maximum carbon dioxide emissions of 3,206,688 kg per year, highlighting the trade-off between cost and environmental impact. The integration of RESs with power grids and the use of batteries enhances network reliability.

Simulation results show that scenario 3 (Base case), which involves a hybrid system of PV/WT/BES with energy exchange with the power grid, is the most reliable and cost-effective option for supplying electricity on the island. This scenario not only reduces the TNPC and carbon dioxide emissions but also prevents excess electricity production, thereby improving grid reliability. The analysis also emphasizes the issue of excess electricity production and non-utilization in renewable energy production on the island. To tackle this challenge, selling excess production to the off-grid electricity grid is suggested as one of the most attractive scenarios to create an energy market for electricity sales. This energy market can provide a sustainable way for the island to generate income. The use of the power grid in conjunction with renewable energy production and the sale of excess production energy can significantly reduce battery losses. This approach combines renewable systems and the power grid to supply electricity to the island, reducing losses and increasing reliability. Moreover, the integration of renewable energy sources with the power grid improves the operational lifetime of the battery, enhances the quality of the power supply, reduces carbon dioxide emissions and improves overall system performance. Future studies can focus on designing optimal systems for different consumption domains, such as remote, industrial and commercial residential areas and islands. It is also crucial to examine the impact of implementing other renewable energy sources, energy storage systems, carbon emission limits and taxes on the reliability and emissions of optimal systems. Overall, the analysis demonstrates the benefits of using a hybrid system of PV/WT/BES with energy exchange with the power grid as the most reliable and cost-effective option for supplying electricity on the island. The integration of renewable energy sources with the power grid not only reduces costs and emissions but also improves network reliability and prevents excess electricity production.

7. Conclusions

This study offers an in-depth assessment of the feasibility of a Hybrid Renewable Energy System for the residential area of Hengam Island in Iran. The evaluation process involved optimizing a variety of configurations that included Photovoltaic panels, Wind Turbines and Battery Energy Storage within a hybrid energy system using the HOMER. The annual load requirement was ascertained by analyzing the historical electricity demand data for the residential area on Hengam Island. A peak demand of approximately 1236.92 kilowatts was taken into account for the technical-economic analysis of the proposed hybrid system. The results of the optimal system design, which were based on the analysis of minimum carbon dioxide emissions, unmet electric load and capacity shortage, suggest that a hybrid system comprising 12779267 kilowatts (accounting for 55.8% of production) of solar Photovoltaic panels and 10141978 kilowatts (accounting for 44.2% of production) of Wind Turbines is the most suitable for this case study with a first prototype. In this scenario, the unmet electric load is a mere 164 kilowatt-hours per year, and the capacity shortage is 5245 kilowatt-hours per year. This makes it the best case for maintaining environmental sustainability due to zero carbon dioxide emissions and the highest reliability over the 25-year project lifetime. However, this case does come with a high initial cost of equipment, with a Total Net Present Cost of $54,493,590. If the power grid is also utilized for energy exchange with the island, the Total Net Present Cost can be significantly reduced by 76.95%, and battery losses can be reduced by 96.44%. In addition, the grid-connected hybrid system was evaluated for carbon emissions by incorporating renewable energies into the system. The analysis shows that the proposed grid-connected system can reduce carbon emissions to zero, making it highly environmentally compatible. Given the weather conditions, wind speed, temperature and solar radiation in the studied area, the region has very suitable conditions for harnessing renewable energies. In this era of energy crises and increasing carbon emissions, the transition of the residential sector towards renewable energies is crucial to overcome these issues. To address the challenge of high prices for renewable energy production, increasing renewable equipment production and improving technology can alleviate investor reluctance in power production using renewable systems. Therefore, with this practical method and the sale of surplus electricity to the power grid, it creates an energy market for the island. By selling excess energy to the power grid, the costs incurred in the design of the hybrid system can be compensated in a shorter period of time.

Acknowledgments

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Use of AI tools declaration

The authors declare that they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors declare no conflicts of interest.

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