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Research Article

Technical Design and Economic Investigations for Reducing CO_2 Emission considering Environmental Protection Agency Standards by Employing an Optimum Grid-Connected PV/Battery System

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Pollutant emission is one of the most important problems the world faces. Using sustainable energies is among the best solutions which can be employed to reduce CO_2 and other pollutants as in Environmental Protection Agency (EPA) standards. In this study, a case study region located in the south of Iran, including 100 households, is studied to find practical methods of investment to partially replace the required energy by renewables where the total emission is confined to the EPA standards. The solar irradiant of the region is 5.36 kWh/m^2/day which causes high energy consumption (3000 kWh/day). If the government invests $495705, which is equal to the social penalty that has to be paid for emissions in 20 years, a 230 kW PV with a vertical tracker can be implemented to reduce 36% of the total emission that will be produced through the current system. The payback period for the proposed system will be around 11 years. Using an optimized hybrid system instead of a system without any renewables modeled in HOMER software in which the initial capital is limited reduces the cost of energy (COE) and the total net present cost (NPC) by 16% and 11%, respectively. The COE and NPC for the current system without any renewables are 0.121 ($/kWh) and 2.28 M ($), respectively. Although the acceptable Renewable Fraction (RF) is about 55%, using 38.5% RF can significantly fulfill the EPA standards and consider the plan's economic and executional conditions.

1. Introduction

Compared with fossil fuels, there are several benefits in using renewable energy sources [1], such as lower emission of greenhouse gases and availability of these sources in the far future due to its abundance [2]. CO_2 emission of countries is significantly dependent on the energy system. Renewable energy technologies are applicable for various usages [3], such as desalination, heating, cooling, and electricity generation. For electricity generation, which is the main topic of this study, different renewable energy-based technologies are applicable, including geothermal power plants [4], wind turbines [5], fuel cells [6], solar thermal, and solar photovoltaic (PV) cell [7]. Depending on the applied technology and source, there are several advantages, but its worldwide availability is the most attractive. Since the PV cells are applicable for direct conversion of solar radiation to electricity, they have been widely developed in recent years [8]. Despite several advantages of solar cells, it is necessary to use a storage unit or integrate them with other technologies to provide continuous operation due to the intermittent nature of solar energy [9, 10].

Several studies have been conducted on solar systems integrated with the storage units such as batteries and other energy-storing technologies [11]. For instance, Rehman and Hadhrami [12] proposed a hybrid configuration composed of solar cells, diesel generators, and batteries to supply the electricity demand of a region in Saudi Arabia. In another work, Ahmed and Miyatake [13] proposed a configuration composed of solar cells, a wind turbine, and a control system to generate power. In another work [14], a hybrid system composed of solar PV and wind turbines was proposed to supply the required power of a desalination system. The hybrid systems composed of solar PV cells have been optimized for various objectives. For instance, Maleki et al. [15] optimized the size of a hybrid system composed of solar PV and battery for utilization in off-grid conditions. The objective function of their study was defined based on the total life cycle cost. In another work, Zhang et al. [16] optimized the design of a system composed of solar, wind, and battery as storage and proposed an optimal size for the systems by considering the total cost as the objective function. Barakat et al. [17] performed a multiobjective optimization on a grid-connected hybrid system composed of PV and wind turbines by considering cost, environmental, and reliability criteria.

There has been significant growth of using PV systems in Iran during the past decade [18]. Three PV power plants were installed in Hamedan, Isfahan, and Kerman provinces on a megawatt scale in 2017 [19]. Installing a 1 GWe PV power plant in Qazvin province by 2026 is another ongoing plan to increase renewables' size in Iran [20]. Shabani and Mahmoudimehr [21] investigated the effect of various tracking systems for a stand-alone PV-PSH system in the south of Iran and concluded that the selection of the tracking systems could lead to saving about 18%. Mohammadi et al. [22] investigated the different tracking systems in the south of Iran and concluded that the one-axis continuous tracking mode has the least COE compared to other tracking modes. Alayi et al. [23] investigated a wind-solar-fuel cell hybrid off-grid system based on the calculated loads (7.95 kwh/m2/day of solar radiation) for a case study located in Iran. The obtained COE for a 100% RF was reported to be 0.134 $/kWh.

Iran, located in the Middle East, is one of the countries with the greatest potential for solar power generation. The present study investigates a grid-connected system composed of PV cells and batteries by considering technical and economic criteria. Unlike the previous similar studies, which have not been designed based on the limitation of pollutants, the total emission of the proposed system in this research is limited according to the EPA suggestions as the main scenario for the case study region. Hence, considering the emission constraint, the optimization of the designed system will significantly fulfill EPA's standards and the optimum size of components is calculated. The sell-back to the grid is also considered when there is excess electricity in the proposed renewable system. In addition, the system is assessed and optimized by considering different scenarios. Details of the study and the findings are provided in the following sections of the article.

2. Methodology

In this section, various scenarios and the details of each selected region are discussed. In addition, the most important equations and input parameters used in HOMER software are presented as well.

2.1. Economic Equations in HOMER Software. In order to understand the technical and economic analyses of a system modeled by HOMER, its equations should be presented. The optimum combination of components and their capacity, operating cost, COE, and NPC can be calculated by HOMER [24]. Calculating the reduction expenses of CO_2 emission due to using renewable equipment for power production instead of the grid for supplying all or a part of the demand load is another important economic factor that can be determined using this software [25]. In the following sections, the most important economic parameters used in this research are presented:

NPC is the total expenses of purchase, installation, and O&M of components, along with other related costs such as emission penalties minus salvage which is the revenues gained through the project's lifetime as in equation (1) [26].

$$\mathrm{NPC} = \frac{C_i + C_m + C_r - S}{\mathrm{CRF}(i, n)}, \quad (1)$$

where C_i is the initial cost, including purchase and installation, C_m is maintenance expenses, C_r is replacement cost of new components, S presents the salvage, and CRF is determined as the capital recovery factor.

