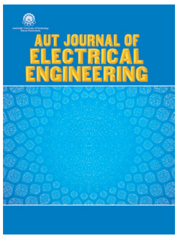

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Optimal Hybrid Renewable Energy System Design: A Techno-Economic Analysis Across Diverse Sites

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ABSTRACT: Enhancing the efficiency and environmental compatibility of hybrid systems through renewable energy sources is a highly motivating concept. Two tourist destinations, one Sarab Gian region in Nahavand city of Iran and the other in Zurich city in Switzerland, were analyzed. Using HOMER Pro software, photovoltaic panels (PVs), wind turbines (WTs), battery energy storage systems (BESS), and diesel generators (DGs) were evaluated. Sensitivity factors such as varying fossil fuel costs, fuel supply limitations, inflation rates, discount rates, carbon dioxide penalties, and capacity shortages were taken into account. The findings indicate that as fuel prices and emission penalties rise, renewable resources become more cost-effective. Comparing the lowest net present cost (NPC) in Switzerland to Iran, which is also influenced by fuel prices, 180% increase was observed. Furthermore, due to the impact of fuel prices and the optimal capacity of PVs, we observed a 5.3% increase in total operational costs in scenario Sarab Gian (CA) compared to Zurich (CB). Additionally, Switzerland benefits from lower inflation and discount rates, leading to a 19.3% reduction in NPC and a 41% decrease in the cost of energy (COE) compared to Iran. This study emphasizes the economic feasibility of renewable energy in hybrid systems, particularly in regions with high fossil fuel costs and strict emission regulations.

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1- Introduction

1- 1- Motivation and approach

The role of energy supply in the socio-economic growth of any nation is crucial, as reliable and sustainable energy provision is a prerequisite for survival in modern civilization [1,2,3]. On the other hand, energy consumption in developing countries is increasing due to population growth, the rapid evolution of living standards, and the rise in per capita consumption [4,5]. However, the required energy must be environmentally friendly, affordable, reliable, efficient, and always available [6]. Various types of energy sources exist, including conventional and renewable (unconventional) energy. Conventional energy sources encompass coal, oil, natural gas, and other fossil fuels. A common Traditional energy system is the diesel generator, which provides a stable base load, the lowest cost among all combined heat and power (CHP) systems, high efficiency, short startup times to full loads, and high reliability. Nevertheless, it contributes to environmental pollution and increases greenhouse gas emissions, which are not environmentally friendly [7,8]. However, many developing countries are unable to provide their customers with electricity through such types of power supply [9]. Furthermore, due to the depletion of conventional energy reserves and their environmental impacts, the emergence of a new global energy policy focusing on the use of renewable energy sources has become essential [10]. Unplanned, frequent, and prolonged network outages are a common problem in most developing countries [11]. Therefore, to estimate future energy demand, systems based on renewable energy sources are essential [4]. In the last two decades, significant progress has been made in the usage of renewable energies, making them capable of generating power at mega-scale capacities, such as solar energy [12], wind energy [13], and biomass energy [14]. Renewable energy systems can be configured in standalone/off-grid [15], [16], [17], [18] or grid-connected [19] configurations. PV systems, due to their low maintenance, lack of moving mechanical parts, silent operation, and environmental compatibility, are rapidly gaining attention. However, their output, like other intermittent renewable energies, depends on weather conditions, which can be mitigated by integrating them into a hybrid system [15,16]. This demonstrates that alongside other renewable sources and energies such as fuel cells, diesel, wind, and storage technologies like batteries and supercapacitors are used to enhance system stability and smooth out fluctuations [1]. Furthermore, one of the primary concerns regarding renewable energy systems (RES) is energy loss during conversion from natural sources to

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usable forms and during transmission and distribution. One potential solution is the use of modern technologies such as microgrids (MGs), which are controllable electrical networks that can operate in grid-connected or standalone modes. An MG by itself can integrate solar photovoltaics (PV), wind turbine generators (WTG), biomass generators (BMG), diesel generators (DG), and battery sources to provide clean, economical, efficient, and sustainable solutions for every area's integration [4].

1- 2- literature review

In [20], for providing reliable electricity in a village, a hybrid renewable energy system (HRES) including PV, WT, BESS, DG, and biogas generator (BG) have been studied. Socio-techno-economic-environmental (STEE) effects have also been analyzed. The goal in [21] is to model a HRES that is environmentally compatible, economically stable, and also meet technical considerations in the design. An analysis of fuel prices has also been carried out. In [22], optimal sizing of a HRES, considering cash resources has been done. In the proposed model, differential design (DE) is used to reduce energy consumption and optimize the system. The object in [23] is to find the optimal configuration of a HRES in rural areas of north and south of Iran using multi-criteria decision-making (MCDM). Considering the good potential of solar and wind power in Turkalan village located in East Azarbaijan province, the use of an isolated system including solar-wind-DG with BESS has been studied in [24]. Also, sensitivity analysis on parameters such as sunlight and its reflection as well as wind speed have been done. Authors in [25] With the aim of reliability investigation and cost optimization of an isolated system in four regions of Iran including Hamedan, Zahedan, Kerman, and Birjand conducted research. The results indicated that reliability has been increased using storage equipment such as BESS and backup equipment including DG with demand response (DR). In [26], the design of a system with real prices of equipment and fossil fuels has been analyzed, taking into account, transportation costs. A comprehensive study of energy-economy-environment with renewable energy production has also been done. In [27], a network consisting of 3 WT units is modeled, the objective of which is to minimize the costs after attacks on the target system, which is solved by the CPLEX solver of the mixed integer linear programming (MILP) model. In [28], an optimal power planning and techno-economic-environmental analysis of a hybrid renewable energy system has been designed to simultaneously meet electrical and thermal loads. The goal is to minimize greenhouse gas (GHG) emissions, cost of energy (COE), and annual net present costs (NPC). In this paper, considering government regulations, including carbon taxes and subsidies, the issue of generation expansion planning is modeled using a game theory approach. This has resulted in a reduction in CO2 emissions from power plants [29]. The aim in [30] is to find the optimal size and techno-economic analysis of an energy-efficient and cost-effective standalone multi-carrier microgrid (SMCMG). Using real data from Rafsanjan, Iran, evolution particle swarm optimization (E-PSO) was applied to this research. In [31], economic optimization has been conducted for medium-sized hotels situated on Kish Island, taking into account both renewable and CON options. Also, the effect of wind speed, solar irradiance, and fuel costs as variables has been taken into account. The results suggest that to combination of PV/DG/WT/BESS can be an optimal design to supply the electricity demand of the hotel.

1- 3- Research gap and Contributions

According to the literature review, to the best of the author's knowledge, no study has focused on the optimal design of a hybrid energy system in two different locations with proportionally the same weather conditions across two different countries. This is done to minimize the effect of weather inputs in the comparison and focus on economic inputs. The significance of this research lies in its better ability to compare the impact of economic conditions in Iran and Switzerland as two developing and developed countries respectively.

