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Techno-economic optimization and Strategic assessment of sustainable energy solutions for Powering remote communities

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ABSTRACT

The purpose of this research is to identify the optimal configuration of a diesel generator with a hybrid renewable energy system that can sustainably meet the energy demands of a rural area. Some of the main challenges of using diesel generators to supply the required electric load in remote areas are the high operating cost, unmet electric load, carbon dioxide emissions, very high total net cost, and the quality of electricity. This study, which combined diesel generators with renewable resources, accurately analyzed eight different system outputs from the hybrid optimization of multiple energy resources software. The analysis considered factors such as site-specific conditions, fuel costs, and solar radiation levels. The software prefers a load following strategy over a cycle charging strategy. This load following strategy involves combining a diesel generator with renewable energy sources, specifically configured as a combination of photovoltaic cells, a diesel generator, a wind turbine, and a battery. This configuration, with a total net cost of approximately $180,065.43 and a levelized cost of energy of $0.32, is identified as the most effective configuration chosen. Operating cost, carbon dioxide emission, and total net present cost are reduced by 53.17 %, 60.46 %, and 30.02 %, respectively. It highlighted the combination of diesel generator with renewable energies and their role in promoting environmental sustainability. By providing 100 % of the load demand, it increased the quality of electricity such that the unmet electric load is reduced to zero.

Nomenclature	
P_{PV}	PV electricity produced by the solar system (kW)
Y_{PV}	Standard conditions for the PV panels' output power (kW)
f_{PV}	Derating factor (%)
G_T	Sunlight incidence on the photovoltaic array (kW/m^2)
$G_{T,STC}$	The radiation incident under typical test circumstances (kW/m^2)
α_P	Temperature coefficient of power (%/°C)
T_C	PV cell temperature (°C)
$T_{C,\ STC}$	PV cell temperature under typical testing circumstances (25 °C)
P_{WT}	Output power of wind turbine (kW)
ρ	Actual air density (kg/m^3)
ρ_0	Air density at standard temperature and pressure (1.225 kg/m^3)
$P_{WT,STP}$	Wind power output at standard temperature and pressure (kW)

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$P_{Battery,cmax}$	The maximum power that the battery system is capable of absorbing (kW)
$P_{Battery,cmax,kbm}$	The maximum power that the kinetic battery model can store (kW)
$P_{Battery,cmax,mcr}$	The maximum charging rate-corresponding stored charge power (kW)
$P_{Battery,cmax,mcc}$	The maximum charge current multiplied by the stored charge power (kW)
$\eta_{Battery}$	The battery efficiency (%)
$P_{Battery,dmax,kbm}$	The maximum discharge power of the battery (kW)
k	The storage rate constant $(h)^{-1}$
C	The storage capacity ratio (%)
Q_{max}	The storage system's overall capacity (kWh)

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(*continued*)

Q_1	The energy that was accessible for storage at the start of the interval (kWh)
Δt	The time-steps duration (h)
Q	The entire amount of energy stored at the start of the time step (kWh)
α_c	The highest rate of battery charge (A/Ah)
$N_{Battery}$	The quantity of batteries within the battery bank
I_{max}	The highest charge current in storage (A)
V_{nom}	The storage nominal voltage (V)
P_{Con}	The output power of the converter (kW)
P_{Peak}	Maximum power output of the converter (kW)
η_{Con}	Converter efficiency (%)
E_{DG}	Fuel consumption (L)
M_1	The coefficient of the fuel curve (L/h/kW)
X_{DG}	The rated capacity of the DG (kW)
M_2	The fuel curve slope (L/h/kW)
P_{DG}	The generated power of the DG (kW)
η_{DG}	DG efficiency (%)
ρ_{DG}	The density of the diesel fuel (kg/m^3)
H_{LD}	The lower heating response of the diesel fuel (MJ/kg)
TAC	Total annualized cost ($/year)
$CRF(i,n)$	The capital recovery factor (constant)
i	Real interest rate (%)
n	The project lifetime (year)
i'	Real nominal rate (%)
f	The inflation rate (%)
C_{CC}	The annual capital cost ($)
C_{RC}	Annual replacement cost ($)
C_{OM}	Annual O&M cost ($) AES Annual energy served (kWh/year)
$C_{i,ref}$	The reference system nominal annual cash flow ($)
C_i	The current system nominal annual cash flow ($)
C_{cap}	Denotes the current system capital cost ($)
$C_{cap,ref}$	Represents the reference system capital cost ($)
Abbreviations	
HRES	Hybrid renewable energy system
HOMER	Hybrid optimization of multiple energy resources
TNPC	Total net present cost ($)
LCOE	Levelized cost of energy ($/kWh)
PV	Photovoltaic
DG	Diesel generator
WT	Wind turbine
RESs	Renewable energy sources
STP	Standard temperature and pressure
ROI	Return on investment
IRR	Internal rate of return
LF	Load following
CC	Cycle charging
OC	Operating cost
UEL	Unmet electric load
EF	Emission factor (2.4–2.8 (kg/lit))
FC	Fuel consumption (lit)
CO_2	Carbon dioxide (kg)
CO	Carbon monoxide (kg)
PM	Particulate matter (kg)
SO_2	Sulfur dioxide (kg)
UHC	Unburned hydrocarbons (kg)
NO_X	Nitrogen oxides (kg)

1. Introduction

Technical barriers, such as long-distance transmission networks, rugged terrain, and dispersed populations, hinder the accessibility of electricity in remote areas [1]. Due to the high transmission costs, power generation is often nonexistent in remote rural locations [2]. As a result, improving the socioeconomic circumstances of rural communities in emerging nations is heavily dependent on energy access [3]. Factors such as the village's location or distance from the current grid point, peak energy demands, and available energy resources contribute to the availability of energy. Electrification improves the quality of life for villagers, and the use of diesel generator (DG) and renewable energy sources (RESs) in hybrid renewable energy system (HRES) can play a crucial role in global power grids, gradually reducing dependence on fossil fuels. This is particularly significant for developing countries [4,5]. Ensuring the reliability and efficiency of RESs continues to pose a significant challenge for electrical engineers. Optimizing costs, along with network penetration, further presents a significant hurdle [6]. RESs, typically comprising small machines with low inertia driven by sources such as the sun, water, and wind, are preferably connected close to load points to meet local energy demands [7]. Non-renewable energy sources have detrimental effects on the environment [8]. Environmental degradation, harmful gas emissions, and rising fuel and electricity prices are the primary drivers for transitioning toward renewable energy [9,10]. Inadequate scaling of photovoltaic (PV), DG, and battery can lead to high installation, maintenance, and operational cost (OC), as well as environmental pollution [11,12]. Hybrid systems can offer cost-effective solutions by leveraging shared infrastructure, addressing energy intermittency issues, and enhancing grid stability [13,14]. Moreover, transitioning from fossil fuels to renewable energies has the potential to reduce pollutant emissions [15]. Numerous studies have focused on energy savings and emission reductions in HRES, with the main objectives being the minimization of total net present cost (TNPC) and levelized cost of energy (LCOE), as well as the reduction of pollutant emissions. In a study [16], the feasibility of energy storage for electric vehicle loads was investigated, considering technical-economic factors, cost-effectiveness, and economic dispatch. The results demonstrated that HRES offers an economical and environmentally friendly solution.

In another research [17], a hybrid energy system (HES) comprising PV, wind turbine (WT), battery, and DG was developed. Size optimization using hybrid optimization of multiple energy resources (HOMER) software was employed to reduce TNPC and LCOE. Rising fuel prices and supply constraints contributed to the increased utilization of RESs. This study emphasizes how economically viable renewable energy is for hybrid systems, particularly in areas with high fossil fuel prices and stringent pollution laws. A measurement method for grid-connected PV systems with various battery technologies was proposed in Ref. [18], utilizing technical-economic feasibility analysis with HOMER software. The results revealed that communities heavily rely on fossil fuel-based technologies to meet their electricity demands, which has significant social and economic implications. Utilizing the Hybrid Genetic Firefly algorithm, a techno-economic analysis of off-grid WT, PV, biomass gasifies, and PV systems, incorporating additional wind and solar energy storage through hydrogen conversion, was conducted [19]. The optimal sizing demonstrated the substantial environmental impact of combining solar and wind energy with hydrogen.

Employing the Harmony Search method, the ideal size of an autonomous microgrid was investigated, encompassing PV, WT, battery, and DG components, as discussed in Ref. [20]. The results showed that the Harmony Search algorithm method approaches the global optimal value quickly. Operational strategy and optimization concerns for an off-grid hybrid PV-wind system based on battery storage were examined in Ref. [21]. After comparing the simulation-annealing approach, the Culture algorithm, the Hybrid Firefly and Harmony Search algorithm, and the Harmony Search algorithm, the study found that the particle swarm optimization was the most effective in achieving the lowest total system cost. In Ref. [22], it was anticipated that a grid-connected PV/battery system would utilize HOMER to supply power during erratic times. The penetration of renewable energy, surplus electricity, and investment cost were the primary comparable indicators. The findings showed that the size of the projected solar PV/battery system, the percentage of renewable energy, carbon dioxide (CO_2) emissions, and unmet electric load (UEL) were all unaffected by the length of the investment plan. To attain the TNPC, a hybrid PV-biomass microgrid was the subject of a technical and financial analysis [23]. With 98 TNPC batteries, two mass biomass generators, 25 PV modules, and two mass search generators, the microgrid was optimized using the Firefly and Harmony algorithms. The results suggested that the size of the biomass and fuel cell microgrid should be smaller.

The TNPC was shown to be somewhat unaffected by changes in the interest rate when the optimal size of a biomass and fuel cell microgrid was determined using the Multi-Objective Particle Swarm Optimization algorithm [24]. On the other hand, the value of the TNPC decreased by 0.84 % when the interest rate dropped from 15.25 % to 14 %, but increased to 16 %. Grid-connected biomass PV integrated biomass RESs efficiently decreased emissions without increasing the energy system expenditure, according to a feasibility analysis of the technology utilizing HOMER optimization software [25]. Four optimization strategies the Flower Pollination algorithm, Harmony Search algorithm, Artificial Bee Colony algorithm, and Fire Flight algorithm were compared in Ref. [26] for a PV/biomass/battery hybrid system. According to the study, the Flower Pollination and Harmony Search algorithms, and the Firefly algorithm were the quickest ways to reach the best answer. In contrast, the Artificial Bee Colony method required additional time. After considering variables and capital costs, the study confirmed the potential of hybrid systems in the realms of economics, the environment, and society.