Cost of energy indicates the cost of useful obtained energy per amount of obtained electricity (kWh) as a most important factor for the economic evaluation of the system. From equation (2), COE is denoted [27]:

$$\mathrm{COE} = \frac{C_{\mathrm{ann.tot}}}{E_{\mathrm{served}}}, \quad (2)$$

where $C_{\mathrm{ann.tot}}$ and E_{served} are annual expenses for energy production and served electricity, respectively.

2.2. Renewable Fraction. Most power plants in Iran utilize natural gas to produce electricity. According to EPA criteria determined in 2015, this kind of power plant should have 453.6 kg/MWh CO_2 emission [28]; however, the emission for Iran's power plants is 790 kg/MWh [29]. Based on the fact that CO_2 emission in Iran is 42% higher than the EPA standard, local renewable systems are investigated in this research to find the best combination of components as a solution to reduce greenhouse gases to reach theEPA standard.

2.3. Scenarios. Given that the solar irradiation potential in southern parts of Iran is remarkable, PV panels can be used to supply the electricity demand in these regions. Due to the limitation of land in residential regions, PV panels are assumed in all scenarios with and without a tracker systems.

As the first step, a grid without any renewables is considered, where the grid's costs for people (S'1) and the government (S1) are considered to calculate emissions and expenses in 20 years. In the next step, optimization is done to find the best combination of sustainable equipment from government's point of view as HOMER's preferences (S2). In the third step, initial capital is confined to the emission penalties which the government will pay in 20 years (S3). Finally, emissions are confined to EPA standards (S4). Sensitivity analysis is also employed to determine feasible economic solutions that fulfill the environmental limitations. The schematic view of the proposed system including PV, battery, converter, and grid, along with two separated demand loads, is shown in Figure 1 [30]. An overview of the methodology steps is shown in Figure 2, and optimization steps are characterized in Figure 3.

2.4. Description of the Case Study Region. Hormozgan is one of the southern provinces of Iran facing Oman and UAE. Solar radiation and clearness index for Hormozgan is shown in Figure 4 [30], and in Figure 5, respectively [31], an overall view of the province can be seen. Longitude and latitude are 55°8.3′E and 27°8.3′N, respectively. 1.776 million people live there, and in most parts of this region, relative humidity is more than 90% in summer, and the annual average ambient temperature is 27°C. Solar irradiation is 5.36 kWh/m^2/day, and the residential section is responsible for about 70% out of total produced electricity.

2.5. Electricity Consumption. The proposed system presented in Figure 1 is supposed to supply a part of the electricity demand for a project including 100 households. Although the average electricity demand in Iran for each household is 12.5 kWh/day, due to the high temperature and relative humidity, which increases the cooling demand, this parameter for Hormozgan is 30 kWh/day. Furthermore, the lack of drinking water makes desalination inevitable. Considering each family consists of 4 people, each person uses 0.045 m^3/day of water, which requires 4 kWh/m^{3}of electricity to desalinate water based on the reverse osmosis process [32, 33]; 72 kWh/day of electricity is required for 100 households in this project to desalinate water. The total annual electricity consumption is shown in Figure 6.

2.6. Grid Expenses. Most of the produced electricity in Iran is supplied through gas power plants, and less than 1% is produced in nuclear power plants. Low gas prices in Iran, as one of the largest gas producers in the world, and subsidies for energy in residential and industrial sections, have declined the purchase price of electricity from the grid, and as a result, excessive consumption is common which leads to production of a large amount of greenhouse gases [29]. The electricity price of the grid for people in Hormozgan is 0.017 $/kWh for off-peak times of day and 2.5 times higher in peak hours from Nov. to Jan. and 0.006 $/kWh in off-peak times and 2.5 times higher in peak hours from Feb. to Oct. In addition to the previously mentioned points, the sell back price for excess residential electricity to the grid is 0.07 $/kWh, and the cost of electricity production for the government is about 0.12 $/kWh. It means that the government subsidizes about 0.1 $/kWh for power production [34].

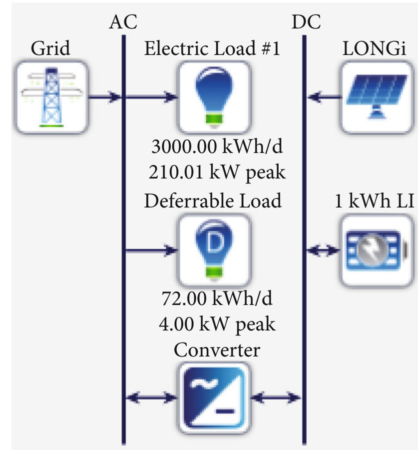

Figure 1: Schematic view of the proposed system.

2.7. Components. All devices employed here do not have a rotating component. For this reason, O&M costs are assumed to be 2% of the capital cost. Considering the recent years' average, inflation and discount rates are assumed 18% and 20%, respectively.

2.7.1. Photovoltaic Panel. In this project, LONGi LR6-72HV-350M PV is selected along with Vertical Axis Continuous Adjustment as a tracker if needed. The selected PV is popular and accessible in Iran; which it's efficiency (%), rated capacity (kW), temperature coefficient, and operating temperature (°C) are 18.1, 0.35, −0.41, and 45, respectively. The prices for this kind of PV and its tracker are 1500 $/kW and 420 $/kW, respectively. Power generation of PV (kW) is calculated based on equation (3) [30]:

$$\text{Output power of PV} = \text{RC} * \text{DF} * \left(\frac{\text{SRI}}{\text{IR}}\right) * [1 + \text{TCP} * (\text{CT} - \text{CT}_{\text{STC}})], \tag{3}$$

where RC is the rated capacity (kW) of PV equal to the output power generated by PV under standard test condition (STC), when radiation is 1 kW/m^2, the cell temperature is 25°C, and there is no wind. The derating factor (DF) (%) of PV means the reduced percentage of the power output along the PV's lifetime. SRI is the solar radiation incident (kW/m^2) in the current time step, while IR (1 kW/m^2) is the incident radiation at STC. TCP is the temperature coefficient of power (%/°C) as the dependency on power output on the cell temperature. CT and CT_{STC} are PV's cell temperature (°C) at reality and STC, respectively.