The purpose of this paper is to design and analyze a hybrid system including renewable energies such as solar and wind, as well as the use of storage devices such as BESS and supporting equipment like DG to supply the load of a tourism complex. The mentioned tourism complex includes a hotel and a hypermarket. A comparative overview of recent studies on HRES from the existing literature, along with the present study, is presented in Table I. The considered economic factors are net present cost (NPC), annual costs of the studied system, and cost of energy (COE). The following list includes the main items of this research:

- Economic evaluation of supplying the tourism complex demand for two different locations with different weather conditions and different costs for the components of the proposed hybrid system.
- The studied microgrid is formed by integrating existing energy sources such as PV, WT, BESS, DG, and CON, which can improve local social and economic activities by providing a reliable electricity supply.
- Different sensitivity variables are considered including 3 different fuel prices (the fuel price of each country, the average global fuel price, and a hypothetical price higher than the global average), 2 Inflation rates and 2 discount rates, restrictions on fuel supply, lack of capacity shortage (CS) (or annual capacity shortage) and carbon emissions tax.
- The optimal combination of systems in some cases with different sensitivity values is presented to supply the load with the lowest NPC and COE.

The paper's subsequent sections are structured as follows: in Section 2 provides Detailed geographical and technical simulation data. Section 3 covers economic variables and sensitivity parameters. Section 4 thoroughly examines and analyses the impacts of each variable on the desired outcomes. After that, a summary conclusion is presented in Section 5.

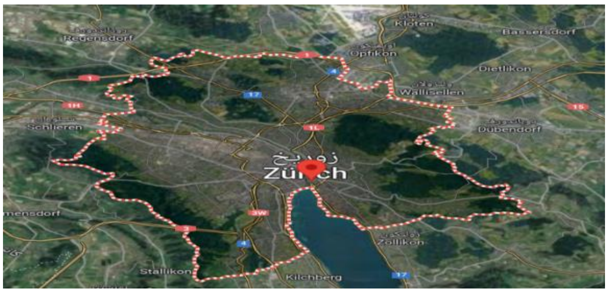
The primary objective of this research is to design a hybrid system to supply electricity to a tourism complex located in two different locations. Given that the climatic

Table 1. A brief overview of recent researches in the field of HRES

Ref.	Methodology	Load Modeling		Hybrid Energy Sources					ESS	Sensitivity variables					
		Electric	Thermal	PW	WT	DG	BMG	boiler	BESS	D.W	F.L	F.P	C.S	G.E	D.I rate
[20]	HOMER	√		√	√	√	√		√						
[22]	HOMER/PSO/GA	√		√	√	√	√		√						
[23]	HOMER	√		√	√	√	√		√						
[24]	HOMER	√		√	√	√			√						
[25]	HOMER/PSO/ABSO	√		√	√	√			√						
[28]	HOMER	√	√	√	√	√		√	√		√	√	√	√	√
[30]	PSO/GA/HSA	√	√	√	√	√		√	√						
[31]	HOMER	√		√	√	√			√						
This study	HOMER	√		√	√	√			√	√	√	√	√	√	√

Different weather conditions (D.W), Fuel limit (F.L), Fuel price (F.P), Capacity shortage (CS), GHG Emission (G.E), Discount rate and
Inflation rate (D.I rate)

(a)



(b)

Fig. 1. Sarab Gian region (a) and Zurich city (b), (source: Google Maps)

data for Nahavand, in Iran, and Zurich, in Switzerland, are very similar, they are chosen as case studies. This approach allows us to minimize the impact of environmental variables at the comparison process and focus more on the economic aspects of the model in the two regions. By doing so, it can be determined which combination of energy sources is most suitable for each country. And the economic justifications for these choices can also be discussed.

2- Input data and constituent elements

2- 1- Location

Two case studies are considered in this work, the first case study (also called CA) is a hypothetical tourism complex in the Sarab Gian region Located in the Hamadan province of Iran. This city is situated in the southwest of Hamadan province and among the Zagros Mountains area and is visited by many tourists every year. In the second case study (also called CB), the above-mentioned tourism complex has been considered in the city of Zurich, located in Switzerland. Figure 1 shows the aerial view of the above places.

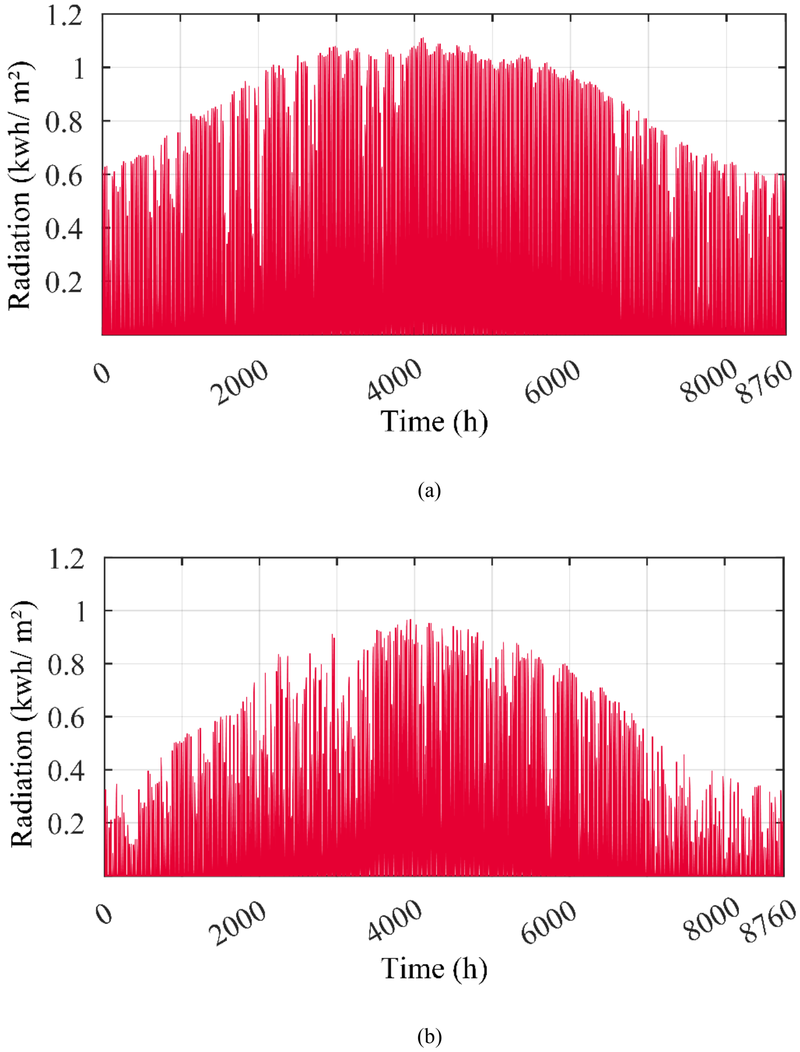


Fig. 2. Clearness index and solar radiation Sarab Gian (a) and Zurich(b)

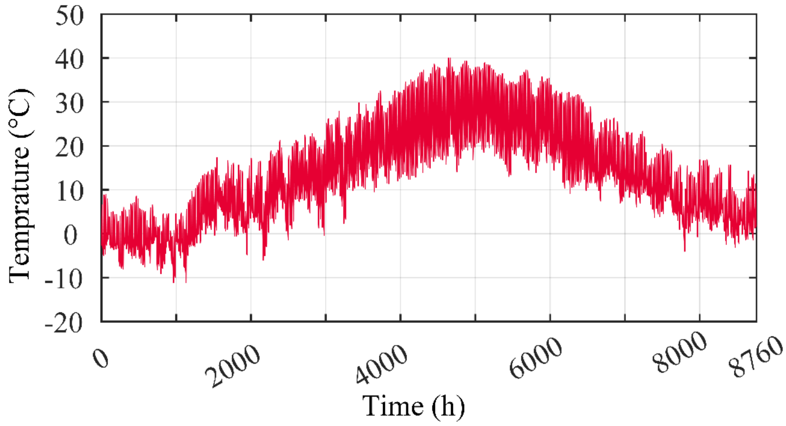
2- 2- Temperature and radiation

The solar radiation data are shown in Fig. 2. As shown in Fig. 3, temperature constitutes another vital factor affecting photovoltaic panels [32]. Figure 2 shows that solar radiation rarely reaches its maximum value of 1.10 kWh/m^2 for C_A and 0.98 kWh/m^2 for C_B. Also, the average transparency index for C_A and C_B were recorded as 0.588 and 0.467, respectively. Also, according to Figure 3, the highest daily temperature remains below 40°C for C_A and below 30°C for C_B.