Utilizing HOMER, researchers evaluated the techno-economic feasibility of initiatives proposed in Ref. [27]. TNPC and LCOE were taken into account as break-even points. The outcomes demonstrated that the most advantageous designs for energy systems from both environmental and financial perspectives were those that exclusively utilized RESs. However, its implementation in underprivileged regions was hindered by the high projected investment costs.

A feasibility study comparing the Cultural algorithm, JAYA algorithm, and Particle Swarm Optimization algorithm were conducted for RESs utilizing solar, wind, and hydrogen fuel cells [28]. The study looked into how the TNPC and LCOE would change if the initial costs of system components were altered. It was discovered that the most significant impact on the overall TNPC and LCOE were attributable to changes in the initial cost of the solar PV system, with fuel cells ranking next in influence. The least significant impact was caused by altering the cost of battery banks. Another study [29] examined wind, solar, and battery combinations using HOMER and a backward search method. The researchers concluded that using more solar panels meant using fewer batteries. According to the sensitivity analysis conducted in Ref. [30] with HOMER on an integrated energy system comprising batteries, biomass, hydrogen, and optimized solar power, it was found that solar

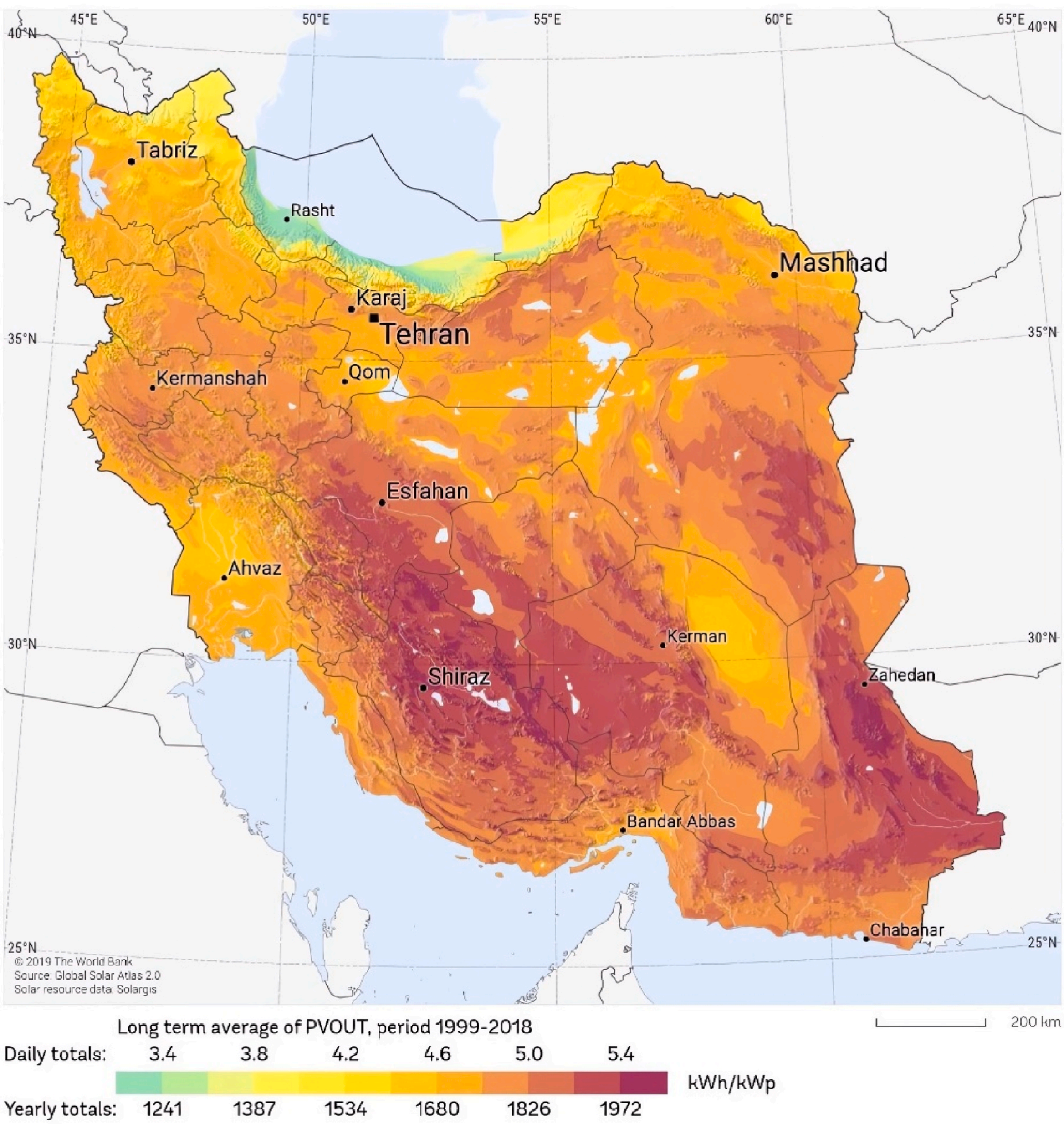

Fig. 1. Spatial distribution map of solar potential in Iran [33].

irradiance exhibited the lowest sensitivity to TNPC, whereas electric charges showed the highest sensitivity. The study emphasized the critical importance of optimizing systems with these factors in mind.

Solar energy is one of the most crucial RESs in addressing the increasing energy demand in the present era. PV systems are a practical means of producing power from solar radiation [31]. Due to geographical location of Iran, it has significant investment potential in solar energy utilization [32]. Spatial distribution map of solar potential Fig. 1 and global horizontal irradiance Fig. 2, indicating a favorable potential for solar systems in Iran [33]. Iran also has excellent potential for wind energy development, with a predicted capacity of over 100 GW [31]. The wind atlas map of Iran in Fig. 3 illustrates the viability of wind energy power plants and the economic sustainability of investments in the wind energy sector.

The studies which were mentioned above provided various scenarios for HRES and highlighted their key findings and comparisons. They emphasized the importance of reducing pollutant emissions and achieving the lowest TNPC and equivalent energy cost. While traditional fossil fuel-based energy sources are commonly used in remote rural areas, combining RESs with DG offers a cleaner and more sustainable alternative. The feasibility of these systems is examined in this research, taking into account the OC of DG. The goal of this study is to optimize the combination of RESs and DG based on fuel cost and solar radiation levels to achieve sustainable energy solutions. One of the main challenges with DG is its high OC, although integrating solar and wind energy sources can help lower the TNPC and UEL. The research suggests that utilizing solar and wind energy sources to their full potential while lowering the DG operating current is the best way to reduce costs, maintain electricity quality, and avoid pollution.

The remainder of the paper is divided into the following sections: The approach’s flow diagram, techniques, and materials are all covered in the second section of the methodology. The third part analyzes and discusses the input information, case study, and obtained results. Finally, the article concludes in the fourth section.

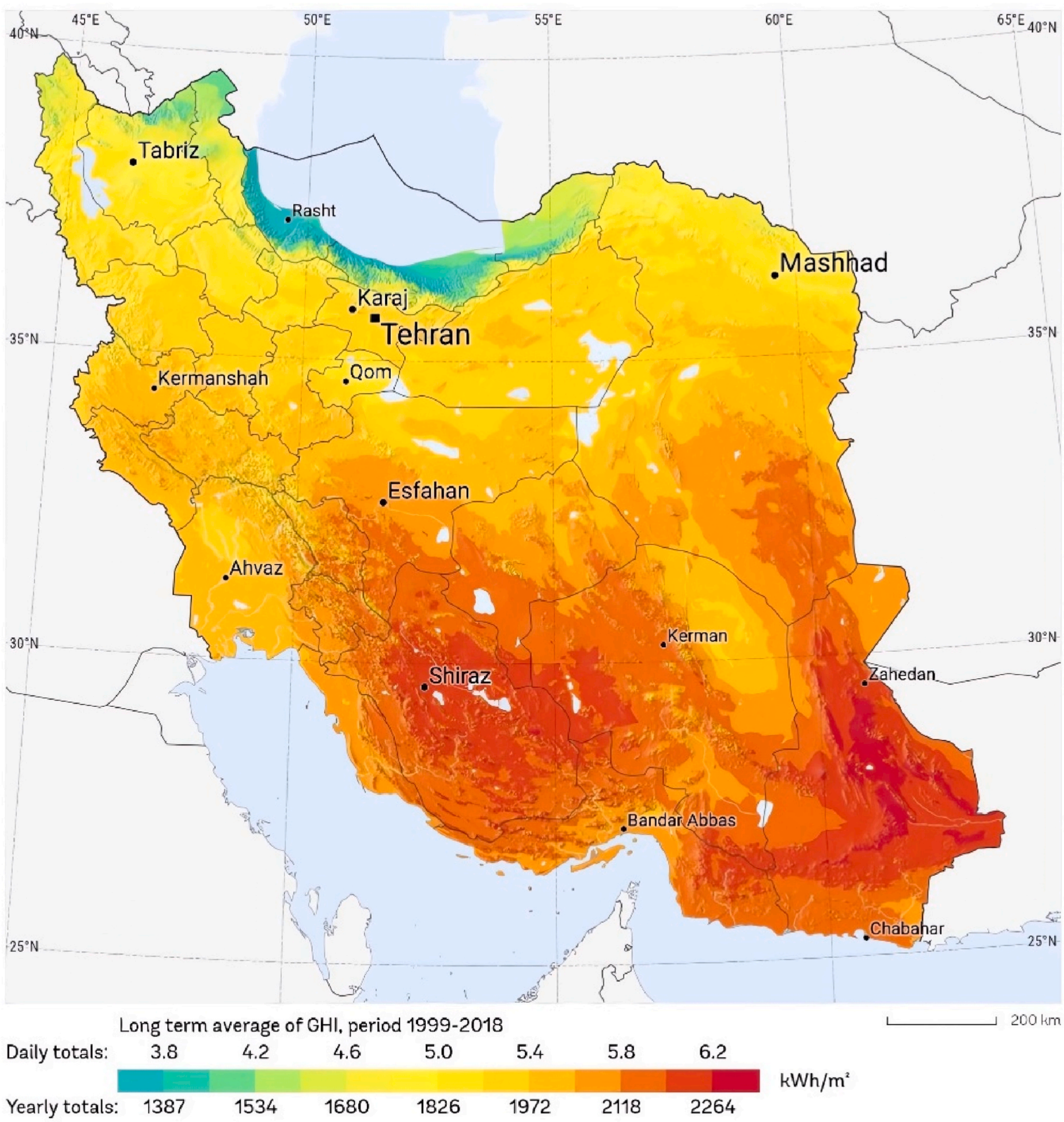

Fig. 2. Global horizontal irradiance in Iran [33].