2.7.2. Converter. To convert DC electricity to AC, a converter is selected, the price of which is 200 $/kW, with an efficiency of 95% and a 15 years lifetime.

2.7.3. Battery. Batteries are used to increase the reliability of the system and can release stored electricity to supply a part of demand load in peak hours, especially at nights when

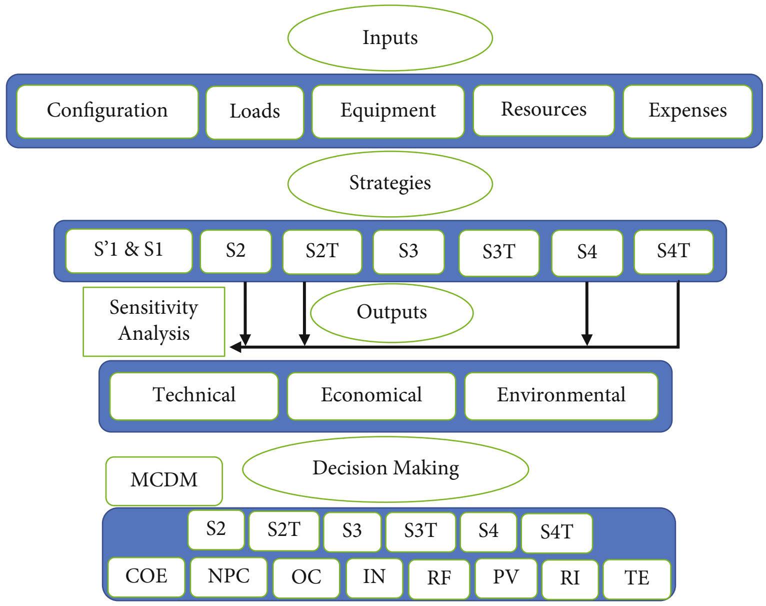

Figure 2: Methodology steps.

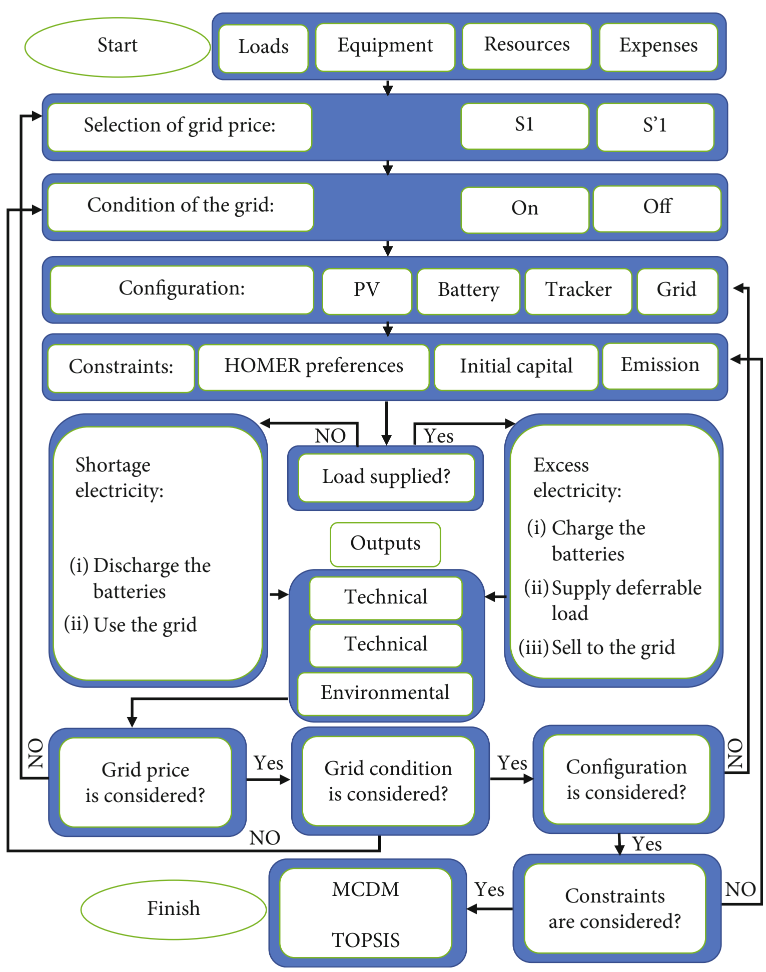

Figure 3: Intended flow chart of optimization for the designed system.

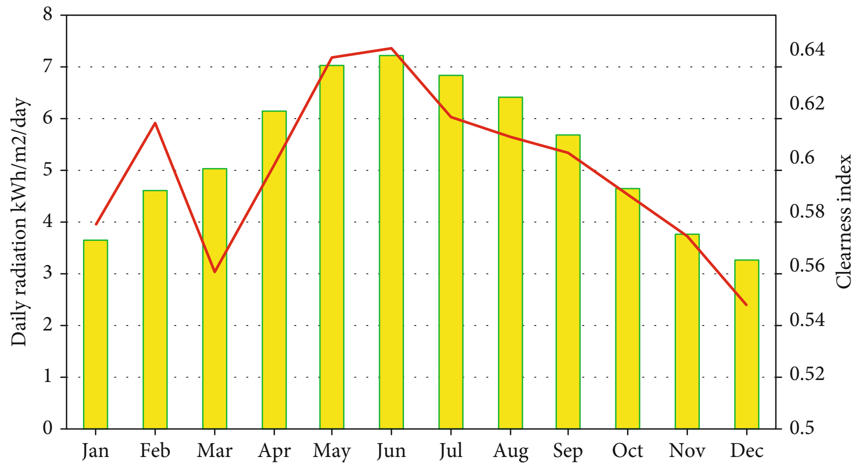

Figure 4: Solar irradiant and clearness index for Hormozgan.