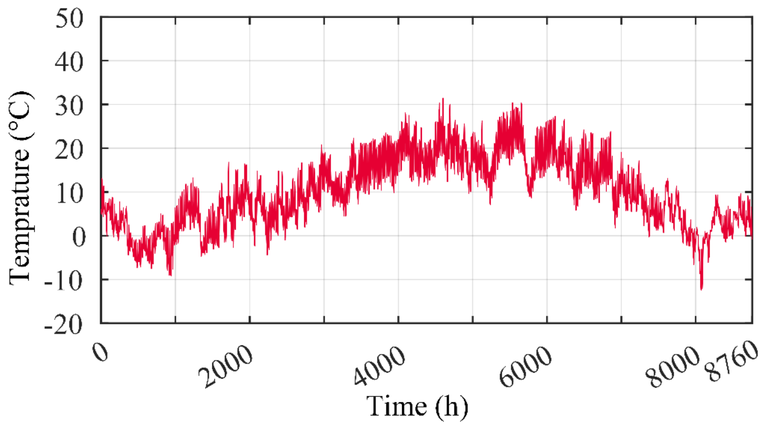
2- 3- Wind speed

Wind speed for case study C_B (city of Zurich) is shown in Fig. 4[32]. However, in the context of the case study C_A, WTs are excluded for two primary reasons. First, based on data from NASA, the wind speed of the area is not high. Second, the mountainous terrain is unsuitable for the installation of wind turbines.

Given that the hotel within the tourism complex is hypothetical, it is conceptualized as a mid-scale hotel establishment comprising 40 rooms. There are also other energy-consuming places such as the corridors, lobby, and kitchen Initially, the dimensions and consumption of the proposed hotel within the complex are determined. This has already been done in [33]. A mid-range hotel's area is generally calculated by multiplying the number of rooms by 100. The average annual consumption of the mentioned hotel is considered 14 kWh/ft2/year. Summer is considered the peak season for demand [33]. Then to gain whole tourism complex consumption, the hypermarket average consumption (nearly 400 kWh/day) which has been determined with field studies is added to hotel consumption Eqs. (1)-(3):



(a)



(b)

Fig. 3. Monthly average temperature Sarab Gian (a) and Zurich (b)

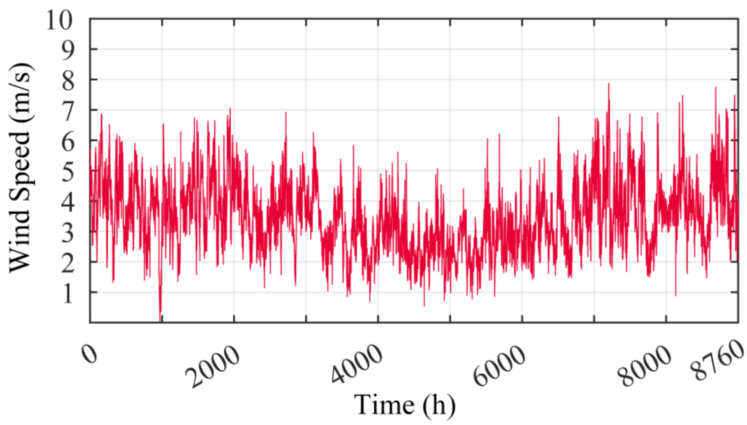


Fig. 4. Wind speed – Zurich city

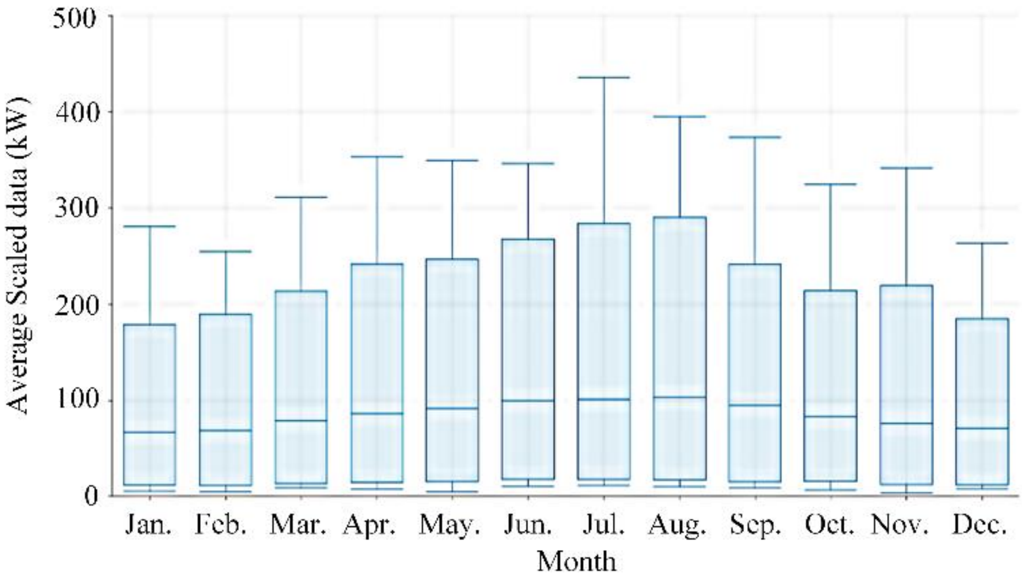


Fig. 5. Monthly average load

$$Hotel\ area = 100 \times 80 = 8000 m^2 = 86111.2 ft^2 \quad (1)$$

$$Hotel\ consumption = \frac{14 \times 43055.64}{365} = 1652 \frac{kWh}{day} \quad (2)$$

$$Tourism\ complex\ consumption = 2052 \frac{kWh}{day} \quad (3)$$

Fig. 5 shows the average monthly load determined by HOMER based on average load setting of 2052 kWh/day, 10% daily load variation, and summer peak selection.

Also, the condition of power balance according to the available resources and the calculated load is given in Eq. (4).

$$P^{DG} + P^{PV} + P^{WT} + P^{BESS} = P^{Load} \quad (4)$$

2- 4- Diesel Generator

Fuel flow rate, lower heating value (LHV), and electrical efficiency determine how much power a DG produces. DG produces produce electricity as Eq. (5) [34]:

$$P_{DG,e} = m_{fuel} \times LHV_{fuel} \times \eta_{DG,e} \quad (5)$$

In this equation, m_{fuel} is the fuel flow rate, and $\eta_{DG,e}$ represents diesel generator efficiency. The diesel generator's heat output is determined by its heat recovery ratio ($\eta_{DG,hr}$) which is presented in Eq. (6):

$$P_{DG,h} = m_{fuel} \times LHV_{fuel} \times \left(1 - \eta_{DG,e}\right) \times \eta_{DG,hr} \quad (6)$$

2- 5- PV Array

To increase the voltage and current of a PV array, different modules are connected in series and parallel. The output power of the array, based on the maximum power point tracking efficiency and the working conditions can be calculated with Eq. (7) [34].

$$P_{PV} = M_p \times M_s \times P_{mudule} \times \eta_{MPPT} \times \eta_{oth} \quad (7)$$

In this research, the effect of temperature on PV panels is taken into account to achieve more accurate results.