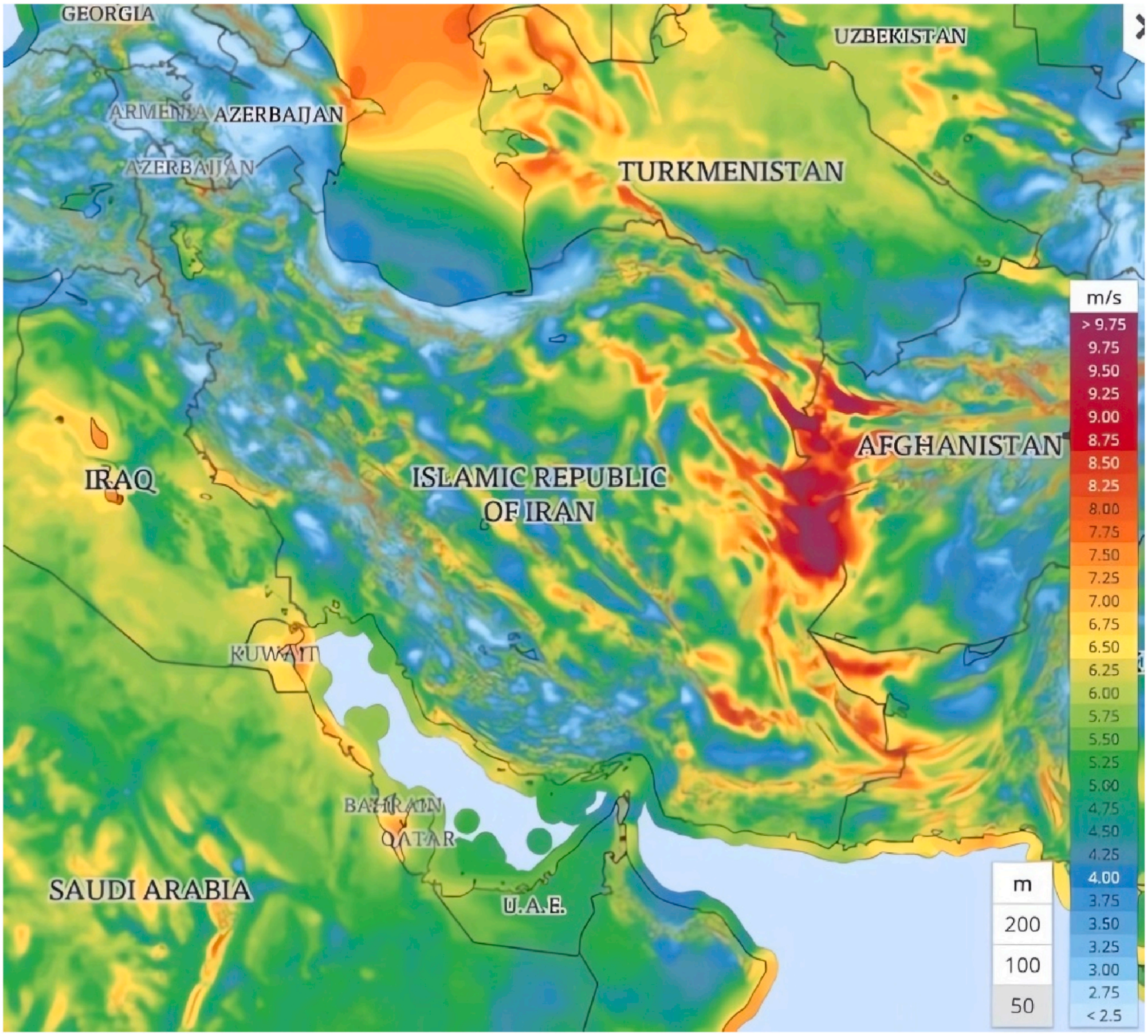

Fig. 3. Wind Atlas map of Iran [34].

2. Methodology

The HOMER software, when aided by techno-economic analysis, can be a highly effective tool in the design and planning of HRES, aiding in the determination of the ideal component size. HOMER needs six variety of data to simulate and optimize: search space, equipment profile, load profile, weather data, and economic and technical data. Climate-related information is input into the program as time series or monthly averages, including wind speed, solar radiation, temperature, and stream flow. HOMER utilizes these input values to compute the output powers of the WT, PV array, and hydropower. In both simulation and optimization, the most crucial element is the load profile of each location. Actual load consumption data from various establishments, including hotels, hospitals, universities, and industrial parks, are available for modeling. Time series data, including this actual data is imported into HOMER. However, in certain places, particularly isolated and rural ones, where actual load consumption data is unavailable, the load characteristics should be estimated based on the local features. The daily profile of this data is imported into HOMER, where it is utilized for the power balancing constraint. Each piece of equipment is simulated in HOMER, and its efficient operation is estimated in HRES based on its features. Because the size of the various HRES components such as the WT, PV array, generator, battery, and converter varies, a search space is considered during simulation and optimization. Every piece of equipment in HRES has associated expenditures, including capital, replacement, and operation and maintenance costs. Other economic parameters that can be considered in HOMER are the price of fuel, the price of grid-traded electricity, the real interest rate, the project lifetime, the system fixed capital cost, the system fixed operation and maintenance cost, and the emission penalty. Based on the consideration of these expenses during the stages of simulation and optimization, the TNPC of every plan is computed. Three phases are involved in determining the ideal sizes of HRES equipment: simulation, optimization, and sensitivity analysis, as seen in Fig. 4. As discussed in the previouse section, this process starts when the input data enters HOMER [35].

The constraints guide the minimization of the objective function. The total TNPC, or the present value of all costs less all revenues, is the goal function for any plan. The expenses cover fuel, start-up, replacement, operation, and maintenance expenditures in addition to the cost of energy received from the grid. In addition, the salvage cost plus the money received from selling electricity to the grid are considered. The constraints include power balance, battery charging and discharging, network transaction energy, and generator technical restrictions. The necessary output, including TNPC, pollutant emissions, energy exchanged with the grid, and the operating results of resources like generators, batteries, and converters at each time-step, are estimated for feasible designs. When something is feasible, the power balance constraint is met at every time-step. Every time-steps desire is satisfied. When the possible designs are sorted by minimal TNPC, the design with the lowest TNPC is deemed the best. Specific characteristics, including

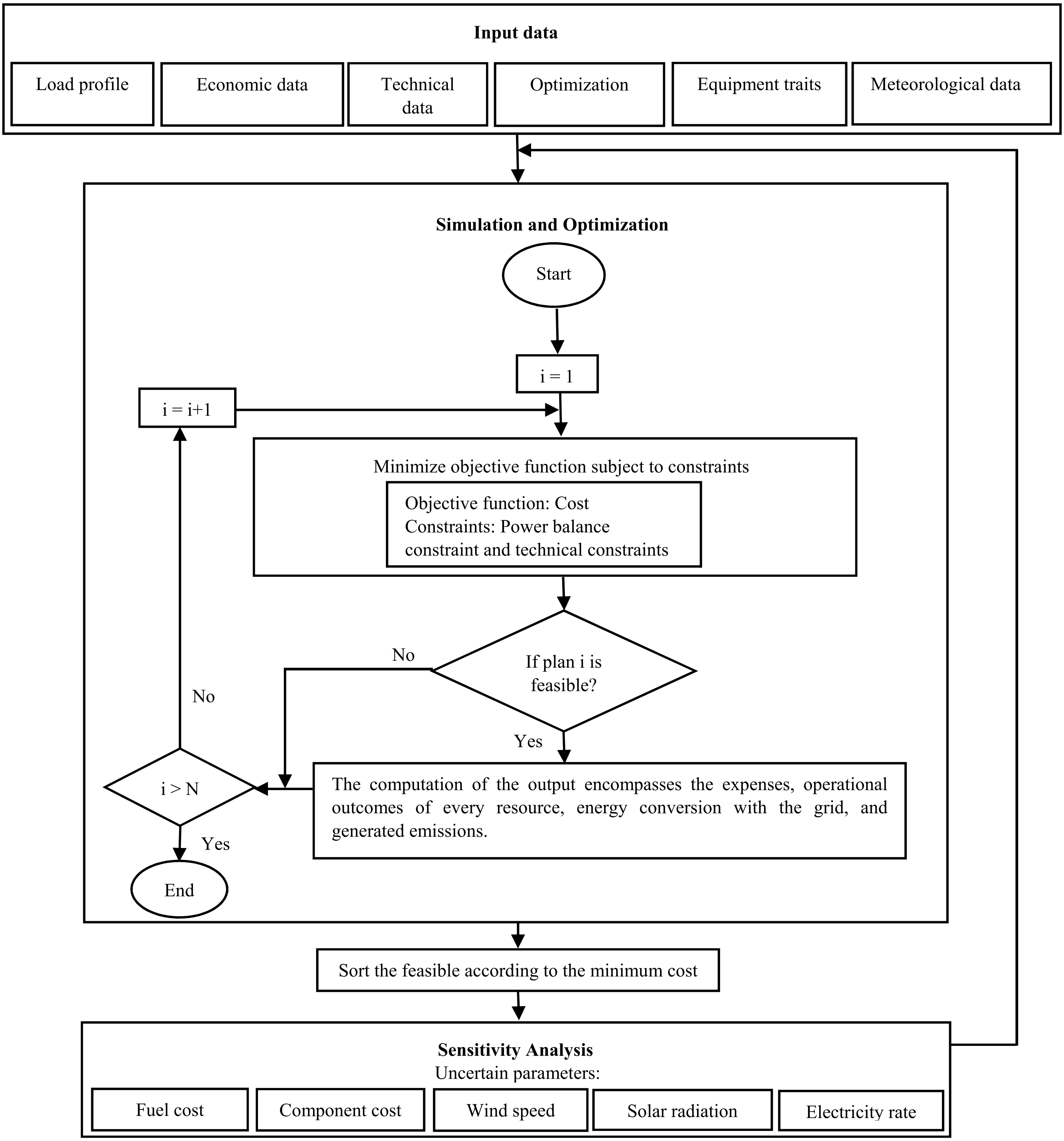

Fig. 4. The overall architecture of the HOMER simulation process [35].

fuel cost, wind speed, solar radiation, power price, and components cost, are not well-defined in the ideal measuring method of HRES equipment. As a result, the simulation and optimization processes are affected by the uncertainty of these parameters. Various values are entered for these parameters in HOMER. Once the simulation and optimization are finished and the potential designs are ranked by minimum TNPC, sensitivity analysis is performed, as shown in Fig. 4 [35].

