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The Potential of Renewable Energy Sources in Providing Sustainable Power for Natural Disaster Zones: TOPSIS Method for Gaziantep, Turkey

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ABSTRACT

Renewable energies (REs) can be a reliable and sustainable source of energy for communities affected by natural disasters. The present work investigates the potential of wind and solar in providing sustainable energy for natural disaster areas with a focus on Gaziantep, Turkey. This study aims to find the optimal scenario based on REs using the TOPSIS method. It also evaluates the feasibility of implementing solar and wind to supply the required electricity. Four different scenarios are compared based on 25-year energy-economic-environmental analyses using HOMER v2.81 software. The simulation outputs are weighted by the opinions of 10 renewable experts and classified into Beneficial and Non-Beneficial categories. The results of the energy-economic-environmental analyses showed that the cheapest electricity produced with a price of 0.426 $/kWh in the scenario of solar cell-diesel generator-battery (scenario one). The most environmentally friendly scenario, the wind turbine-solar cell-diesel generator-battery scenario (scenario three), had about 1054.3 tons/year of pollutant reduction compared to the conventional scenario of only using diesel generator (scenario four). The ranking results indicate that the best scenarios are scenario one, followed by scenario three and scenario two, even though scenario three has the highest scores in parameters of renewable fraction, losses, pollutants and excess electricity.

1. Introduction

Natural disasters have become a common occurrence in different parts of the world and cause significant damage to infrastructure and human lives. Communities affected by natural disasters often lack access to basic necessities such as electricity, water and food [1]. Renewable energy sources can provide a reliable and sustainable solution for these disaster-prone areas [2]. They are abundant, clean and locally available, making them an ideal option for such disaster-prone areas [3].

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This paper examines the role of wind and solar energy in supplying electricity after earthquakes. Earthquakes can damage power grids and disrupt conventional electricity sources. Wind and solar energy can serve as emergency power sources in these situations, as they do not depend on fuel or other resources and are naturally active [4, 5]. Installing solar and wind power systems near or within residential and industrial areas can also enhance electricity provision after earthquakes. Moreover, these energy sources are portable and can be deployed in remote and off-grid areas, which may be inaccessible or deprived of electricity after earthquakes [6]. Therefore, renewable solar and wind power sources can be a viable solution for electricity provision after earthquakes and contribute to energy security and emergency electricity supply.

Some of the previous studies on renewable energy sources and their use in providing sustainable energy during natural disasters are summarized in Table 1. Based on the analysis of these studies, this paper proposes a set of scenarios for Gaziantep to effectively utilize its renewable energy potential. These scenarios involve policy actions that can enhance investment in renewable energy infrastructure and promote local community involvement in renewable energy projects. It should be noted that the assessment of using wind and solar energy, as well as the use of multi-criteria decision-making methods to find the superior scenario for electrifying the earthquake-affected area of Gaziantep, has not been studied so far. In other words, it has not been determined how much of the essential electricity can be supplied by wind and solar energy and which scenario is overall the most suitable.

Table 1 shows that the previous works have different scales, methodologies, or locations. This not only emphasizes the novelty of this work, but also highlights the importance of this study for the disaster-prone city of Gaziantep. As can be seen in the first column from the left of Table 1, previous works have either not been comprehensive (simultaneous technical-economic-energy-environmental analysis has not been addressed) or have been in a different location and climate, making their results not generalizable to the current location. Also, they have merely assessed potential and aimed at providing sustainable electricity, not finding an optimal and superior system using ranking methods. This work uses HOMER v2.81 software to compare different scenarios in terms of energy-economic-environmental criteria. The opinions of different experts are used to find the best scenario, and the TOPSIS multi-criteria decision making method is used to rank the different scenarios. All the renewable scenarios are compared with the conventional method of using only diesel generator.