2- 6- Wind turbine

The output power of the wind turbine is obtained from the Eq. (8) [34]:

$$P_{WT} = \frac{1}{2} \times \rho \times A \times V^3 \times C_P \quad (8)$$

where ρ is the air density, A is the area of the turbine, V is the wind speed and C_P is the power factor of the WT.

2- 7- Battery energy storage system

Microgrid systems mostly include BESS for storing excess energy and supplying electricity when the generation is less than needed. The BESS has been proposed as a solution due to economic and technical considerations [35]. In this study, the battery employed is the Surrette 4 KS 25P model

2- 8- Converter

HOMER generic converter is used for the purpose of this research. Rectifiers and inverters in both modes are 95% efficient and the converter can be used parallel to a diesel generator.

2- 9- Problem optimization

In the proposed microgrid architecture, the primary goal is to optimize component sizing to minimize NPC of the system. A microgrid's development is significantly influenced by the economy. The cost of a microgrid increases significantly when technical constraints are considered. On the other hand, the reliability decreases by lowering the cost. A trade-off is to decrease system costs by incorporating the most cost-effective electrification methods in consideration of power electricity shortages [22].

The net present cost of the microgrid can be expressed as Eq. (9) [34]:

$$NPC = \frac{\left(C_{cap} + C_{rep} + C_{O\&M} + C_{fuel}\right)}{CRF} \quad (9)$$

where C_{cap}, C_{rep}, $C_{O\&M}$, C_{fuel} are the capital cost, replacement, operation & maintenance, and fuel costs respectively. CRF is also known as the capital recovery factor, which is calculated by Eq. (10) [34]:

$$CRF = \frac{i\left(1+i\right)^{n}}{\left(1+i\right)^{n} - 1} \quad (10)$$

Based on the nominal interest rate (*i'*) and expected inflation rate (*f*), (11) gives the annual real interest rate (*i*) in the form of Eq. (11):

$$i = \frac{i' - f}{1+f} \quad (11)$$

Microgrids are designed to provide the lowest COE in selected areas. COE ($/kWh) can be calculated from the average NPC using Eq. (12).

$$COE = \frac{\left(NPC\right)}{\sum_{N=1}^{8760} P_N} \times \phi_{cpv} \quad (12)$$

The proposed study aims to minimize NPC which will result in the least COE [22].

3- Sensitivity Variables and Costs

Various sensitivity parameters are chosen to generate 48 distinct scenarios for C_A and 96 distinct scenarios for C_B. Therefore, for current or potential future events, different decision-making scenarios can be examined and their effects analyzed. In relation to the selected sensitivity values, a few points need to be mentioned:

- There is no CO_2 penalty in Iran yet. However, it is estimated to be 12 dollars per ton of CO_2 [33]. The CO_2 penalty for Switzerland is 36 dollars per ton [36].

- In the case of a CS of 0%, load shedding will never happen. CS of 5% is also considered to examine the impact on costs caused by this variable.

- The current running price for Iranian diesel fuel is 0.006 $/Lit, while the global average price stands at 1.20 $/Lit [37]. 5 $/Lit represents a proposed situation in which the cost of fuel increases. Additionally, in Switzerland, the fuel price is 2.888 $/Lit [37].

- 24,000 liters of fuel is the limit based on the capacity of one tanker truck[33].

The nominal discount rate and expected inflation rate for Iran at the moment based on the average from 2000 to 2020 are 18% and 17% respectively [38]. In case of improvement in economic conditions, the other values for the nominal discount rate and the expected inflation rate for Iran are expected to be 10% and 11% respectively. Also, these variables are -0.5% and 1.6% in Switzerland [34]. Since Switzerland is a country with high economic stability, the next case values for these variables are considered to be 1% and 2% respectively (which are not that much different from the real values).

A schematic of the systems is given in the Fig.6 which includes 2 proposed scenarios that can be compared from technical and economic aspects. Please note that because of the aforementioned reasons, WT can only be present in C_B. The optimal configuration is determined by HOMER software.

• In C_A, the system in Sarab Gian can be composed of DG/PV/BESS.

• In C_B, the system in Zurich can be composed of DG/PV/WT/BESS.

Tables II and III present four types of main equipment cost variables, including initial cost, replacement cost, operation and maintenance cost, and device lifetime. Variables including the inflation rate, the discount rate, and the project's lifetime are presented in Table IV. Since inflation and discount rates fluctuate over time The most accurate results can be obtained using long-term average values.

Table 2. Economic data for the equipment of a case CA

Parameter	PV[40]	DG[40]	BESS[39]	CONV[33]
Investment cost ($/kW)	2000	300	1259	800
Replacement cost ($/kW)	2000	300	1100	700
Maintenance cost ($/year)	10	0.010	5	0
Lifetime (year)	25	90000	10	15

Table 3. Economic data for the equipment of a case CB

Parameter	PV[34]	DG[34]	BESS[34]	WT[34]	CONV[34]
Investment cost ($/kW)	1354	564	188	2257	530
Replacement cost ($/kW)	1354	451	169	1693	474
Maintenance cost ($/year)	4.51	0.034	1.8	22.6	11.3
Lifetime (year)	25	35000	5	25	15

Table 4. The project economic data

Parameter	value	
	C_A	C_B
Inflation rate (%)	17	0.93
Discount rate (%)	18	-0.5
Project lifetime (year)	25	25

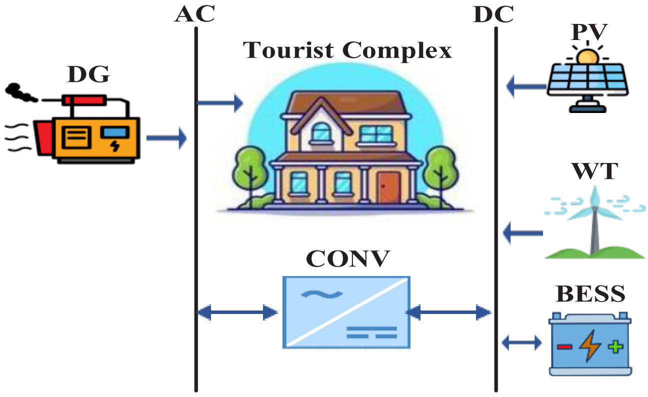


Fig. 6. Schematic of the system

Table 5. Economic comparison of case CA

Scenario number	Diesel fuel price ($/Lit)	Diesel fuel limitation (Lit/year)	Expected inflation rate (%)	Nominal discount rate (%)	CO2 penalty ($/t)	Capacity shortage (%)	Net present cost (NPC) (M$)	Cost of energy (COE) ($/kWh)	Initial capital (M$)	Operating cost ($/year)
3	0.006	0	17	18	0	0	1.281	0.076	0.303	43546.78
7	0.006	0	17	18	0	5	1.222	0.072	0.219	44713.55
19	1.2	0	17	18	0	0	3.888	0.231	2.29	71076.91
35	5	0	17	18	0	0	4.79	0.285	2.910	83053.61
7	0.006	0	17	18	0	5	1.222	0.072	0.219	44713.56
8	0.006	0	17	18	12	5	1.417	0.084	0.247	51270.78
3	0.006	0	17	18	0	0	1.281	0.076	0.303	43546.78
7	0.006	0	17	18	0	5	1.222	0.072	0.219	44713.55
5	0.006	0	11	10	0	5	1.472	0.069	0.240	43709.45
13	0.006	24000	11	10	0	5	1.101	0.057	0.219	44713.55
41	5	24000	11	10	0	0	4.794	0.246	3.00	77681.31
43	5	24000	17	18	0	0	5.193	0.285	2.93	83053.61

4- Result and Discussion

As shown in Tables V and VI, the information necessary to compare models economically is presented. Because of lack of space, not all of 48 cases for C_A or 96 cases for C_B are mentioned. Instead, some of them are chosen in order to investigate the impact of the sensitivity variables on the result. Some cases are repeated, but in each row, one of their sensitivity variables is analyzed. Also, the same colors are used for cases that are being compared to be easily found in the table. Using these tables, each sensitivity variable is evaluated in terms of its effect on decision-making and costs.