Figure 5: Overview of Hormozgan province.

there is no solar irradiation. A generic 1 kWh Li-Ion battery is proposed for this system, and the price of which is 400 $/kW.

3. Results and Discussion

After finding the optimum system for power generation, economic and environmental parameters are investigated to find the most appropriate RF for the case study. Considering the constant amounts of loads, expenses, annual capacity shortage 2%, and sell back price for different values of RF, the obtained results are analyzed. Tables 1–4 include the results of different scenarios in which capacities, emissions, and expenses are given. The effect of different RFs on expenses, components'optimized capacity, and related dispatches will be investigated in the next section.

3.1. S1 and S'1 Scenarios. People benefit immensely from government subsidies, and they do not directly pay any penalty for emissions. As shown in Table 1, COE and NPC for people (S'1) are almost trifle, and as a result, they will not pay for changing their energy supply system. S1 scenario is designed based on a subsidy that the government pays for electricity at almost 0.1 $/kWh. Pollutant gas emission and their penalties for gas power plants are presented in Table 1 according to the Iran energy balance sheet (2017) [29].

According to Table 1, if there is not any renewable, the total emission of CO_2, CO, Unburned Hydrocarbon (UH), Particulate Matter (PM), SO_2, and NO_x in 20 years will be 17824 tons.

3.2. S2 and S2T Scenarios: HOMER Preferences. In this scenario, HOMER software calculates the best optimum combination of components without any constraint, and the results are presented in Table 2. Compared to S1 for the system, including the tracker (S2T), COE and NPC are decreased by 24% and 11%, respectively. For this system, RF is increased to 48.7% as well as decreased in COE and NPC compared to a system without a tracker (S2). Although using more PV cells in S2T than S2 leads to emission reduction, the system with a tracker needs more initial capital, which is an important factor along with the needed land for installing PV panels. For both S2 and S2T, cycle charging (CC) dispatch (in which supplying the demanded load by renewables is its priority) is selected as the best strategy by HOMER. The operation and maintenance cost (OC) in S2 is higher than in S2T since RF in S2 is 22%. Consequently, the grid, which has high amount of OC, has higher share in supplying electricity.

3.2.1. Sensitivity Analysis on the Price of PV and the Load. In order to investigate the effect of different PV prices and

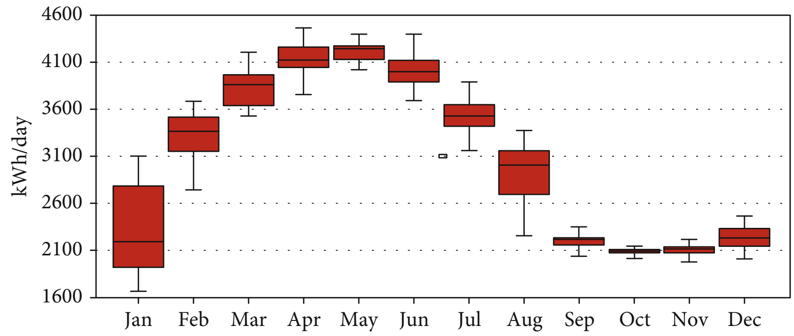

Figure 6: Mean of total electricity consumption per day for each month.

Table 1: Expenses and emissions from people's (S'1) and government's (S1) points of view without a renewable system.

	COE ($/kWh)	NPC ($)	OC ($/yr.)	Dispatch		
S'1	0.0134	252258	14977	CC		
S1	0.121	2.28 M	135369	CC		
S1 and S'1 emission	CO_2	CO	UH	PM	SO_2	NO_x
Value (ton in 20 yrs.)	17715	15.7	0.358	2.58	37.24	53.44
Emission for Iran's power plants (g/kWh)	790	0.7	0.02	0.12	1.66	2.38
Emission penalties ($/ton)	16.1	54	335	6923	2936	965
Total emission penalties ($)	285212	848	120	17861	109337	51570

Table 2: Obtained results for S2.

	COE ($/kWh)	NPC ($)	OC ($/yr.)	Initial capital ($)	RF (%)	PV (kW)	Return investment (yr.)	Dispatch
S2	0.113	2.12 M	110081	269171	22	160	10.82	CC
S2T	0.0919	2.01 M	78350	687628	48.7	319	11.94	CC

Table 3: Obtained results for S3.

	COE ($/kWh)	NPC ($)	OC ($/yr.)	Initial capital ($)	RF (%)	PV (kW)	Return investment (yr.)	Dispatch
S3	0.101	2.06 M	92890	494450	38.5	288	13.13	CC
S3T	0.102	2.03 M	91113	495705	38.5	230	10.96	LF

Table 4: Obtained results for S4.

	COE ($/kWh)	NPC ($)	OC ($/yr.)	Initial capital ($)	RF (%)	PV (kW)	Return investment (yr.)	Dispatch
S4	0.083	2.09 M	69807	917898	56.8	530	13.99	LF
S4T	0.0891	2.07 M	75680	792682	52.9	366	12.03	CC

demanded loads on economic, environmental, and components' capacity for other situations, sensitivity analysis on 0.8–1.3 of the price of PV and 2000–4000 kWh/d of the load are done as shown in Figure 7. According to Figure 7, S2-a and S2-b, increasing load up to 3000 kWh/d at low prices of PV does not significantly change the value of COE while NPC will be increased despite of decreasing the size of PV, and as a result, the amount of CO_2 emission will be increased up to the determined value by EPA. At higher PV prices (up to 1.1), the optimized system based on economic parameters includes low amounts of PV and an increasing trend of CO_2 emission with a constant value of COE. As can be seen in Figure 7, S2T-a and S2T-b, due to using a tracker in S2T, COEs and CO_2 emissions are significantly lower than S2for a wide range of loads at low PV prices. The suggested optimum size of PV is increased very much when the load is up