2. The place under investigation

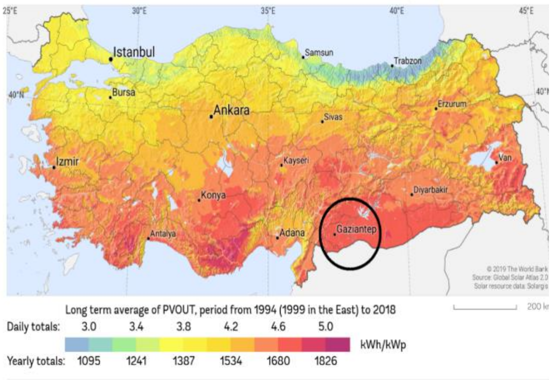
Turkey is one of the world's most populous countries with about 82 million people [17]. Turkey has abundant wind and solar resources and a large population, which makes renewable energy sources such as wind and solar energy an effective way to meet the country's energy needs. Some areas of Turkey have an average wind speed of 5-7 m/s. Turkey also has strong solar radiation and many sunny hours [18].

This paper aims to explore the potential of renewable energy sources for providing sustainable energy for areas affected by natural disasters. The case study is Gaziantep, Turkey, which is a major city in Turkey and is vulnerable to earthquakes and other natural disasters. Gaziantep has suffered from several destructive earthquakes in the past, which have damaged its infrastructure and affected the lives of its people. Emergency electricity can be very important in the event of an earthquake. Providing electricity and energy for various purposes, including the people's basic needs, is also very essential for this highly populated city. Gaziantep has strong solar radiation and rich wind resources, so renewable energy sources such as solar and wind power can be an effective way to meet the city's energy needs. These methods can also serve as emergency power sources in the event of an earthquake. Figures 1a and 1b, show the location of the Gaziantep station on the solar and wind maps of Turkey, respectively. The figures show that Gaziantep has a better situation in terms of radiation than wind speed in Turkey.

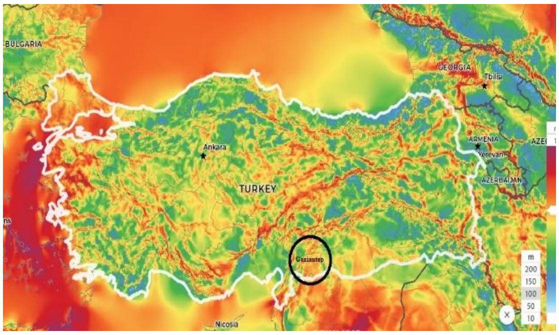
Table 1. Some recent studies on the use of renewable energy in areas affected by natural disasters

Ref., Year	Purpose of work	Result	Method	Location	The difference with the present work
[7], 2007	Developing sustainable electricity and water supply using a hybrid mini-grid system for remote areas and	A test system for solar water pumping and RO water treatment plant was built and the results were	HOMER software & laboratory setup	Indonesia	- Energy, economic and environmental analyzes have not been done.