A useful tool for planning and developing HRES systems is the HOMER program, as it can do techno-economic analysis in both connected and independent modes to optimize the performance of its components. A sample of an HRES design in HOMER is displayed in Fig. 5. This section describes the input data needed for simulation with HOMER as well as a thorough structure for illustrating the level of HRES equipment optimization determined by HOMER.

Based on the energy consumption of the electrical appliances utilized in this province, the electric load profile in the study region is estimated in Table 1. The gadgets being taken into account include the TV, lamp, fan, and refrigerator. In January, February, and December, the TV consumes 1.4 kWh of electricity daily, with a total usage of 4 h per day. Each of the five TVs has a power rating of 0.07 kW. During these months,

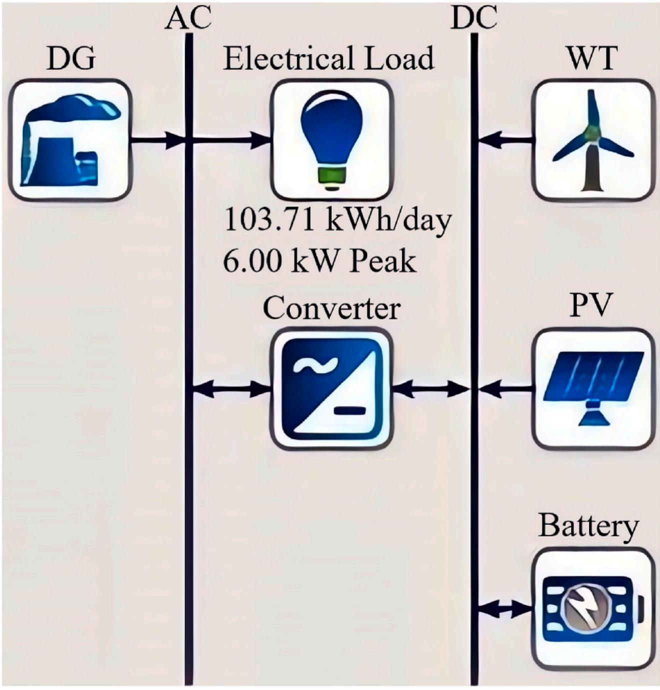

Fig. 5. Architecture of the designed system using different technologies for energy generation.

the lamp is used for 8 h a day, using 2.16 kWh of electricity. Each of the fifteen bulbs has a power rating of 0.018 kW. The fan consumes 7.5 kWh of energy when operated for 20 h a day in the months of May, June, July, and August; however, it remains unused in January, February, and December. Each of the five fans has a power rating of 0.075 kW, and the refrigerator consumes 42 kWh of energy daily throughout the year, operating continuously for 24 h each day. Each of the five refrigerators has a power rating of 0.35 kW. When considering all devices and their respective usage patterns, the daily energy consumption for January, February, and December amounts to 2.745 kWh. In contrast, the total daily energy usage rises to 45.56 kWh during the months of May, June, July, and August. The daily energy consumption amounts to 53.06 kWh for November, October, and September, and 46.31 kWh for April and March. When considering all the gadgets and their respective usage patterns, the projected daily energy consumption for typical families in Nimbazaar village is 47.435 kWh [36,37]. The load profile diagram for the system being constructed in Zahedan village is displayed in Fig. 6 for various months of the year. The temperature, wind speed, and solar radiation of the area were obtained from the research location, downloaded from NASA's global energy resources forecast, and inputted into HOMER. The key components in the design of integrated systems are outlined in Table 2, encompassing the type of equipment employed, capital cost, replacement cost, operation & maintenance cost, and the lifespan of each equipment based on either years or hours.

2.1. Photovoltaic system model

The annual curve of solar radiation in kilowatt-hours per square meter per day is depicted in Fig. 7, with data from HOMER and the NASA global energy resource forecast omitted. The technical data of the WT is presented in Table 2, considering the study location. The necessary area is determined by the longitude and latitude coordinates.

HOMER calculates the power generated by PV as follows [41]:

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

2.2. Wind turbine model

The wind speed utilized in our HOMER study is chosen according to the study location and is derived from NASA. The technical data for the WT is provided in Table 2. Fig. 8 shows the WT total output power curve at a cutting speed of 24 m/s. Wind speed was measured at the highest point of the study location, and the approximate center of the WT was higher than the earth's surface. The power output of the WT can be computed based on the hub height and wind speed using the power curve. The performance of any WT under standard temperature and pressure (STP) conditions is typically delineated by the power curve in the HOMER software [42]. The power value is scaled by the air density ratio to account for real-world conditions. The HOMER computer program typically employs the power curve to assess the performance of each WT under standard pressure and temperature conditions. In this case, a standard 3 kW turbine with a 17-m-high hub has been employed.

HOMER calculates the output power of WT as follows [41]:

$$P_{WT} = \left(\frac{\rho}{\rho_0} \right) P_{WT,STP} \tag{2}$$

2.3. Battery energy storage system model

The significant and irregular fluctuations in the load curve during different times of the day and night result in increased operational expenses for HRES, a concern that is of paramount importance to system operators. High capacity and high reaction time storage devices are typically utilized for operation storage in HRES, whereas high response speed storage devices are employed for frequency storage [43]. The need to enhance the efficiency of the power grid has spurred the advancement of electrical energy storage batteries, a development stemming from technological progress and the emergence of modern battery technologies [44]. Furthermore, battery has the potential to reduce fluctuations in electricity production. It is crucial to utilize battery to enhance the integration of RESs in order to minimize pollution and reduce reliance on fossil fuels. Battery technical information is shown in Table 2.

HOMER determines how much power a battery can discharge in its utmost capacity and charge in a specific time Δt as follows [43]:

$$P_{Battery,cmax} = \frac{Min \left(P_{Battery,cmax,kbm}, P_{Battery,cmax,mcr}, P_{Battery,cmax,mcc} \right)}{\eta_{Battery}} \tag{3}$$

Table 1
Demand of regular households in Sistan and Baluchestan province, Iran, Nimbazaar village [36,37].

Device	Power rating (kW)	Quantity	Energy consumption (kWh/day)	Use hours in January, February, December (h)	Energy (kWh/day)	Use hours in May, June, July & August (h)	Energy (kWh/day)	Use hours in November, October & September (h)	Energy (kWh/day)	Use hours in April & March (h)	Energy (kWh/day)
TV	0.07	5	0.35	4	1.4	4	1.4	4	1.4	4	1.4
Lamp	0.018	15	0.27	8	2.16	8	2.16	8	2.16	8	2.16
Fan	0.075	5	0.375	0	0	20	7.5	2	0.75	5	1.875
Refrigerator	0.35	5	1.75	24	42	24	42	24	42	24	42
Total	0.513	30	2.745	36	45.56	56	53.06	38	46.31	41	47.435

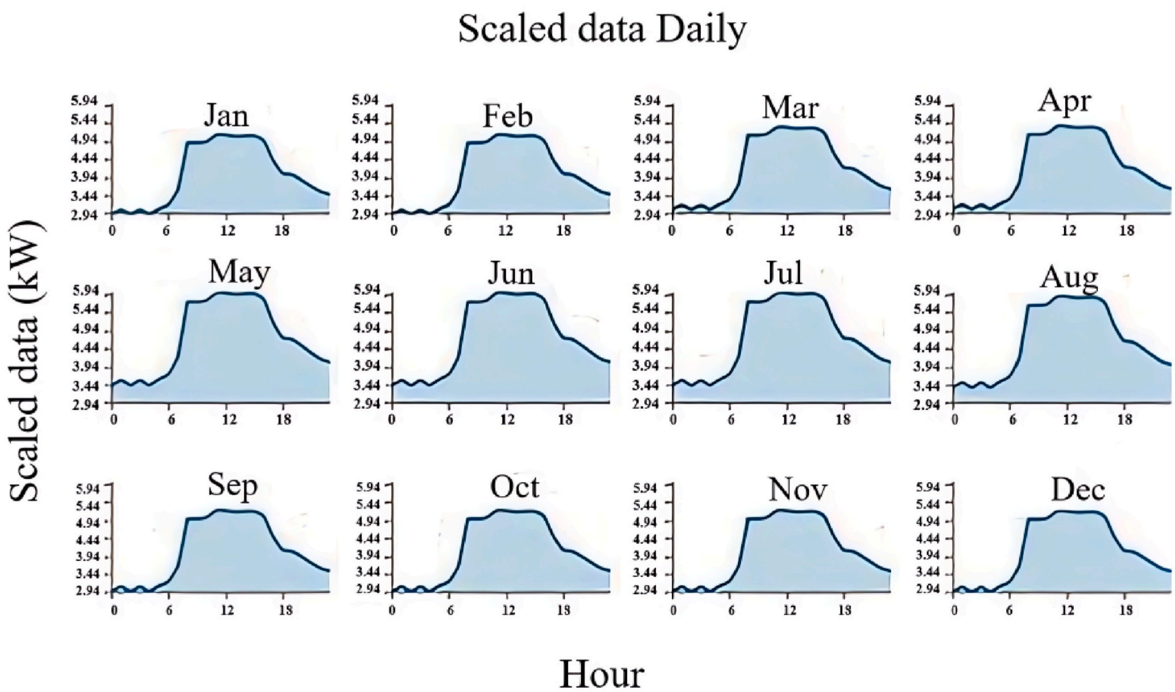

Fig. 6. Monthly profile of electrical load.

Table 2
System component costs and technical details [38–40].