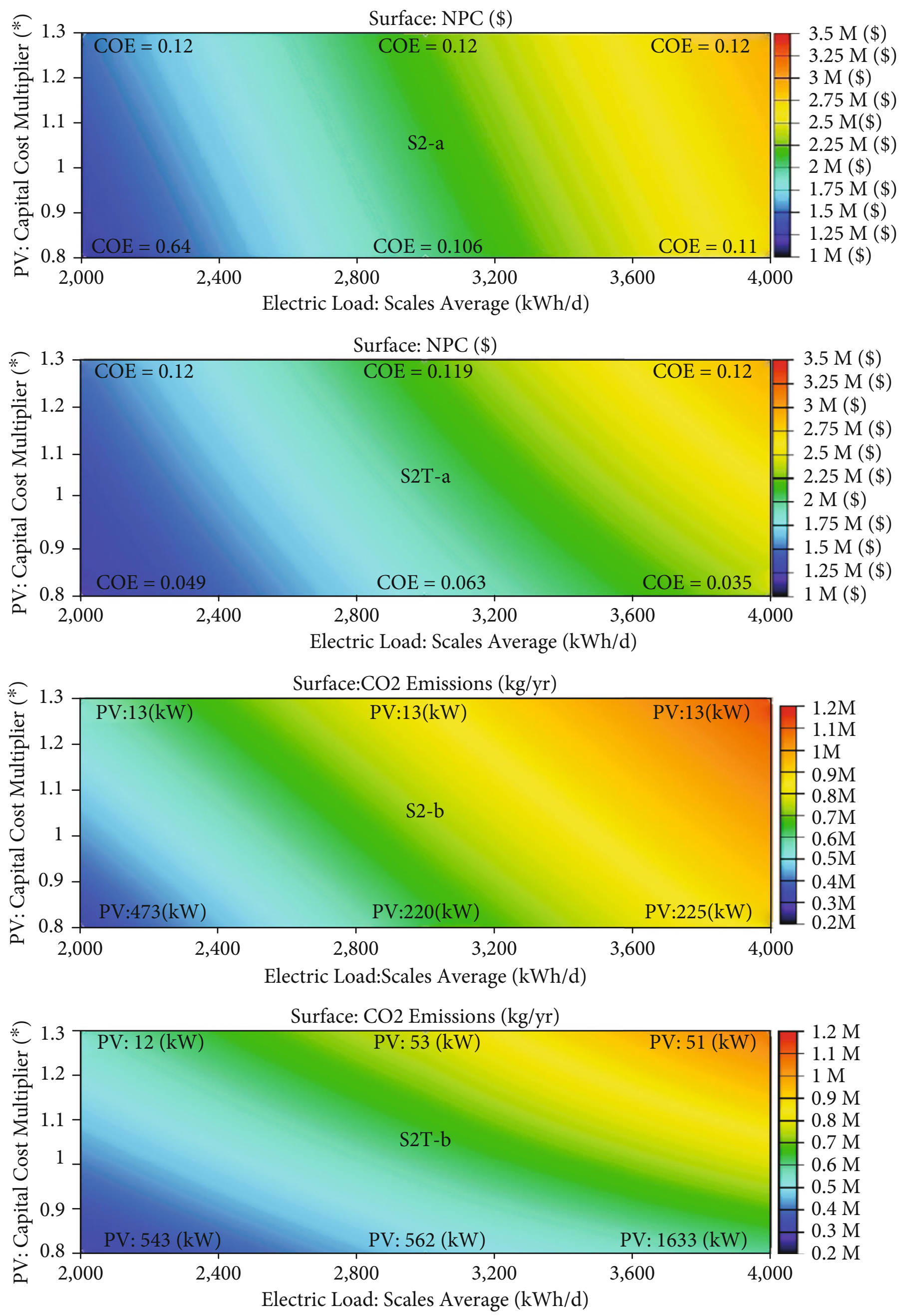

Figure 7: Heat maps from sensitivity analysis on PV and load for S2 and S2T.

to 3000 since the excess electricity can be sold to the grid in peak hours. Furthermore, S2T-b shows that with increasing 20% in the price of PV, EPA standards can still be fulfilled when the load is less than 3000 kWh/d. In an equal change in PV price and the amount of the demanded load, using a tracker causes less NPC, COE, and CO_2 emission.

3.3. S3 And S3T Scenarios: Emission Penalty as the Initial Capital. Given that about 20% of NPC is related to emission penalties from the government side, it will be rational to invest in local, sustainable power supply systems with $464948 as the total emission penalty in 20 years.

Table 3 shows the result of a system in which the initial capital is almost confined to the mentioned value. Compared to S2 for with (S3T) and without (S3) the tracker systems, COE and NPC have been increased by about 5%,10% and 7%,1%, respectively.

For an equal RF and economic condition, the required panel for the system with a tracker is 64 kW less than that without a tracker system. Considering the 10 m^2 land for the 1 kW panel, 640 m^2 less land will be needed. Return investment (RE) for the system with the tracker is about three years less than the other one. Return investment for the system with the tracker is the least among all scenarios