	disaster response and recovery	compared with the simulation results.			- Ranking is not done to find the best scenario. - The location and climate of the study was different.
[8], 2009	Designing a system for producing electricity and drinking water using solar, wind and diesel generator for remote areas before and after tsunami	The optimal system after tsunami is wind-diesel generator which has a price of 0.437 $/kWh of electricity, which is 0.073 $ lower than using only diesel generator before tsunami.	HOMER software& laboratory setup	Maldives	- Ranking is not done to find the best scenario. - The location and climate of the study was different.
[9], 2011	Designing an emergency power system for relief and refugee camp situations	The optimal system consists of wind-solar-biomass generator-battery which has a price of 0.275 $/kWh of electricity	HOMER software	Chad-Sudan border	- Environmental analyzes have not been done. - Ranking is not done to find the best scenario. - The location and climate of the study was different.
[10], 2016	Using hybrid renewable energies for electricity generation for an emergency shelter in natural disaster conditions	New techniques and practices for providing electricity and water for relief tents using wind, solar and rain were introduced"	Descriptive	No specific location	- Energy, economic and environmental analyzes have not been done. - Ranking is not done to find the best scenario. - Specific location and climate have not been investigated.
[11], 2017	Feasibility of a renewable energy system for off-grid emergency operations	Renewable energies, especially solar energy, can act as good backup power systems in cases of shortage of conventional energy sources	HOMER software	Tehran	- Environmental analyzes have not been done. - Ranking is not done to find the best scenario. - The location and climate of the study was different.
[12], 2019	Using hybrid renewable energies for electricity generation for an emergency clinic and comparison with the conventional method of using only diesel generator.	The economic and environmental parameters of the hybrid renewable energy system are more satisfactory than the conventional system	HOMER software	Tehran	- Ranking is not done to find the best scenario. - The location and climate of the study was different.
[13], 2020	Designing a mobile container of wind turbine-solar cell for natural disaster areas	The scenario that produces 2982 kWh of solar electricity, 667 kWh of wind electricity, and 727 kWh of excess electricity is the best.	HOMER software	Central Java	- Economic and environmental analyzes have not been done. - Ranking is not done to find the best scenario. - The location and climate of the study was different.
[14], 2020	Finding the most reliable and economical way to supply energy and water for residential and sanitary containers in different climatic conditions of Iran in areas affected by natural disasters	The cost of each kWh of energy can be practically attainable in the range of 0.130 to0.167	HOMER software & TOPSIS method	Different climates of Iran	- The parameters used for ranking were not independent of each other. - The location and climate of the study was different.
[15], 2022	Designing a microgrid system for earthquake and storm-prone areas	In the optimal system, the number of solar panels is 180 and the number of batteries is 264.	HOMER Pro software	Puerto Rico	- Environmental analyzes have not been done. - Ranking is not done to find the best scenario. - The location and climate of the study was different.
[16], 2023	Using hybrid renewable resources to supply electricity and heat for a small medical center in the COVID-19 epidemic conditions	Increasing the price of wind turbines reduces the use of turbines in simulation, increases the number of photovoltaic panels and reduces the fuel consumption of diesel generators.	HOMER Pro software	Rasht, Shiraz	- Environmental analyzes have not been done. - Ranking is not done to find the best scenario. - The location and climate of the study was different.
Present work, 2024	Finding the optimal wind-solar-diesel generator system for areas affected by natural disasters	The cheapest electricity produced was at a price of 0.426 $/kWh and the most environmentally friendly scenario reduced the pollutants by about 1054.3 tons/year.	HOMER software &TOPSIS method	Turkey	-



a) Output of generated solar power [19]



b) Wind speed [20]

Figure 1. Atlas of Turkey and the location of the investigated station on it

3. Methodology

3.1. Energy-economic-environmental analysis

In this work, HOMER software is used for 25-year simulations. The data diagram for assessing wind and solar power is shown in Figure 2. The software outputs are also described. The climatic data of wind speed and solar radiation are entered into HOMER software as 20-year averages from NASA website [21]. Other input data include the price of diesel fuel, annual interest rate, and equipment price and technical information. The software compares different scenarios from low to high cost among 614922 existing configurations. The comparisons are based on technical, economic, energy and environmental criteria.

Table 2 shows the governing equations of the software, which cover the power production by solar cells (Equation 1)and wind turbines(Equation 2), the diesel generator efficiency(Equation 3), the battery operation equation (Equation 4)and the economic computations(Equations5 and 6).

Figure 3 shows the system diagram under investigation. The backup system in emergency situations consists of a battery and a diesel generator and aims to provide electricity to a mobile medical clinic [28].