Abbreviation	Name	Capital Cost ($)	Replacement cost ($)	O&M ($)	Lifetime (hour or year)	Properties
DG	Generic 10 kW Fixed Capacity Genset	3700	3700	1.3	15000 h	(Fuel: Diesel Fuel curve intercept: 0.48 Lit/hour Fuel curve slope: 0.286 Lit/hour/kW Lower Heating value: 43.2 MJ/kg Density: 820 kg/m^3 Carbon content: 88 % sulfur content: 0.4 %) carbon monoxide: 19.76 g/Lit of Fuel unburned hydrocarbons: 0.72 g/Lit of Fuel Particulate Matter: 1.198 g/Lit of Fuel The proportion of Fuel Sulfur converted to PM: 2.2 % Nitrogen Oxides: 22.46 g/Lit of Fuel
PV	Generic flat plate	1420.7	1420.7	30.2	25	Temperature coefficient: −0.5 Operating temperature: 45 °C Efficiency: 17 % Derating factor: 80 %
WT	Generic 3 kW	3291	3291	32.91	20	Hub height: 17 m
Battery	Generic 1 kWh Lead Acid	800	800	16	25	Nominal voltage: 12 V Maximum capacity: 83.4 Ah Capacity ratio: 0.403 Rate constant: 0.827 h^{-1} Roundtrip efficiency: 80 % Maximum charge current: 16.7 A Maximum discharge current: 24.3 A Maximum charge Rate: 1 A/Ah Throughput: 800 kWh Initial state of charge: 100 % Minimum state of charge: 40 %
Converter	System Converter	600	600	30	25	Inverter efficiency: 95 % Relative efficiency: 95 % Relative capacity: 100 %

$$P_{Battery,dmax,kbm} = \frac{-kcQ_{max} + kQ_1 e^{-k\Delta t} + kcQ\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)} \quad (4)$$

$$P_{Battery,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc\left(1 - e^{-k\Delta t}\right)}{1 - e^{-k\Delta t} + c\left(k\Delta t - 1 + e^{-k\Delta t}\right)} \quad (5)$$

$$P_{Battery,cmax,mcr} = \frac{(Q_{max} - Q)\left(1 - e^{-\alpha_c \Delta t}\right)}{\Delta t} \quad (6)$$

$$P_{Battery,cmax,mcc} = \frac{N_{Battery} \times I_{max} \times V_{nom}}{1000} \quad (7)$$

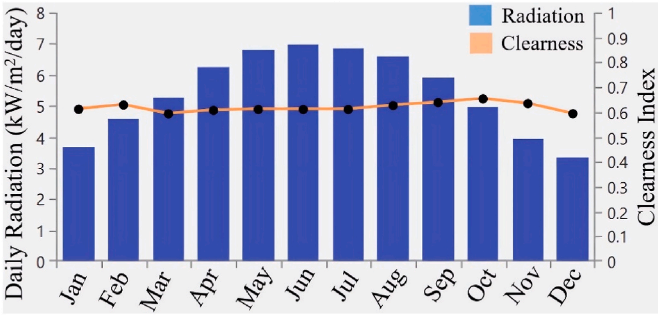

Fig. 7. Annual solar radiation in the study area (kWh/m^2/day).

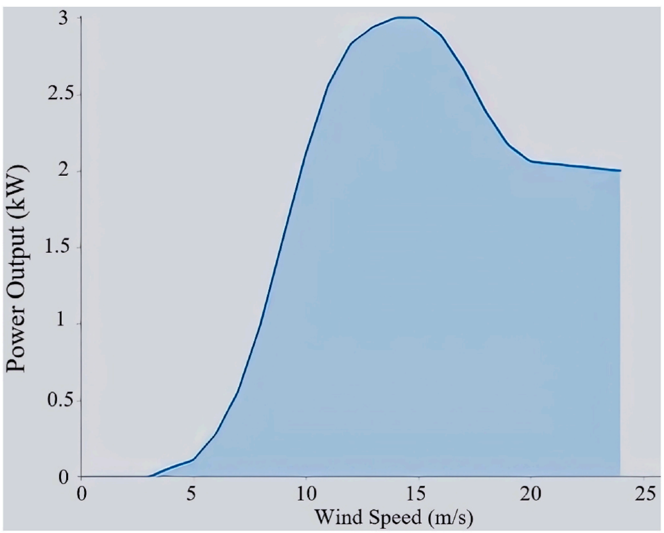

Fig. 8. WT power curve in HOMER.

2.4. Converter model

Converters are devices that change the form of electrical energy by connecting them to circuits with both AC and DC capabilities, facilitating the conversion of power between AC and DC in both directions [45]. By attaching these converters to each PV panel, they may be controlled separately. Table 2 displays the technical details of the converter.

HOMER calculates the output power of the converter as follows [46]:

$$P_{Con} = \frac{P_{Peak}}{\eta_{Con}} \tag{8}$$

2.5. Diesel generator model

Diesel fuel is employed in DG systems that generate energy across different scales, with RESs and DG units often combined in areas lacking grid electricity to serve as backup power sources for auxiliary demands and improve power quality [47]. If the power shortage cannot be addressed by the hybrid power system design comprising PV arrays, WT, and energy storage, a diesel-based generator is utilized. DG can serve as a primary or secondary power source. The technical information of DG is shown in Table 2.

HOMER calculates fuel consumption (FC) and DG efficiency based on the generated electrical energy as follows [48]:

$$E_{DG} = M_1 X_{DG} + M_2 P_{DG} \tag{9}$$

$$\eta_{DG} = \frac{3.6 P_{DG}}{E_{DG} \rho_{DG} H_{LD}} \tag{10}$$

2.6. Economic model

A key challenge in HRES design is cost estimation. The optimal sizing of DG, battery, WT, solar panels, and converters in relation to financial costs are determined through the HOMER simulation. One of these economic concerns is minimizing the total TNPC, LCOE, and total annualized cost (TAC). The factors considered in the technical and economic study include the annual rate of inflation, the project lifespan, and the annual interest rate.

HOMER calculates economic relations as follows [49–52]:

$$TNPC = \frac{TAC}{CRF(i,n)} \tag{11}$$

$$i = \frac{i' - f}{1 + f} \tag{12}$$

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{13}$$

$$TAC = C_{CC} + C_{RC} + C_{OM} \tag{14}$$

$$LCOE = \frac{TAC}{AES} \tag{15}$$

A helpful metric in financial management is the return on investment (ROI), a simple calculation that indicates how long the initial investment will take to pay for itself. The superior investment option would be the one with the shorter payback period, which refers to the time needed to recover the initial investment cost. The ROI is a metric that quantifies the time needed to recover the variance in investment costs between the benchmarked systems and the present system.

HOMER calculates and determines the ROI using the formula below [53]:

$$ROI = \frac{\sum_{i=0}^{n} C_{i,ref} - C_i}{n\left(C_{cap} - C_{cap,ref}\right)} \tag{16}$$

2.7. Environment model

When evaluating environmental issues in the power production system, CO_2 emissions are considered the most prevalent type of emissions compared to other pollutants. The quantity was calculated using the emission factor (EF), which is the same as 7the quantity of CO_2 released by burning 1 L of diesel fuel. The evaluation was based on the annual FC and EF [54].

$$CO_2 = EF \times \sum_{t=1}^{8760} FC(t) \tag{17}$$

3. Result

3.1. Results with HOMER validation

A different study from 2016 [55] was randomly chosen and subjected to simulation and optimization using the HOMER software to validate the findings. The results closely align with those previously reported by Mamaghani et al., as displayed in Table 3. Therefore, the outcomes of the present study utilizing HOMER are expected to be suitably precise.

Table 3
Optimization results of the hybrid energy system for a village in Colombia [55].

	DG	PV	WT	PV/WT	PV/DG	WT/DG	PV/WT/DG
PV (kW)	–	200	–	200	150	–	150
DG (kW)	25	–	–	–	25	25	25
Converter (kW)	40	40	40	40	40	40	40
PV (kW/year)	–	356460	–	356460	267345	–	267345
DG (kW/year)	84584	–	–	–	5250	80281	4465
WT (kW/year)	–	–	481770	3392	–	3392	3392
CO_2 emissions (kg/year)	93543	–	–	–	5923	88943	5052
Initial capital ($)	173750	308530	860282	335908	268100	201128	295478
Opetating cost ($/year)	55610	13279	27448	13816	13855	54084	13958
TNPC ($)	884632	478283	1211164	512528	445207	892503	473904
LCOE ($/kWh)	1	0.481	2.193	0.516	0.448	0.898	0.477

3.2. Discussions

In this research, optimization methods and sensitivity analysis of the HOMER software have been employed to reduce pollutant emissions, decline the costs associated with renewable energy devices, and save energy and diesel fuel. This research simulation includes fuel price variables of 0, 0.25, 0.5, 0.75, and 1 dollar per liter, as well as solar radiation levels of 5.42, 7, and 10 kWh per square meter outlined in Table 4.

After analyzing 8760 h of data, HOMER has identified and classified optimization findings. The study analyzed regional electricity consumption over a span of 25 years, considering a 15 % discount rate, a 10 % inflation rate, and a project duration [56]. Based on the average solar radiation levels and diesel fuel prices, HOMER has selected eight states for this simulation, as delineated in Table 5 from project 1 to project 8. Among these, the system in Table 4 that achieves the highest fuel efficiency, leading to a total FC of 5942 Lit/year, operates with a fuel price of $0.25 and solar radiation of 10 kW h per square meter per day. In the absence of an FC tax (zero diesel fuel cost), the maximum quantity of diesel fuel that the DG can consume to fulfill the energy demand is 15028 L per year. In such instances where the impact of diesel fuel on emissions is not the design priority consideration, diesel generators are inclined to consume the aforementioned amount of fuel annually, posing significant environmental risks. The optimal sizing of each component, as derived from the outcomes of the HOMER simulation provided in Table 5, indicates that project 1 emerges as the most financially efficient project among projects 1 to 8. In Table 4, the capacities of PV, DG, WT, battery, and converter are 20 kW, 2 kW, 10 kW, 13.2 kW, and 6 kW, respectively. Project 1 with $180,065.43 TNPC and $0.3223 LCOE makes it the most financially profitable project Fig. 9.

HOMER takes into account economic expenses when deciding on the best course of action. When using a load following (LF) distribution approach, a generator produces only what is necessary to support the primary load during operation. When supplying the primary load, the generator runs at maximum output power using the cycle charging (CC) distribution approach [48]. In the LF strategy, generating power to meet the shortage is initiated by the DG when power is supplied from the PV and WT systems. This strategy is less effective in FC compared to the CC strategy. From the results obtained in Table 5, with the increase of RESs, the appropriate strategy is LF, while CC strategy is more suitable in places where renewable resources are less or non-existent, from the HOMER point of view. According to the LF strategy, the DG initiates enters the power generation cycle based on demand and shortage, starting to supply load demand and not transferring energy to the battery. Therefore, the battery loses the effect of helping to supply the load. The RESs handles lower-priority tasks like filling a storage bank or providing a deferred load. The generator might still be located and able to supply electricity to the grid if it is profitable.

Table 4
Annual fuel consumption calculated by intensity of solar radiation and diesel fuel cost.

Diesel fuel price ($/L)	Solar radiation averaged (kWh/m^2/day)	Total fuel (L/year)
0.25	10	5942
0.25	5.42	5671
0.25	7	6100
0.5	10	5409
0.5	5.42	5418
0.5	7	5297
0.75	10	4970
0.75	5.42	5185
0.75	7	5056
0	10	15028
0	5.42	15028
0	7	15028
1	10	4761
1	5.42	4866
1	7	4820

Project 1 (optimal project) includes PV, WT, and DG systems, which account for 25.9 %, 25.1 %, and 48.9 % of the total power generation, respectively, as shown in Fig. 10. Compared to other power generation sources, PV systems in the power generation of this study have higher output power than DG and WT, which indicates a promising future for investing in PV power generation systems in remote areas of Iran. The power output of any renewable system can be significantly impacted by the availability of renewable resources in accordance with local weather conditions. Considering that the OC of PV is lower than the OC of DG, it is possible to produce as much power as possible from PV systems and have a significant impact on reducing TNPC and pollutants.