Further, table VII presents a comparative analysis of the impact of fuel prices on electricity production by various devices. The results indicate a correlation between higher fuel prices (Scenario numbers: 19, 35, 41, and 43) and increased electricity production by photovoltaic (PV) systems, leading to a corresponding increase in the required battery capacity and quantity.

Furthermore, Table VIII presents a comparative analysis of the impact of fuel prices on electricity production by various devices. In scenario C_B, where fuel prices are higher than in scenario C_A, an increase in electricity generation by photovoltaic (PV) systems is observed. Consequently, the required battery capacity and quantity are greater in scenario

Table 6. Economic comparison of case CB

Scenario number	Diesel fuel price ($/Lit)	Diesel fuel limitation (Lit/year)	Expected inflation rate (%)	Nominal discount rate (%)	CO2 penalty ($/t)	Capacity shortage (%)	Net present cost (NPC) (M$)	Cost of Energy (COE) ($/kWh)	Initial capital (M$)	Operating cost ($/year)
3	1.2	0	1.6	1	0	0	3.43	0.169	2.03	51746.6
2	1.2	0	1.6	-0.5	36	0	3.71	0.149	2.10	48406.5
33	2.288	0	1.6	-0.5	36	0	3.912	0.157	2.27	49254.5
65	5	0	1.6	-0.5	36	0	4.191	0.168	2.54	49535.1
41	2.288	0	1.6	-0.5	0	5	3.935	0.159	2.28	49301.1
42	2.288	0	1.6	-0.5	36	5	3.983	0.161	2.30	49921.5
49	2.288	24000	1.6	-0.5	0	0	3.912	0.157	2.27	49254.5
57	2.288	24000	1.6	-0.5	0	5	3.631	0.154	2.21	49670.8
66	5	0	1.6	-0.5	36	0	4.197	0.168	2.52	50318.5
82	5	24000	1.6	-0.5	36	0	4.263	0.194	2.63	57367.1
81	5	24000	1.6	-0.5	0	0	4.191	0.168	2.54	49535.1
87	5	24000	2	1	0	0	4.000	0.187	2.41	55574.1

Table 7. Optimal architecture f CA

Scenario number	PV (kW)	Diesel (kW)	BESS (Qty.)	Convertor (kW)
3	1.12	480	71	85.1
5	2.47	480	49	46.9
7	1.48	480	36	38.1
8	1.06	480	50	50.8
13	1.01	480	47	47
19	676	480	454	284
35	844	480	631	381
41	863	480	653	390
43	844	480	631	381

Table 8. Optimal architecture of CB

Scenario number	PV (kW)	WT 3 kW (Qty.)	Diesel (kW)	BESS (Qty.)	Convertor (kW)
2	1011	41	480	969	343
3	968	43	480	996	344
33	984	114	480	1149	382
41	984	118	480	1154	390
42	996	114	480	1154	396
49	990	115	480	1152	391
57	966	104	480	1023	356
65	1111	151	480	1167	404
66	1060	173	480	1159	402
81	1095	153	480	1161	397
82	1060	173	480	1159	402
87	986	167	480	1167	406

C_B to accommodate the increased PV output and address the inherent variability of renewable energy sources.

4- 1- Effect of changes in Prices for diesel fuel on the supply of fuel

DGs tend to be a more cost-effective option compared to renewable energy sources in Iran primarily because of subsidized fuel. In case 7, where fuel is at its lowest and there are no restrictions on its supply, the lowest NPC is 1.22 M$ according to Table V. The battery and inverter are at minimum capacity, with PV not installed. For all cases where a DG is present, its capacity consistently stands at 480 kW. In accordance with the optimization algorithm used by Homer, the generator with the minimum capacity required to meet the peak load and batteries falls in this specified range. By considering cases 3, 19, and 35, a study can be conducted to analyze the impact of the price of fuel independent of constraints to its supply. These cases involve fuel rates of 0.006 $/Lit, 1.20 $/Lit, and 5 $/Lit, correspondingly. In light of the fuel price increase, the NPC values have increased to 1.28 M$, 3.88 M$, and 4.79 M$, accordingly. The rise in NPC is drastic in the transfer of fuel rates from 0.006 $/Lit to 1.2 $/Lit, which reflects the use of PV also increased BESS capacity. According to Fig.12, the production levels by the system components in scenario 7 show that with the lowest fuel prices in this case, most of the production is by DG, while the PVs contribute very minimally. Furthermore, in scenario 43, where we observe the highest NPC, due to high fuel prices, fuel limitations, and high inflation and interest rates, most of the electricity generation is generated by PVs, with a small amount produced by DG.

Also, based on Table VI, the least expensive NPC is related to case 3, which is equal to 3.43 M$. Then, taking into account cases 2, 33, and 65, the fuel price effect can be checked independently of fuel limitations in these 3 cases. The price of fuel at 1.2 $/Lit, 2.288 $/Lit, and 5 $/Lit, accordingly. As demonstrated in Table VI, as the fuel price escalates, the NPC values correspondingly rise to 3.71 M$, 3.912 M$, and 4.191 M$, accordingly. The COE also experienced the same increasing impact. According to Fig.12, the production levels by the system components in scenario 3 show that with the lowest fuel prices, most production is by PVs, while WTs and DGs have very minimal contributions. This is due to high carbon tax costs and high fuel rates for DG in C_B. Additionally, in scenario 82, where we observe the highest NPC, due to high fuel prices, fuel limitations, and high carbon taxes, most of the electricity is generated by PVs, with a small amount produced by DGs and WTs. The slight difference in production by DGs, caused by high fuel and carbon tax costs, results in a higher NPC in this case compared to scenario 3. DGs tend to be a more cost-effective option compared to renewable energy sources in Iran primarily because of subsidized fuel. In case 7, where fuel is at its lowest and there are no restrictions on its supply, the lowest NPC is 1.22 M$ according to Table IV. The battery and inverter are at minimum capacity, with PV not installed. For all cases where a DG is present, its capacity consistently stands at 480 kW. In accordance with the optimization algorithm used by Homer's, the generator with the minimum capacity required to meet the peak load and batteries falls in this specified range. By considering cases 3, 19, and 35, a study can be conducted to analyzes the impact of the price of fuel independent of constraints to its supply. These cases involve fuel rates of 0.006 $/Lit, 1.20 $/Lit, and 5 $/Lit, correspondingly. In light of the fuel price increase, the NPC values have increased to 1.28 M$, 3.88 M$, and 4.79 M$, accordingly. The rise in NPC is drastic in the transfer of fuel rates from 0.006 $/Lit to 1.2 $/Lit, which reflects the use of PV also increased BESS capacity. According to Fig.12, the production levels by the system components in scenario 7 show that with the lowest fuel prices in this case, most of the production is by DG, while the PVs contribute very minimally. Furthermore, in scenario 43, where we observe the highest NPC, due to high fuel prices, fuel limitations, and high inflation and interest rates, most of the electricity generation is generated by PVs, with a small amount produced by DG.