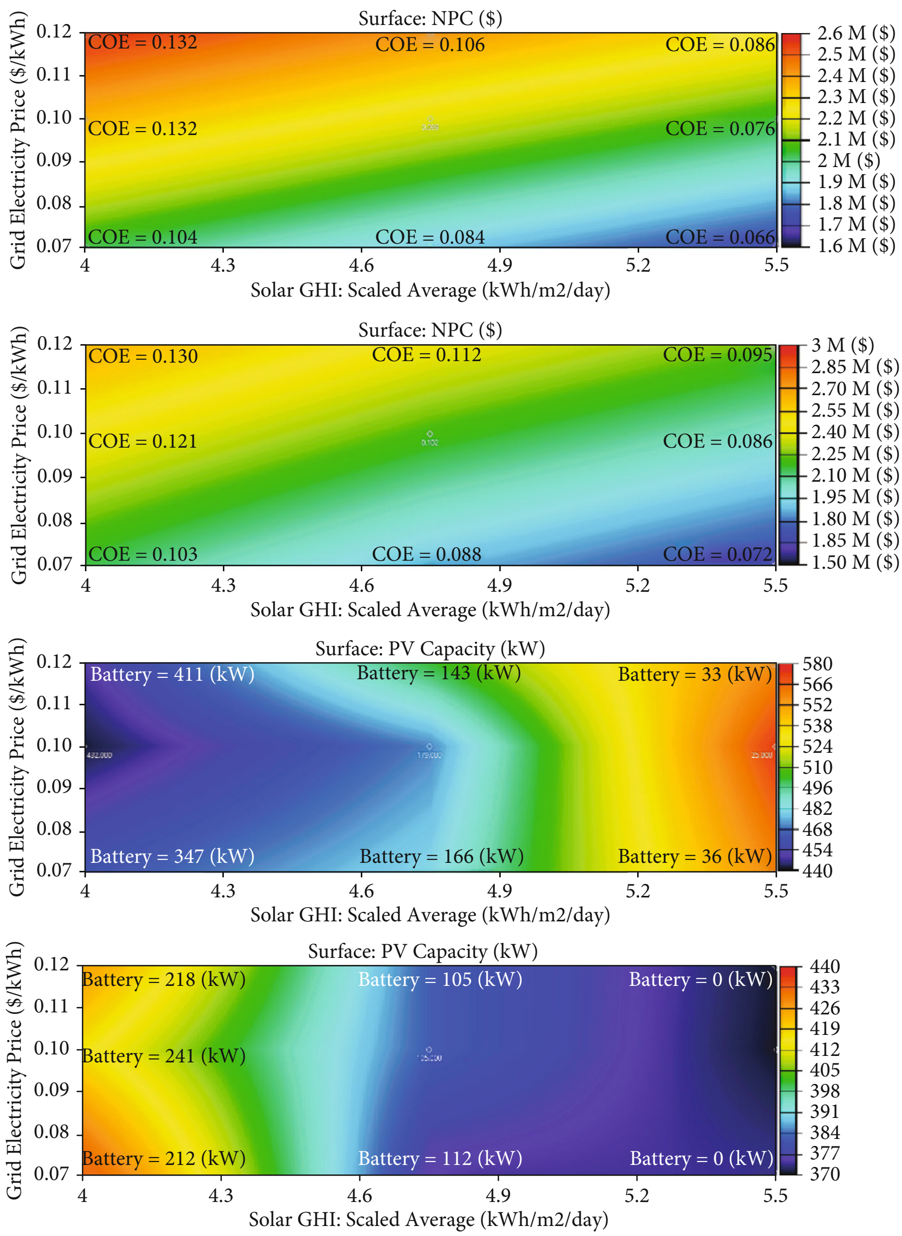

Figure 8: Heat maps from sensitivity analysis on the price of the grid and solar resource for S4 and S4T.

with a tracker since it sells much excess electricity to the grid. OC for both S3 and S3T is almost equal. The S3 system is optimized based on CC while S3T is optimized based on load following (LF), in which after supplying the demanded load, batteries and deferrable load will be supplied.

3.4. S4 and S4T Scenarios: Confining Emission. According to the reported emissions for S1 and S'1 in Table 1, they should be confined to 58% of the present value to fulfill the EPA standards. The obtained results show a 26% & 3% reduction and 2% & 3% increase in COE and NPC for with (S4T) and without (S4) a tracker system compared to S2 as in Table 4. Moreover, an 18% & 13% increase in COE and 2% & 2% in NPC compared to S3 is the other change resultingfrom confining emissions. Increasing RF by about 52.9% to 56.8% due to confining emission will increase the initial capital to 85% and 60% for S4T and S4 compared to S3, respectively. The other problem is the size of PV compared to those of S2 and S3, which needs a large amount of land for installation. The return of investment for both systems is close to S2 and S3. The return investment for both S4 (13.99 yr.) and S4T (12.03 yr.) is higher than that of other scenarios. While in S4 LF is selected as the best optimization method in HOMER, CC has been employed for S4T.

3.4.1. Sensitivity Analysis of the Price of the Grid and Solar GHI. Variations in solar irradiation and the price of electricity purchase are inevitable for each case study. In this

Table 5: Weight and the decision matrix.

	COE	NPC	OC	Initial capital	RF	PV	Return investment	Total emission
S2	0.113	2.12	110081	269171	22	160	10.82	13858.08
S2T	0.0919	2.01	78350	687628	48.7	319	11.94	10565.46
S3	0.101	2.06	92890	494450	38.5	288	13.13	11868.76
S3T	0.102	2.03	91113	495705	38.5	230	10.96	11532.88
S4	0.083	2.09	69807	917898	56.8	530	13.99	10289.9
S4T	0.0891	2.07	75680	792682	52.9	366	12.03	10311.18
Weights	0.1	0.125	0.05	0.15	0.15	0.125	0.1	0.2

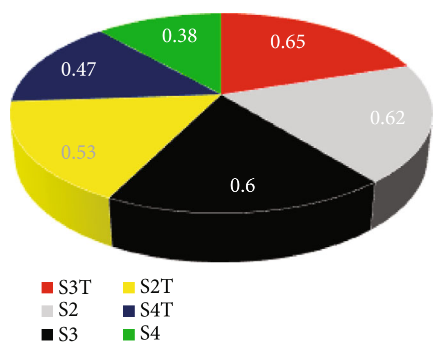

Figure 9: Obtained P_i values based on the TOPSIS method.

section, by considering constant values of pollutant gases as in the EPA standard, the effects of changing 4–5.5 kWh/m^2/day in GHI and 0.07–0.12 $/kWh in grid electricity price on economic parameters and the size of components for optimized systems are illustrated.