DG is the primary option for supplying electric load demand in remote areas. Providing energy demand using DG is faced with fundamental challenges such as OC, UEL, CO_2 emission, TNPC, and electricity quality. If only the DG is used as a supplier of electric load demand, the OC is $168,004.60, TNPC is $257,319.19, UEL is 20.9 kW/year, and CO_2 emission is 39,261 kg/year. By combining DG with RESs, OC changes to $78670.40, TNPC $180065.43, and CO2 emission 15523 kg/year Table 5. CO2 emissions have been reduced by 60.46 %, as all load demand has been met, resulting in a zero UEL. The reduction of OC by 53.17 % has played a significant role in reducing the TNPC. TNPC and CO2 have declined by 30.02 % and 60.46 %, respectively Table 6.

The TNPC has been less affected by DG with high OC due to the combination of RESs and environmental DG. Furthermore, it contributes to a cleaner atmosphere in the region that is used for energy production by decreasing pollution emissions. To improve investment conditions, it's better to focus on cutting expenses and emissions while also creating a safer living environment.

Positive results are shown in Table 7 financial evaluation. The net present worth of the project's future cash flows is $77,254 based on the discounted total anticipated cash inflows and outflows. In addition, the project's annual cost of $5234 is shown. It is lucrative and offers a similar annual worth of cash flows throughout its lifetime. The project is profitable as the ROI is 14.5 % and it has an internal rate of return (IRR) of 18.6 %, which represents the project's predicted rate of return and its

Table 5
Categorized optimization results in HOMER.

Configurations	PV	WT	DG	Battery	Converter	PV (kW)	WT (kW)	DG (kW)	Battery (kW)	Converter (kW)	Initial Capital ($)	LCOE ($)	TNPC ($)	Dispatch
Project 1	✓	✓	✓	✓	✓	13.2	2	10	20	6	48312	0.322	180065.43	LF
Project 2		✓	✓	✓	✓	0	3	10	12	6	25402	0.385	215248.30	LF
Project 3			✓			0	0	10	0	0	3700	0.461	257319.94	CC
Project 4	✓		✓		✓	0.000085	0	10	0	0.102	3761	0.461	257426.70	CC
Project 5		✓	✓		✓	0	1	10	0	1.67	7991	0.464	258895.00	CC
Project 6	✓	✓	✓		✓	2.17	1	10	0	1.88	11194	0.466	260307.50	CC
Project 7			✓	✓	✓	0	0	10	4	0.0419	6925	0.468	261507.50	LF
Project 8	✓		✓	✓	✓	0.716	0	10	4	0.0176	7927	0.471	262740.20	CC

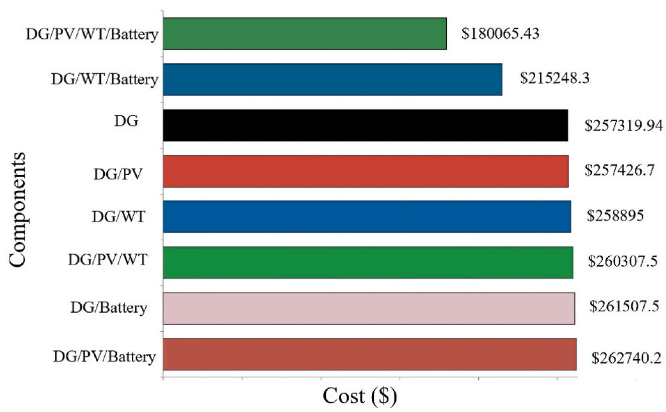

Fig. 9. TNPC in different solar radiation and diesel fuel price scenarios.

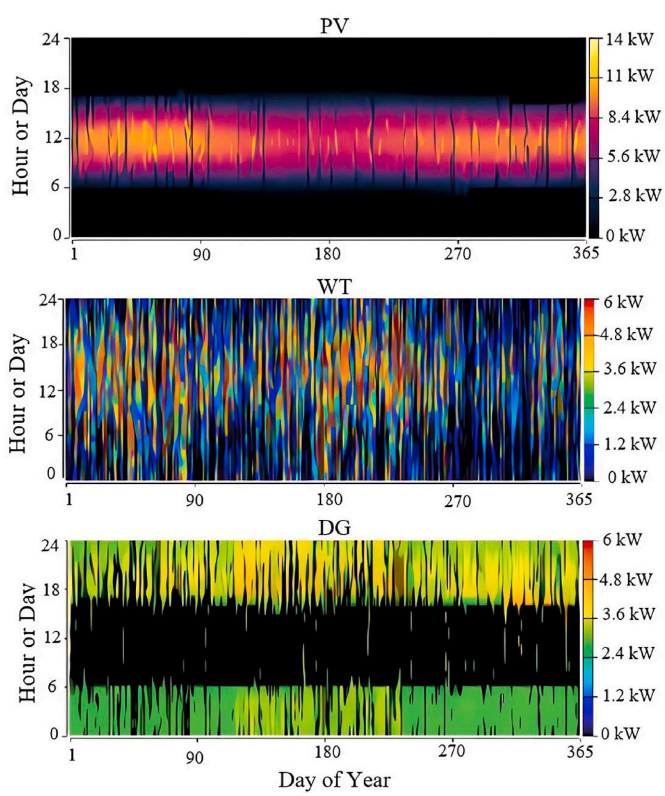

Fig. 10. Power output in the outcomes of the simulation in PV, WT, and DG.

profitability. The simple payback period for recovering the initial investment is 5.37 years when only cash flows are considered, without taking into account the time value of money. The 6.03-year payback period is calculated based on the time value of money and shows the time required to recover the initial expenditure. When these financial metrics are combined, they provide a favorable picture of a successful project.

For energy production sector investors, it can be advantageous to meet the appropriate financial requirements. Investors are more likely to boost the production of renewable products if the investment return period is shorter. Regarding RESs, this feature could drastically reduce their initial cost. As a result, this project can be one of the options for attracting investment in the renewable energy production business with a quick return on investment.

The OC in the base system is 65.29 % of the TNPC of the project. The integration of DG with RESs has reduced the OC share of DG in TNPC to 43.68 %. Renewable resources have a high initial cost compared to other expenditures, which is one of the main obstacles to their non-use. The results presented by HOMER software, which include 8 different configurations of DG and RES combination in Table 8, show that the capital cost in PV and WT is 19011.38 and 6000 dollars, respectively. According to the total cost of each component, the capital cost in PV and WT accounts for 76.11 % and 77.68 % of the total cost of each of these two components, respectively.

The DG incurs a significantly lower capital cost in comparison to WT and PV. However, the total cost for the DG amounts to $117,145.93 due to increased fuel and OC. Consequently, the total cost for the DG surpasses that of other components. By the conclusion of the project's lifecycle, year 25 remains the solerevenue generating period, with salvage costs amounting to $5304.86. Due to their distinct construction and the presence of more recyclable materials compared to other equipment, batteries contribute to 68.25 % of the revenue in year 25. The increased output of renewable energy and the rapid payback period associated with renewable resources have mitigated the impact of fuel costs on the TNPC, 12.17 % of the TNPC is allocated towards fuel costs. Additionally, endeavors to reduce fuel costs to zero not only eliminate the adverse effects of gasoline on the TNPC but also foster an environment devoid of pollution.

CO_2, carbon monoxide (CO), particulate matter (PM), sulfur dioxide (SO_2), unburned hydrocarbons (UHC), and nitrogen oxides (NO_X) are the six primary pollutants assessed using HOMER [57]. CO_2 emerges as the most potent and prevalent pollutant resulting from the combustion of fossil fuels, as indicated by an assessment of the emissions of the six major pollutants in Table 9 by the HOMER software. Maximizing the utilization of RESs alongside DG leads to a significant reduction in CO_2 emissions, a reduction that is evident in Refs. [58,59]. Project 1 distinctly demonstrates this variance in CO_2 emissions. The substantial impact of incorporating renewable sources in curbing future emissions, particularly CO_2, is profound. It is paramount to extensively integrate RESs in energy production from fossil fuels, as the latter emit significantly more CO_2 compared to other pollutants. One of the primary consequences of this process is the massive generation of CO_2, a key

Table 6
Provides a cost-benefit analysis contrasting the recommended system with the baseline system.

System	PV	WT	DG	Battery	Converter	PV (kW)	WT (kW)	DG (kW)	Battery (kW)	Converter (kW)	Operating cost ($)	TNPC ($)	UEL (kWh/year)	CO2 Emission (kg/year)
Base System			✓					10			168004.60	257319.19	20.9	39261
Proposed System	✓	✓	✓	✓	✓	13.4	2	10	20	6	78670.40	180065.43	0	15523

Table 7
Economic comparison between optimal and base modes.

Metric	Value
Present worth ($)	77254
Annual worth ($/year)	5234
Return on investment (%)	14.5
Internal rate of return (%)	18.6
Simple payback (year)	5.37
Discounted payback (year)	6.03

greenhouse gas responsible for environmental issues such as global warming.

The six primary pollutants assessed in HOMER across all emission modes in the comparative analysis of all optimization results categorized in 8 projects by HOMER are listed below:

CO_2 emission > NO_X emission > CO emission > SO_2 emission > PM emission > UHC emission.