4- 2- Effect of emissions penalty for CO_2

To analyze the effect of CO_2 penalty, two cases (cases 7 and 8) are selected. According to Table V, projects with a CO_2 emission penalty are always more expensive. This is due to the increase in costs for CO_2 emissions. Case 8, in which there is a CO_2 penalty, has NPC and COE of 1.47 M$ and 0.08 $, respectively, which are higher than case 7, which has NPC and COE of 1.22 M$ and 0.07 $/kWh. This result is valid in all cases with different emission penalties. There is no CO_2 emission penalty when only renewable energies are used, so this variable has no impact on the costs of those cases.

According to Table VI, by considering the two cases 41 and 42, the effect of the CO_2 penalty in C_B (Switzerland) is clearly visible. As a result of the increased penalty, NPC also increases from 3.935 M$ to 3.983 M$. It also increases the COE value from 0.159 $/kWh to 0.161 $/kWh.

4- 3- Effect of the discount rate and the inflation rate

According to Table V, the two cases 41 and 43 are chosen to study the impacts of discount rate and inflation rate. The inflation rate and discount rate for case 41 are 11% and 10% and for case 43 are 17% and 18% respectively. Both NPC and COE are less in case 41. In case 41 NPC decreased to 4.794 M$ (from 5.193 M$ in case 43), on the other hand, COE also decreased to 0.246 $/kWh (from 0.285 $/kWh in case 43). In general, as the discount and inflation rates decreased, the NPC and COE also decreased, indicating that investment in the project is more profitable when economic conditions improve. In this paper, about fuel consumption is not discussed in detail.

Based on Table VI, two cases, 81 and 87, have been considered to study the effect of discount and inflation rates. It is observed that values are close but, in case 81 when the inflation rate is 1.6% and the discount rate has a negative value of -0.5% NPC and COE are higher. It must be mentioned that these two variables influence the NPC and COE as a whole. So, they must be considered together. It can be derived that between these two cases, case 87 with a bit higher value for inflation and discount rates, has lower NPC and COE than case 81 where the inflation rate and discount rates are less but the discount rate is negative.

4- 4- Effect of annual capacity shortage

According to Table V Cases 3 and 7 present the current economic situation, except that the yearly capacity shortage is 0% and 5%, correspondingly. As NPC's annual performance increased by 5% from $1.28 M$ to $1.22 M$, COE decreased from $0.076 M$ to $0.072 M$. Most of the costs are related to the initial project cost, which has decreased from 0.303 M$ to 0.219 M$. Also, because of the increase in revenue, fewer batteries are required to cover off-hours, resulting in significant cost savings. Obviously, COE decreases with an increase in annual performance, but its magnitude also affects other changes. Cases 3 and 7 illustrate this In Table VI. To see the annual capacity shortage impact, cases 49 with 0% and case 57 with 5% annual capacity shortage are chosen. As can be seen, NPC decreased from 3.912 M$ in case 49 to 3.631 M$ in case 57. COE also decreased from 0.157 $/kWh in case 49 to 0.154 $/kWh in case 57.

4- 5- Some examples of changes in elements

According to Fig. 7 and Fig. 8, it is possible to observe changes in diesel fuel consumption in the two cases mentioned above. Fig. 7 corresponds to Case 3 for C_A, where the fuel price is at its lowest, while Fig. 8 represents Case 65 for C_B, where the fuel price is at its highest. Furthermore, Fig. 8 and Fig. 10 depict the state of battery charge. In Fig. 8, the amount of battery charge is illustrated for Case 7 for C_A. Additionally, Fig. 10 illustrates this condition for Case 87 for C_B.