According to Figure 8, S4-a and S4T-a, increasing in GHI causes less COE for both low and high gridelectricity prices due to increasing in efficiency of PV panels. For S4T in GHIs up to 4.4 kWh/m^2/day, NPC is less than S4 while COE is higher since by increasing in GHI, S4 employs more PV than S4T, and it can produce and sell more excess electricity (less purchase) to (from) the grid as well as increasing in RF. Contrary to that for S4, increasing in GHI for S4T causes a decrease in the size of PV, and as a result, less land will be needed. Based on the presented heat maps in Figure 8, in GHI values less than 4.3 kWh/m^2/day, S4 uses 200 kW more battery than S4T. Increasing in grid electricity price in S4 for GHIs by less than 4.3 kWh/m^2/day increases the required battery by about 18%. The needed battery for S4T in GHIs higher than 5.2 kWh/m^2/day is low since the capacity of PV is low and all of the produced power is used.

3.5. MCDM-TOPSIS. In order to rank the scenarios mentioned above, TOPSIS as one of the Multi-Criteria Decision Making (MCDM) methods is employed. Alternatives include S2, S2T, S3, S3T, S4, S4T, while COE, NPC, OC, initial capital, RF, size of PV, return investment, and total emission are assumed as criteria (X_i). The Decision-Making matrix and considered weight values are shown in Table 5. Weight values are assumed based on the importance of each criterion to fulfill the objectives of this research.

After specifying the alternatives and criteria (step 1), they must be normalized using equation (4) as follows (step 2):

$$\text{Normalized}\, Xi = \frac{X_i}{\sqrt{\sum X_i^2}}. \tag{4}$$

In the next step, the obtained values are multiplied by weights (step 3) (X_i'), and then, the positive (V^+) and negative (V^-) ideal solutions are determined (step 4) as follows: V^+ is the minimum of each column where a lower amount of a criterion is better, and the maximum of each column is selected where the higher amount of a criterion is better. V^- is the maximum of each column where a lower amount of a criterion is better and the minimum of each column is selected where the higher amount of a criterion is better.

Then, the relative distances of each solution from V^+ and V^- are calculated as in equations (5) and (6):

$$S^+ = \sqrt{\sum \left(X_i' - V_i^+\right)^2}, \tag{5}$$

$$S^- = \sqrt{\sum \left(X_i' - V_i^-\right)^2}. \tag{6}$$

Finally, the relative closeness (P_i) of each alternative to the ideal solution is computed (step 6) as in equation (7):

$$P_i = \frac{S^-}{S^- + S^+}. \tag{7}$$

The obtained P_i values are shown in Figure 9. The more the value of the P_i, the higher thescenario's rank [35]. According to this figure, S3T, S2, S3, S2T, S4T, and S4 are better scenarios, respectively.

3.6. Comparison of Emissions, the Size of Components, and Scenarios. Converter and battery capacity for all scenarios are presented in Figure 10. Batteries are only used to supply electricity when the grid and PV panels cannot supply the load demand in peak hours. Hence, it is forbidden to sell electricity to the grid through batteries. Also, they are only charged by PVs, and grid power cannot be used to charge the battery. Since peak hours and high potential maximum GHI happen simultaneously for the case study region, the

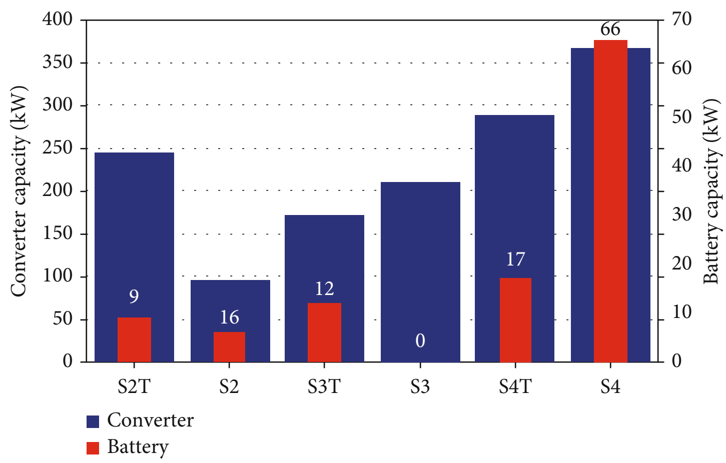

Figure 10: Converter and battery capacity for proposed scenarios.

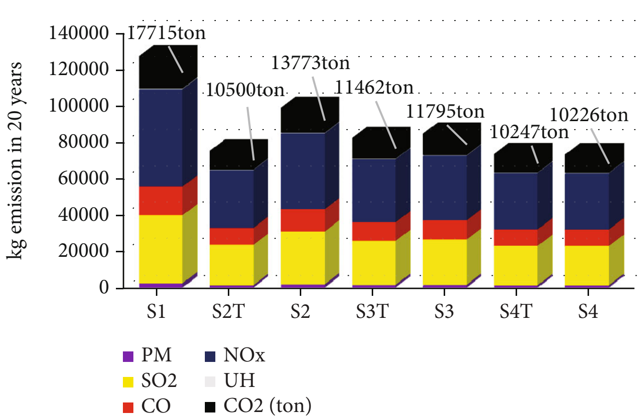

Figure 11: Pollutant emission by each scenario in 20 years (CO_2 must be multiplied by 1000).

demanded load is supplied mainly by PV and the grid, and in all scenarios, the number of calculated batteries is trifle compared to the size of the load. The size of the converter is definitely dependent on the size of PV so that the more the capacity of PV, the more converter is needed, as in Figure 10.

Total emissions (TE) from each scenario are shown in Figure 11. According to the detailsmentioned above, S1 is the produced pollutant emission including PM, SO_2, CO, NO_X, UH, and CO_2 when the current situation continues for 20 years.

Although S4T and S4, in which emissions are limited to EPA standards, although S2T is the nearest option to the EPA standards from the emission point of view, S3T can be the best choice due to its applicable condition and financial results. Emissions from S3T, S3, and S2 are about 10%, 10%, and 35% more than S4T, respectively, while NPC for S3T is 40000 less than S4T. Also, the initial capital, as a very important parameter to invest on renewable power supply centers given the long-term economic conditions changes, for S3T is the least among all scenarios. It is also almost close to the penalty that government will pay for pollutant emissions by 20 years. The optimum size of required PV panels for S3T is significantly the least among scenarios that can almost fulfill EPA standards, and as a result, 38%, 25%, 130%, and 60% less land will be needed compared to S2T, S3, S4, and S4T, respectively. The return of investment for S3T is 10.96 years which is about 1–3 years less than that of S2T, S3, S4, and S4T scenarios.