4. Conclusion

This study explores the sustainability of off-grid HRES in remote areas of Iran through the examination of various scenarios related to diesel fuel pricing and solar radiation intensity. The investigation focused on the potential energy generation from RESs based on Iran's climatic conditions. This research addresse the fundamental challenges associated with the high OC of DG, emission of pollutants, and UEL. The study compares eight distinct HRES configurations using HOMER software, including PV/WT/DG/battery, WT/DG/battery, DG, PV/DG, WT/DG, PV/WT/DG, DG/battery, and PV/DG/battery. Various factors, such as energy demand estimation, resource allocation, cost analysis, and system pollutant emissions, are taken into account in the development of the system's operational strategy. The results from Project 1 over a 25-year design period revealed that the PV/WT/DG/battery configuration, with specific component specifications, led to minimized TNPC of $180,065.43 and a reduced LCOE of $0.3223, achieving reductions in OC, CO_2 emissions, and TNPC by 53.17 %, 60.46 %, and 30.02 %, respectively. Analysis of the HOMER simulation data suggests that the LF strategy aims to emit fewer pollutants compared to the CC strategy. The problem of the high OC of DG is reduced by combining RESs. By resolving load shortages to meet energy demands, the electricity quality in the region has improved, and the issue of UEL has been completely addressed, achieving the primary objective of Project 1. Emphasizing the production of clean energy has significantly reduced the operational cost impact of DG on TNPC. Contrastingly, integrating DG with solar and wind energy to fulfill 100 % of the load requirement has enhanced the power quality. The development of more sustainable energy solutions using this technique aims to provide electricity to isolated populations. The study highlights that the high capital costs associated with PV and WT systems serve as a major deterrent for investment compared to DG. The study demonstrated that solar energy, supported by the Iran solar atlas and optimal solar radiation data for PVsystem design, could soon offer a viable alternative for supplying electricity to remote rural areas. The proposed integrated system based on renewable energy demonstrated a promising emission profile with substantial annual emissions reduction, addressing issues of unmet demand and operational costs. A feasible approach recommends maximizing the utilization of RESs to achieve the study's objectives by boosting renewable equipment manufacturing and reducing initial costs. The village of Nimbazaar in the Sistan and Baluchistan province served as a case study for this research. Nimbazaar Zahedan village possesses significant potential for solar system deployment, marking the first study of its kind for this locale. It is advisable for the local government of Nimbazaar to conduct feasibility studies for other community areas alongside the implementation of integrated RESs. This initiative presents an opportunity to enhance electricity provision to Nimbazaar remote districts, while DG remains the primary electricity supplier for the city. Lastly, state agencies are encouraged to establish a robust framework facilitating private sector investment in integrated RESs. The author's proposal to encourage greater utilization of renewable resources involves enhancing production and reducing acquisition costs through government and private investments. Advanced technology of this nature has the potential to boost RESs production capacity, meet neighboring cities' energy demands, and generate revenue by selling surplus electricity to the grid. In addition to catering to neighboring towns energy needs and earning revenue through electricity sales to the central grid, this advanced technology increases RESs production capacity, reduces

Table 9
Emissions in optimal modes-project 1.

Configurations	**CO_2 (kg/year)**	**CO (kg/year)**	**UHC (kg/year)**	**PM (kg/year)**	**SO_2 (kg/year)**	**NO_X (kg/year)**
Project 1	15523	117	4.28	7.12	38.1	133
Project 2	25539	193	7.04	11.7	62.7	220
Project 3	39261	297	10.8	18	96.3	338
Project 4	39261	297	10.8	18	96.3	338
Project 5	36089	273	9.95	16.5	88.5	310
Project 6	34073	258	9.39	15.6	83.6	293
Project 7	39261	297	10.8	18	96.3	338
Project 8	39206	297	10.8	18	96.2	337

Table 8
Results categorized by cost type.

Components	**Capital Cost ($)**	**Replacement Cost ($)**	**Operating Cost ($)**	**Fuel Cost ($)**	**Salvage Cost ($)**	**Total Cost ($)**
DG	3700	13054.76	78670.4	21923.64	−202.87	117145.93
Battery	16000	6860.88	4722.91	0	−3620.89	23962.9
WT	6000	2466.31	737.95	0	−1481.1	7723.17
PV	19011.38	0	5964.55	0	0	24975.93
Converter	3600.5	0	2657	0	0	6257.5
System	48311.88	22381.96	92752.81	21923.64	−5304.86	180065.43

pollution emissions, lowers intensity, and contributes to combating global warming.

CRediT authorship contribution statement

Mehrdad Heidari: Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Mehran Heidari:** Writing – review & editing, Writing – original draft, Visualization, Validation, Formal analysis, Data curation, Conceptualization. **Alireza Soleimani:** Writing – original draft, Validation, Software, Methodology, Investigation, Formal analysis, Conceptualization. **Behrouz Mehdizadeh Khorrami:** Writing – review & editing, Validation, Methodology, Investigation. **Anna Pinnarelli:** Writing – review & editing, Supervision, Funding acquisition, Formal analysis. **Pasquale Vizza:** Writing – review & editing, Validation, Investigation. **Maria Dzikuć:** Writing – review & editing, Supervision, Methodology.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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References

[1] H. Herwandi, L. Kamajaya, F. Fitri, Designing and analyzing a hybrid photovoltaic-biomass microgrid for rural communities, Int. J. Renew. Energy Resour. 13 (2023) 1070–1081, https://doi.org/10.20508/ijrer.v13i3.14003.g8781.
[2] A. Toopshekan, P. Rahdan, M.A. V Rad, F.R. Astaraei, Evaluation of a stand-alone CHP-hybrid system using a multi-criteria decision making due to the sustainable development goals, Sustain. Cities Soc. 87 (2022) 104170, https://doi.org/10.1016/j.scs.2022.104170.
[3] M. Murshed, I. Ozturk, Rethinking energy poverty reduction through improving electricity accessibility: a regional analysis on selected African nations, Energy 267 (2023) 126547, https://doi.org/10.1016/j.energy.2022.126547.
[4] C. Mokhtara, B. Negrou, N. Settou, B. Settou, M.M. Samy, Design optimization of off-grid hybrid renewable energy systems considering the effects of building energy performance and climate change: case study of Algeria, Energy 219 (2021) 119605, https://doi.org/10.1016/j.energy.2020.119605.
[5] S. Barakat, M.M. Samy, M.B. Eteiba, W.I. Wahba, Viability study of grid connected PV/Wind/Biomass hybrid energy system for a small village in Egypt, in: 18th International Middle East Power Systems Conference (MEPCON), IEEE, 2016, December, pp. 46–51, https://doi.org/10.1109/MEPCON.2016.7836870.
[6] I.C. Meitei, R. Pudur, Optimize model of hybrid renewable system with minimum power fluctuation rate, in: 6th International Conference on Computing, Communication and Automation (ICCCA), IEEE, 2021, December, pp. 389–394, https://doi.org/10.1109/ICCCA52192.2021.9666352.
[7] A.K. Bhoi, K.S. Sherpa, A. Kalam, G.S. Chae, Advances in Greener Energy Technologies, TIDEE: TERI Information Digest on Energy and Environment, vol. 20, 2021, 278-278.
[8] S. Susan, D. Wardhani, Building integrated photovoltaic as GREENSHIP'S on site renewable energy tool, Results in Engineering (RINENG) 7 (2020) 100153, https://doi.org/10.1016/j.rineng.2020.100153.
[9] G. Xinxin, S. Qi, Z. Mingfeng, Z. Qi, L. Shuangshou, L. Weiran, Operation optimization strategy of a BIPV-battery storage hybrid system, Results in Engineering (RINENG) 18 (2023) 101066, https://doi.org/10.1016/j.rineng.2023.101066.
[10] M. Peyvandi, A. Hajinezhad, S.F. Moosavian, Investigating the intensity of GHG emissions from electricity production in Iran using renewable sources, Results in Engineering (RINENG) 17 (2023) 100819, https://doi.org/10.1016/j.rineng.2022.100819.
[11] Z. Zhang, K. Wen, W. Sun, Optimization and sustainability analysis of a hybrid diesel-solar-battery energy storage structure for zero energy buildings at various reliability conditions, Sustain. Energy Technol. Assessments 55 (2023) 102913, https://doi.org/10.1016/j.seta.2022.102913.
[12] A. Shirole, M. Wagh, V. Kulkarni, P. Patil, Short-term energy scenario of district energy system using optimised renewable energy mix with and without energy storage, Results in Engineering (RINENG) 18 (2023) 101017, https://doi.org/10.1016/j.rineng.2023.101017.
[13] Q. Hassan, S. Algburi, A.Z. Sameen, H.M. Salman, M. Jaszczur, A review of hybrid renewable energy systems: solar and wind-powered solutions: challenges, opportunities, and policy implications, Results in Engineering (RINENG) 23 (2023) 101621, https://doi.org/10.1016/j.rineng.2023.101621.
[14] N.F. Alshammari, M.M. Samy, S. Barakat, Comprehensive analysis of multi-objective optimization algorithms for sustainable hybrid electric vehicle charging systems, MDPI, Mathematics 11 (2023) 1741, https://doi.org/10.3390/math11071741.
[15] M.S. Saleem, N. Abas, Optimizing renewable polygeneration: a synergetic approach harnessing solar and wind energy systems, Results in Engineering (RINENG) 21 (2024) 101743, https://doi.org/10.1016/j.rineng.2023.101743.
[16] B. Singh, A. Kumar, Optimal energy management and feasibility analysis of hybrid renewable energy sources with BESS and impact of electric vehicle load with demand response program, Energy 278 (2023) 127867, https://doi.org/10.1016/j.energy.2023.127867.
[17] H. Kiani, M. Najafi, H. Gharibvand, M.H. Nazari, G.B. Gharehpetian, S. H. Hosseinian, Optimal design and economic comparison of a hybrid energy system in Iran and Switzerland with sensitivity analysis, in: 13th Smart Grid Conference (SGC), IEEE, 2023, December, pp. 1–8, https://doi.org/10.1109/SGC61621.2023.10459308.
[18] M.M. Samy, A. Emam, E. Tag-Eldin, S. Barakat, Exploring energy storage methods for grid-connected clean power plants in case of repetitive outages, J. Energy Storage 54 (2022) 105307, https://doi.org/10.1016/j.est.2022.105307.
[19] A.F. Güven, M.M. Samy, Performance analysis of autonomous green energy system based on multi and hybrid metaheuristic optimization approaches, Energy Convers. Manag. 269 (2022) 116058, https://doi.org/10.1016/j.enconman.2022.116058.
[20] A.F. Güven, N. Yörükeren, M.M. Samy, Design optimization of a stand-alone green energy system of university campus based on Jaya-Harmony Search and Ant Colony Optimization algorithms approaches, Energy 253 (2022) 124089, https://doi.org/10.1016/j.energy.2022.124089.
[21] M.M. Samy, R.E. Almamlook, H.I. Elkhouly, S. Barakat, Decision-making and optimal design of green energy system based on statistical methods and artificial neural network approaches, Sustain. Cities Soc. 84 (2022) 104015, https://doi.org/10.1016/j.scs.2022.104015.
[22] S. Barakat, A. Emam, M.M. Samy, Investigating grid-connected green power systems' energy storage solutions in the event of frequent blackouts, Energy Rep. 8 (2022) 5177–5191, https://doi.org/10.1016/j.egyr.2022.03.201.
[23] M.M. Samy, H.H. Sarhan, S. Barakat, S.A. Al-Ghamdi, A hybrid pv-biomass generation based micro-grid for the irrigation system of a major land reclamation project in kingdom of Saudi Arabia (ksa)-case study of albaha area, in: IEEE International Conference on Environment and Electrical Engineering and 2018 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), 2018, June, pp. 1–8, https://doi.org/10.1109/EEEIC.2018.8494543.
[24] M.M. Samy, H.I. Elkhouly, S. Barakat, Multi-objective optimization of hybrid renewable energy system based on biomass and fuel cells, Int. J. Energy Res. 45 (2021) 8214–8230, https://doi.org/10.1002/er.5815.
[25] S. Barakat, M.M. Samy, M.B. Eteiba, W.I. Wahba, Feasibility study of grid connected PV-biomass integrated energy system in Egypt, Int. J. Emerg. Elec. Power Syst. 17 (2016) 519–528, https://doi.org/10.1515/ijeeps-2016-0056.
[26] M.B. Eteiba, S. Barakat, M.M. Samy, W.I. Wahba, Optimization of an off-grid PV/Biomass hybrid system with different battery technologies, Sustain. Cities Soc. 40 (2018) 713–727, https://doi.org/10.1016/j.scs.2018.01.012.
[27] N. Alshammari, M.M. Samy, J. Asumadu, Optimal economic analysis study for renewable energy systems to electrify remote region in Kingdom of Saudi Arabia, in: 20th International Middle East Power Systems Conference (MEPCON), IEEE, 2018, December, pp. 1040–1045, https://doi.org/10.1109/MEPCON.2018.8635287.
[28] A.F. Tazay, M.M. Samy, S. Barakat, A techno-economic feasibility analysis of an autonomous hybrid renewable energy sources for university building at Saudi Arabia, J. Electr. Eng. Technol. 15 (2020) 2519–2527, https://doi.org/10.1007/s42835-020-00539-x.