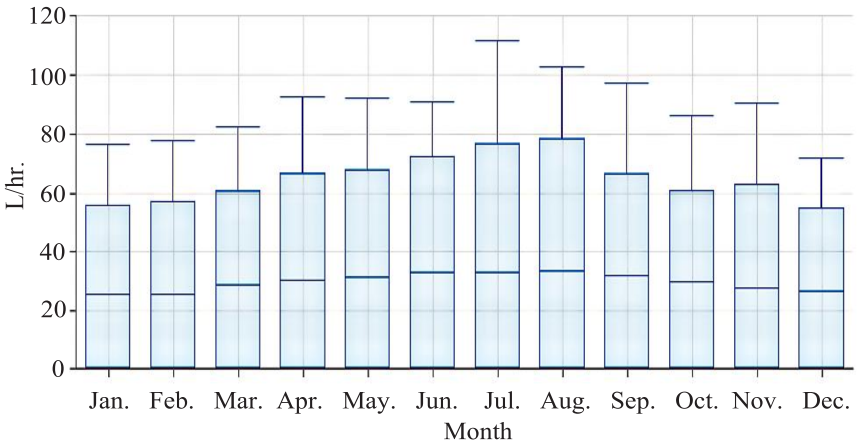


Fig. 7. Fuel consumption amount in CA

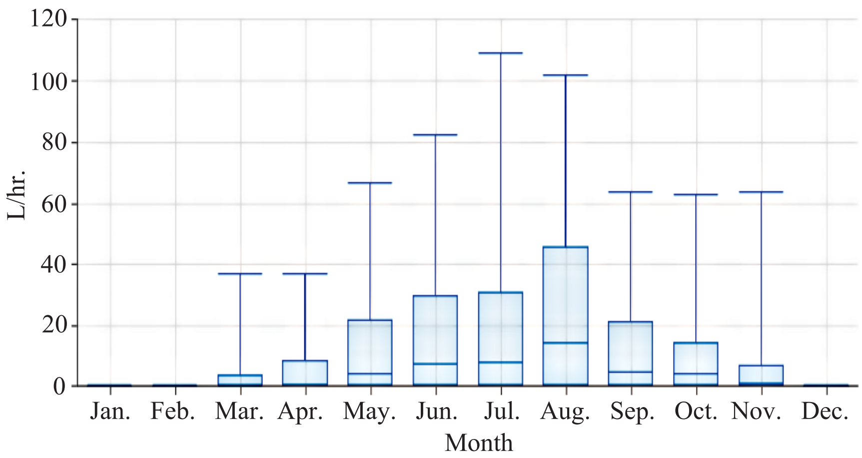


Fig. 8. Fuel consumption amount in CB

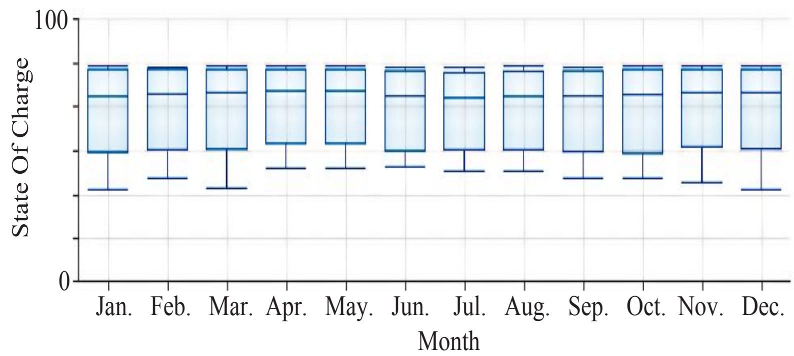


Fig. 9. State of charge in CA

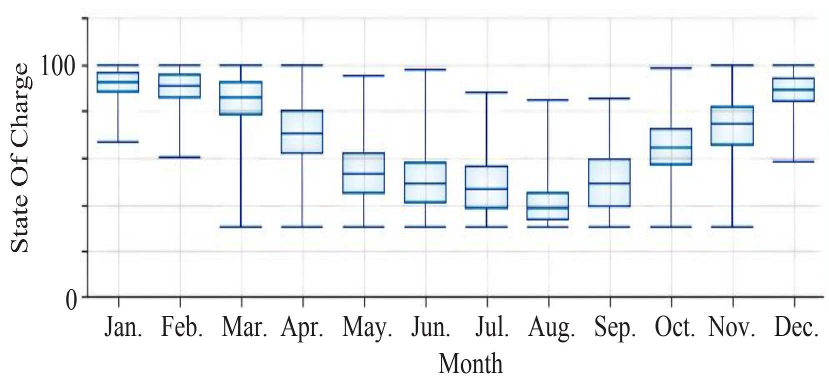
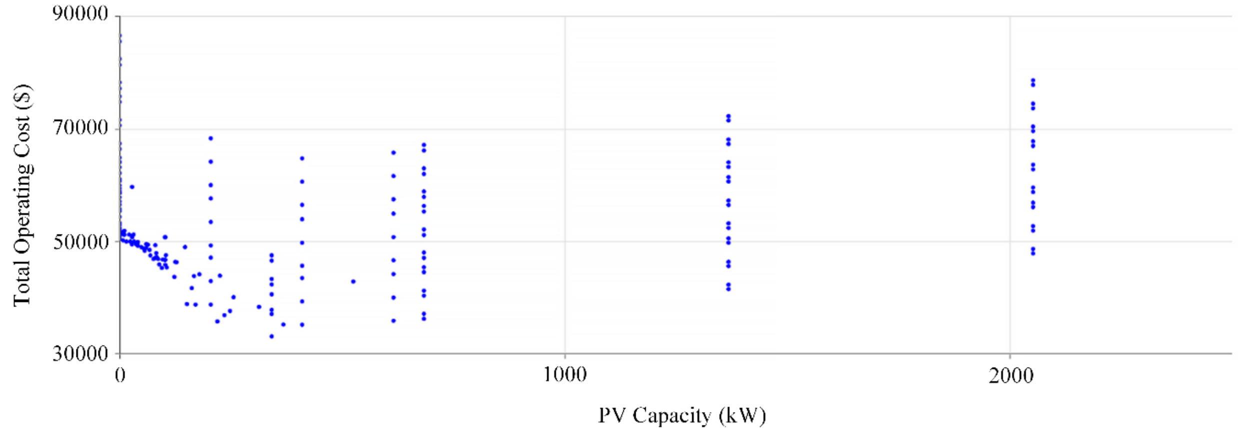


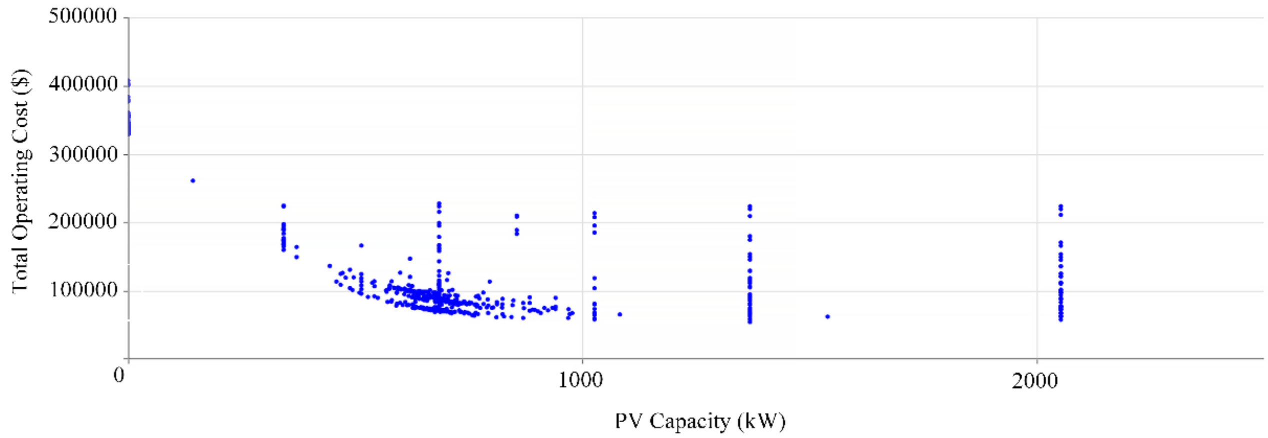
Fig. 10. State of charge in CB

4- 6- Optimization PVs capacity and Total operating cost

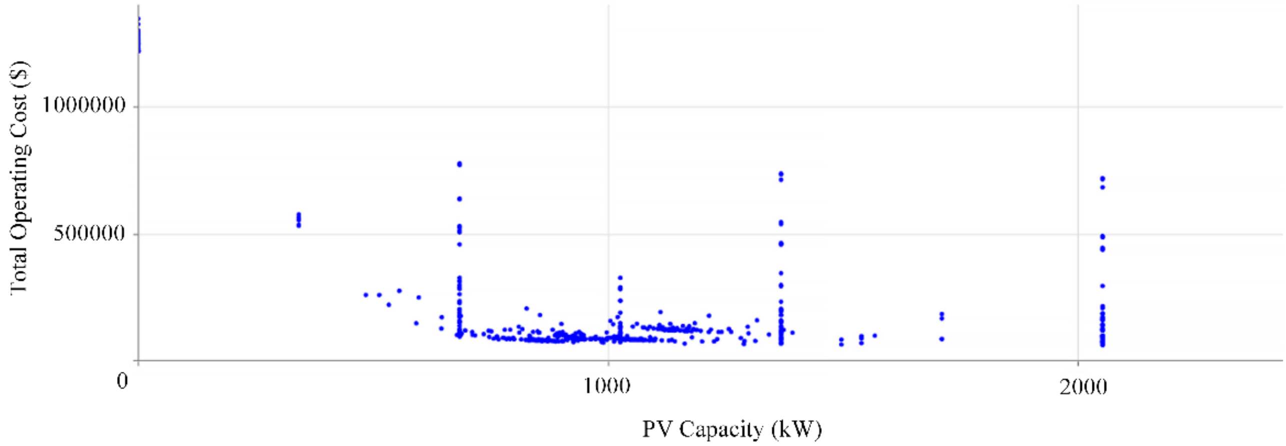
According to Fig. 11, when the fuel price is 0.006 $/Lit, the system's use of DG results in high operating costs, leading to a very small capacity of installed PVs (Fig.11. (a)). However, when the fuel price is 1.2 $/Lit, the optimization system HOMER incorporates PVs with a capacity ranging from 500 kW to 1000 kW, thereby reducing the operating costs (Fig.11. (b)). Furthermore, when the fuel price reaches 5 $/Lit, It is observed that PVs capacity is at its maximum compared to the previous two scenarios. As a result, the operating costs are



(a)