Considering other conducted studies with an almost equal solar radiation to the current case study shows that the vertical tracking system used in the current study has acceptable performance and is useful for the case study region [28, 36], which is also confirmed in the other study in latitudes around 30° [37]. Designed grid-connected systems in other similar studies show 0.164 to 0.293 [38], 0.078 [39], and 0.04 of COE ($/kWh). In addition, the obtained COE for the case study region in a similar study is 0.103 to 0.122 $/kWh [22]. A comparison of the COE of the current study with other studies mentioned above illustrates that the obtained COEs for all scenarios in this study are in an acceptable range and in some cases lower than the previous studies due to having the option of selling back to the grid.

3.7. The Power Supply of S3T as the Best Option. The hourly status of supplied power through PV, grid, and battery discharging along with electricity sold to the grid is shown in Figure 12. As it can be seen in Figure 12(a), PV panels generate power with their maximum power output from 7:00 to 17:0 throughout the year. Since the grid load in the province is high during this period, according to Figure 12(b), which shows the amount of provided energy by the grid, energy purchase from the grid is the least along the day, and as a result, the number of electricity outages will be reduced in the case study region. However, from Feb. to Jul. due to the warmly weather condition, the supplied energy through the grid is higher than Aug. to Jan. between 7:00 and 17:00, and as Figure 12(d) indicates, there will be no enough power to fully charge the batteries. According to Figure 12(c), from Aug. to Jan. due to the low electricity demand compared to Feb. to Jul., electricity sold to the grid increases, while for Feb. to Jan., this value is trifle. Figure 12(d) shows the state

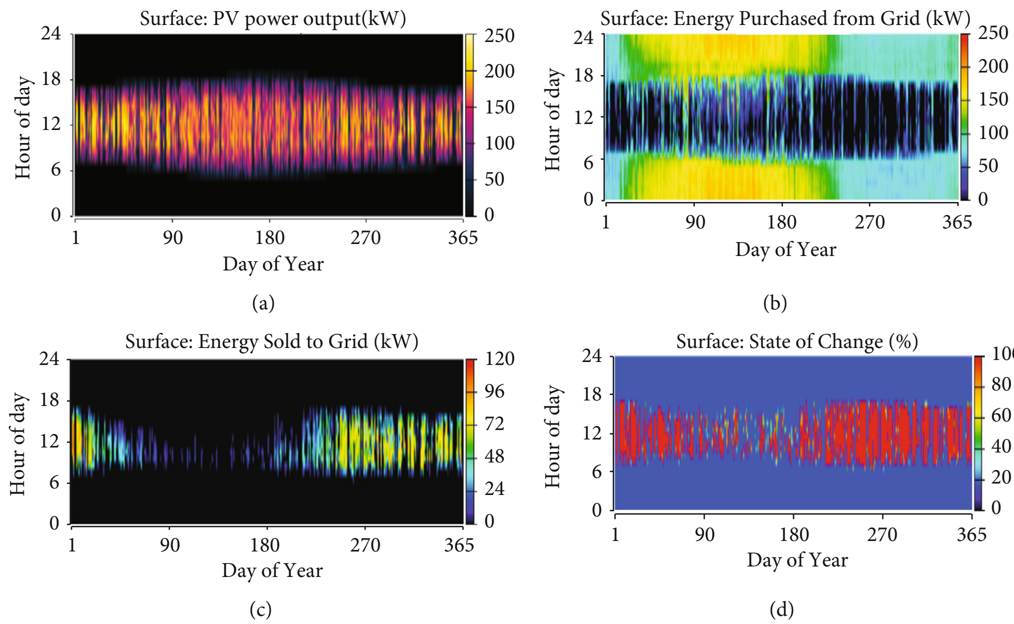

Figure 12: Hourly status of electricity supply through S3T.

of charge for batteries. Based on this figure, from Aug. to Jan., more percentage of load at night is supplied through batteries compared to Feb. to Jul. All in all, energy management for Feb. to Jul. is essential, and increasing the size of batteries would cause less energy consumption between 18:00 and 6:00.

4. Conclusion

In this research, the effect of different strategies on the pollutant emission considering EPA standards as well as economic parameters is indicated for a case study region in which the weather temperature and solar GHI are high, and due to the only grid electricity consumption, CO_2 and other pollutant gases emissions are so high.

(i) According to the TOPSIS method and qualitative analysis, the system with a vertical tracker confined to the initial capital (S3T) is the best option for the current research

(ii) For 2000–4000 kWh/day load demands and 0.8–1.2 of PV prices (1500 \$/kW PV + 420 \$/kW tracker), COE is changed to 0.035–0.12 and 0.064–0.12 \$/kWh for the with- and without-tracker systems, respectively. Also, CO_2 emission will be reduced in an equal RF in the optimized system that HOMER suggests as a result of using more PVs than the system without a tracker

(iii) For the 0.07–0.12 \$/kWh price of the grid electricity and 4–5.5 kWh/m^2/d of GHI, COE is changed to 0.072–130 to 0.066–0.132 \$/kWh for the with- and without- a tracker, and NPC for the system with a tracker is about 16% higher than the other one except when GHI is higher than 5.2 kWh/m^2/d, and the grid electricity price is less than 1 \$/kWh.

(iv) Considering constant conditions of economy in the case study's country, 11–12 years would be enough time for payback on reducing CO_2 emissions close to EPA standards.

(v) Increasing the number of batteries can supply more energy demand for Feb. to Jan. at night when energy consumption is still high.

As the final point, it is suggested that the initial capital would be considered in hybrid system optimization for CO_2 reduction in addition to executive limits. For future research, it is recommended that the effect of battery numbers on the emission would be considered.

Data Availability

Data are available upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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