[29] I.C. Meitei, R. Pudur, Optimization of wind solar and battery hybrid renewable system using backtrack search algorithm, Indones, J. Electr. Eng. Comput. Sci 24 (2021) 1269–1277, https://doi.org/10.11591/ijeecs.v24.i3.pp1269-1277.
[30] S. Chakraborty, D. Mukherjee, P.K. Guchhait, S. Bhattacharjee, A.Y. Abdelaziz, A. El-Shahat, Optimum design of a renewable-based integrated energy system in autonomous mode for a remote hilly location in Northeastern India, Energies 16 (2023) 1588, https://doi.org/10.3390/en16041588.
[31] H. Hekmatnia, A. Fatahi Ardakani, A. Mashayekhan, M. Akbari, Assessing economic, social, and environmental impacts of wind energy in Iran with focus on development of wind power plants, J. Renew. Energy Environ. 7 (2020) 67–79, https://doi.org/10.30501/jree.2020.216401.1074.
[32] M.A. Ebrahim, S.M. Ramadan, H.A. Attia, E.M. Saied, M. Lehtonen, H. A. Abdelhadi, Improving the performance of photovoltaic by using artificial intelligence optimization techniques, Int. J. Renew. Energy Resour. 11 (2021) 46–53, https://doi.org/10.20508/ijrer.v11i1.11563.g8107.
[33] Global solar atlas, Available from: https://globalsolaratlas.info/map, 2023. (Accessed 1 September 2023).
[34] T. Abdali, S. Pahlavan, M. Jahangiri, A. Alidadi Shamsabadi, F. Sayadi, Techno-Econo-Environmental study on the use of domestic-scale wind turbines in Iran, Energy Equip. Syst. 7 (2019) 317–338, https://doi.org/10.22059/ees.2019.37669.
[35] S. Bahramara, M.P. Moghaddam, M.R. Haghifam, Optimal planning of hybrid renewable energy systems using HOMER: a review, Renew. Sustain. Energy Rev. 62 (2016) 609–620, https://doi.org/10.1016/j.rser.2016.05.039.
[36] Office of planning and macroeconomics of electricity and energy (2020)—ministry of energy in Iran, Available from: http://www.pep.moe.gov.ir, 2020.
[37] Fuel consumption optimization company in Iran, Available from: https://ifco.ir/images/99/energy99/tarazname96naft.pdf, 2017.
[38] M. Mohammadi, R. Ghasempour, F.R. Astaraei, E. Ahmadi, A. Aligholian, A. Toopshekan, Optimal planning of renewable energy resource for a residential house considering economic and reliability criteria, Int. J. Electr. Power Energy Syst. 96 (2018) 261–273, https://doi.org/10.1016/j.ijepes.2017.10.017.
[39] L. Uwineza, H.G. Kim, C.K. Kim, Feasibility study of integrating the renewable energy system in Popova Island using the Monte Carlo model and HOMER, Energy Strategy Rev. 33 (2021) 100607, https://doi.org/10.1016/j.esr.2020.100607.
[40] I. Rahimi, M.R. Nikoo, A.H. Gandomi, Techno-economic analysis for using hybrid wind and solar energies in Australia, Energy Strategy Rev. 47 (2023) 101092, https://doi.org/10.1016/j.esr.2023.101092.
[41] Y.Z. Alharthi, M.K. Siddiki, G.M. Chaudhry, Resource assessment and techno-economic analysis of a grid-connected solar PV-wind hybrid system for different locations in Saudi Arabia, MDPI, Sustain 10 (2018) 3690, https://doi.org/10.3390/su10103690.
[42] J. Barzola, M. Espinoza, F. Cabrera, Analysis of hybrid solar/wind/diesel renewable energy system for off-grid rural electrification, Int. J. Renew. Energy Resour. 6 (2016) 1146–1152, https://doi.org/10.20508/ijrer.v6i3.4301.g6898.
[43] A.S. Aziz, M.F.N. Tajuddin, M.R. Adzman, M.A. Ramli, Feasibility analysis of PV/diesel/battery hybrid energy system using multi-year module, Int. J. Renew. Energy Resour. 8 (2018) 1980–1993, https://doi.org/10.20508/ijrer.v8i4.8333.g7506.
[44] A.S. Awad, J.D. Fuller, T.H. El-Fouly, M.M. Salama, Impact of energy storage systems on electricity market equilibrium, IEEE Trans. Sustain. Energy 5 (2014) 875–885, https://doi.org/10.1109/TSTE.2014.2309661.
[45] K. Tiwari, B. Singh, Multienergy source-based microgrid incorporating dual-mode IFC control approach under abnormal grid circumstances, IEEE Trans. Ind. Inf. 20 (2023) 1–9, https://doi.org/10.1109/TII.2023.3303463.
[46] L. Liu, D. Zhou, J. Zou, W. Wang, Zero-vector-regulation-based closed-loop power distribution strategy for dual-DC-port DC–AC converter-connected PV–battery hybrid systems, IEEE Trans. Power Electron. 38 (2023) 6956–6968, https://doi.org/10.1109/TPEL.2023.3242839.
[47] T.S. Mehang, Y. Tanoto, M. Santoso, Potential of small size hybrid diesel-photovoltaic to improve sub-district supply duration in East Sumba, Indonesia, Int. J. Renew. Energy Resour. 6 (2016) 964–969, https://doi.org/10.20508/ijrer.v6i3.4008.g6878.
[48] Z. Wang, G. Fang, X. Wen, Q. Tan, P. Zhang, Z. Liu, Coordinated operation of conventional hydropower plants as hybrid pumped storage hydropower with wind and photovoltaic plants, Energy Convers. Manag. 277 (2023) 116654, https://doi.org/10.1016/j.enconman.2022.116654.
[49] G. Fotis, V. Vita, T.I. Maris, Risks in the European transmission system and a novel restoration strategy for a power system after a major blackout, Appl. Sci. 13 (2022) 83, https://doi.org/10.3390/app13010083.
[50] V. Vita, G. Fotis, C. Pavlatos, V. Mladenov, A new restoration strategy in microgrids after a blackout with priority in critical loads, MDPI, Sustain 15 (2023) 1974, https://doi.org/10.3390/su15031974.
[51] S. Sambhi, H. Sharma, V. Bhadoria, P. Kumar, R. Chaurasia, G. Fotis, V. Vita, Technical and economic analysis of solar PV/diesel generator smart hybrid power plant using different battery storage technologies for SRM IST, Delhi-NCR Campus, MDPI, Sustain 15 (2023) 3666, https://doi.org/10.3390/su15043666.
[52] S. Vendoti, M. Muralidhar, R. Kiranmayi, Techno-economic analysis of off-grid solar/wind/biogas/biomass/fuel cell/battery system for electrification in a cluster of villages by HOMER software, J. Environ. Sustain. 23 (2021) 351–372, https://doi.org/10.1007/s10668-019-00583-2.
[53] J.O. Oladigbolu, M.A. Ramli, Y.A. Al-Turki, Optimal design of a hybrid PV solar/micro-hydro/diesel/battery energy system for a remote rural village under tropical climate conditions, MDPI, Electron. 9 (2020) 1491, https://doi.org/10.3390/electronics9091491.
[54] M. Sharafi, T.Y. Elmekkawy, Multi-objective optimal design of hybrid renewable energy systems using PSO-simulation based approach, Renew. Energy 68 (2014) 67–79, https://doi.org/10.1016/j.renene.2014.01.011.
[55] A.H. Mamaghani, S.A.A. Escandon, B. Najafi, A. Shirazi, F. Rinaldi, Techno-economic feasibility of photovoltaic, wind, diesel and hybrid electrification systems for off-grid rural electrification in Colombia, Renew. Energy 97 (2016) 293–305, https://doi.org/10.1016/j.renene.2016.05.086.
[56] M. Mohammadi, R. Ghasempour, F.R. Astaraei, E. Ahmadi, A. Aligholian, A. Toopshekan, Optimal planning of renewable energy resource for a residential house considering economic and reliability criteria, Int. J. Electr. Power Energy Syst. 96 (2018) 261–273, https://doi.org/10.1016/j.ijepes.2017.10.017.
[57] J.G. Akinbomi, L.C. Ezeilo, O. Fagbuyi, L. Onyebueke, Optimal microgrid power supply system for Nigerian detached communities: environmental impact and energy cost criteria, Niger, J. Technol. 40 (2021) 491–500, https://doi.org/10.4314/njt.v40i3.15.
[58] R. Dai, X. Zhang, J.D. McCalley, G. Liu, Z. Wang, Multilevel dispatch and control for grid interconnected wind-CAES hybrid systems, in: 4th Conference on Energy Internet and Energy System Integration (EI2), IEEE, 2020, October, pp. 1182–1186, https://doi.org/10.1109/EI250167.2020.9346793.
[59] J.O. Oladigbolu, M.A. Ramli, Y.A. Al-Turki, Techno-economic and sensitivity analyses for an optimal hybrid power system which is adaptable and effective for rural electrification: a case study of Nigeria, MDPI, Sustain 11 (2019) 4959, https://doi.org/10.3390/su11184959.