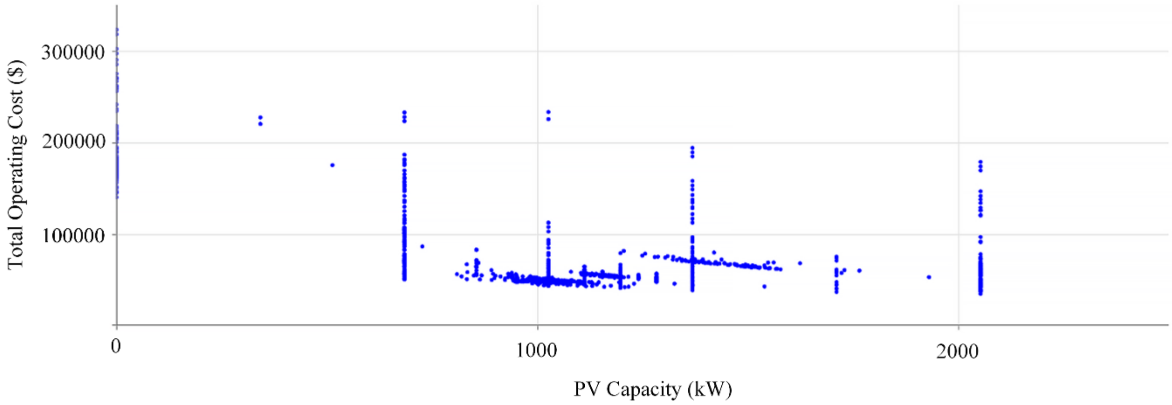


(b)

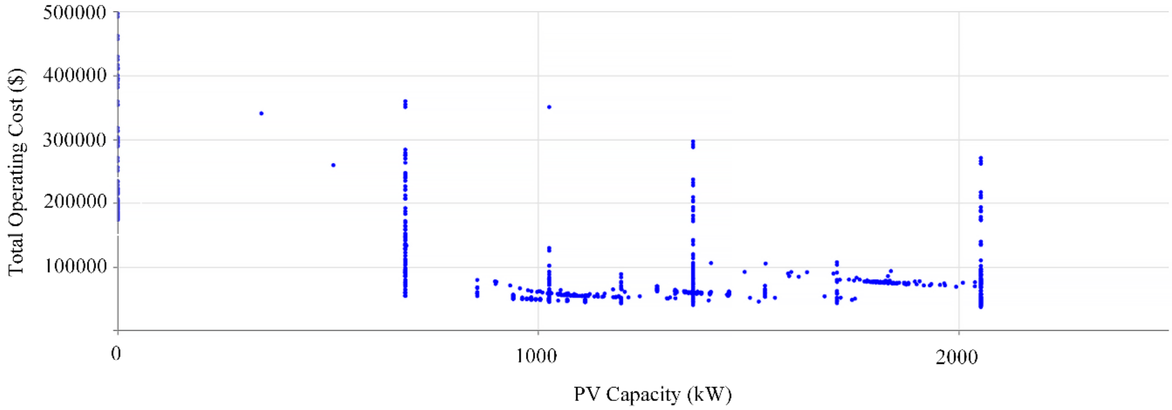


(c)

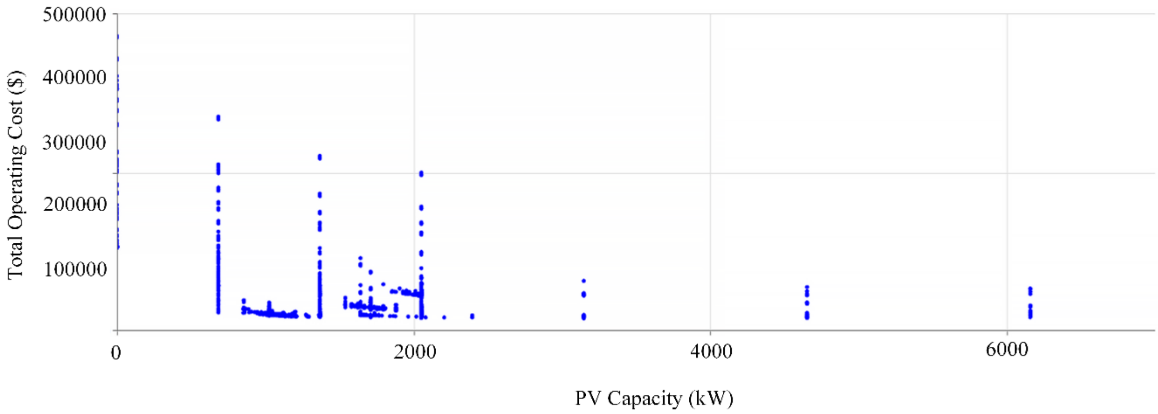
Fig. 11. Optimal PV capacity of CA



(a)



(b)



(c)

Fig. 12. Optimal PV capacity of CB

lower than in the previous cases, primarily due to the minimal use of DG (Fig.11. (c)).

According to Fig. 12, when the fuel price is 1.2 $/Lit per liter, the use of PV in the system leads to reduced operating costs due to the minimal use of DG capacity (Fig. 12. (a)). However, when the fuel price is 2.88 $/Lit, the HOMER optimization system utilizes PVs with a higher capacity than before, further reducing operating costs. Yet, due to the use of WT capacity and its associated costs, we observe spikes in expenses at certain points (Fig. 12. (b)). Additionally, when the fuel price reaches 5 $/Lit, PV capacity is at its maximum compared to the previous two scenarios. Consequently, operating costs are lower than in the previous cases, primarily because of the minimal use of DG. Furthermore, even this small capacity has an impact on prices, leading to increased system costs at certain points (Fig. 12. (c)).

5- Conclusion

In this study, a hybrid energy system including PV, WT, BESS, DG was developed. In order to reduce NPC and COE, size optimization was done using HOMER software. A sensitivity analysis was also conducted to examine the impacts of different sensitivity variables in two locations in Iran and Switzerland. In total, 48 scenarios for Iran and 96 scenarios for Switzerland were simulated. For each scenario, the optimal configuration of the energy system was determined using meteorological, economic, demand, and operational data. Based on the results of the study, the following conclusions can be drawn:

Fuel price increases, fuel supply limitations, and CO2 emission penalties all contributed to the system's utilization of more renewable energy resources.

Inflation and discount rates have a greater impact on projects with higher annual costs, such as fuel and maintenance costs. So in C_B we saw a decrease of 19.3% in NPC index and 41% in COE index compared to C_A.

In systems incorporating renewable energy sources, discussions often arise regarding CS. This study highlights the impact of this parameter on the NPC and COE for C_B, demonstrating a notable increase of 197% and 113% respectively when compared to C_A.

When comparing the lowest NPC values, 180% rise in NPC and 134% increase in COE for Switzerland compared to Iran is observed which is due to higher fuel prices in Switzerland.

In Iran, the carbon emission penalty is 12 dollars per ton, whereas in Switzerland, it is 36 dollars per ton. The impact of these penalties on NPC and COE is clear, leading to a notable 181% surge in NPC and a 91.6% elevation in COE for C_B compared to C_A.

Considering fuel prices and the periodic O&M costs of DG, it can be seen that with changes in fuel prices, the capacity of PVs and the total operating costs of the system fluctuate, resulting in a 90.72% increase in scenario C_A and a 14.8% increase in scenario C_B.

In the case of Iran with high inflation and discount rates and no CO_2 penalty, economic improvement and taxes on emissions is crucial for renewables to become more affordable.

The extent to which sensitivity variables influenced the costs of a case, depended on the values of the other sensitivity variables within that case.

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