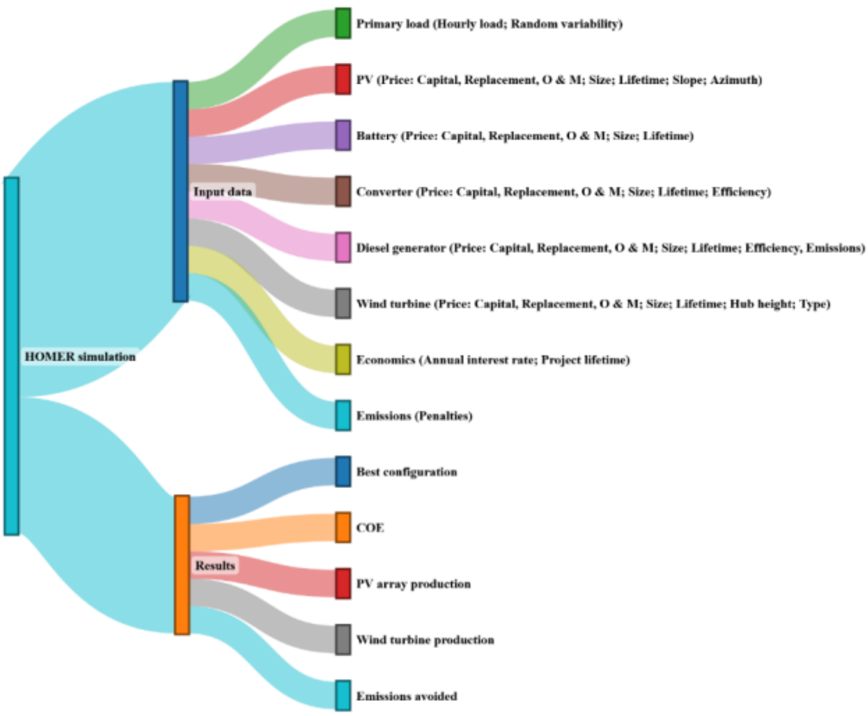


Figure 2. Diagram of software input and output parameters HOMER

Table 2. Governing equations

Parameter	Equation	No.
Power produced by solar cells[22]	$P_{PV} = Y_{PV} \cdot f_{PV} \cdot \frac{\overline{H}_T}{\overline{H}_{T,STC}}$	(1)
Power produced by wind turbines[23]	$P_{WT} = \frac{\rho}{\rho_O} \cdot P_{WT,STC}$	(2)
Diesel generator efficiency[24]	$\eta_{gen} = \frac{3.6\ P_{gen}}{\dot{m}_{fuel} \cdot LHV_{fuel}}$	(3)
Battery performance [25]	$P_{batt,max} = \frac{Min(P_{batt,kbm\ or\ mcr\ or\ mcc})}{\eta_{batt,c}}$	(4)
Total net present cost[26]	$\text{total NPC} = \frac{C_{ann,total}}{\frac{i(1+i)^N}{(1+i)^N-1}}$	(5)
Cost of produced energy (kWh)[27]	$COE = \frac{C_{ann,total}}{E_{load\ served}}$	(6)

3.2. Ranking analysis

Various MCDM methods, such as TOPSIS, were employed to prioritize the examined panels. The formulas that guide the TOPSIS approach are outlined in accordance with previous studies [29].

Step 1: Calculation of Normalized Matrix [30].

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}} \tag{7}$$

Step 2: Calculation of weighted normalized matrix [31].

$$V_{ij} = \overline{X_{ij}} \times W_j \tag{8}$$

Step 3: Computing the ideal best and ideal worst values, denoted as "V^+" and "V^-" for non-beneficial criteria (minimum and maximum of V_{ij}), and "V^-" and "V^+" for beneficial criteria (minimum and maximum of V_{ij}).

Step 4: Calculation of the Euclidean distance from the ideal best and ideal worst [32]

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+\right)^2\right]^{0.5} \tag{9}$$

$$S_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^-\right)^2\right]^{0.5} \tag{10}$$

Step 5: Calculation of Performance Score [33].

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \tag{11}$$

Table 3. Data required for simulation with HOMER

Device	Buy ($)	Replacement ($)	Repair & maintenance ($, $/year)	Power (kW)	Lifetime (year)	More Information
PV [34]	1500	1200	0	0-1000	20	Angle: latitude, Azimuth=0, Without tracker, Derating factor: 80%
Wind Turbine [35]	5725	3650	100	1000-0	25	Installation height: 25 m, Type of wind turbine: BWC XL1, Rated Power: 1 kW DC
Battery [36]	174	174	5	0-2000	845 kWh	Battery type:TrojanT-105 Capacity: 1.35kWh
Converter [37]	200	200	10	0-1000	10	Inverter efficiency: 90%, Rectifier efficiency: 85%
Generator [38]	200	200	0.50	0-1000	15000h	Minimum load ratio: 30%,Efficiency curve coefficients:0.25 and 0.08, Production pollutants:CO_2: 6.5 g/L, Unburned hydrocarbons:0.72 g/L, Suspended matter:0.49 g/L,Sulfur:2.2 g/L, NO_x: 58g/L

4. Simulation data

In Table 3, the data required for the simulation, which includes the price and technical information of the equipment used, are given.

The project has a lifespan of 25 years [39], with a diesel cost of 1.012 $/L [40] and an annual interest rate of 8.5% [41]. The battery operates with both cycle charging and load following modes. No environmental penalties are assumed. Figures 4a and 4b display the other simulation data, such as solar radiation intensity and wind speed. The yearly averages of radiation and clearness index are 4.83kWh/m2-day and 0.59, as shown in Figure 4a.

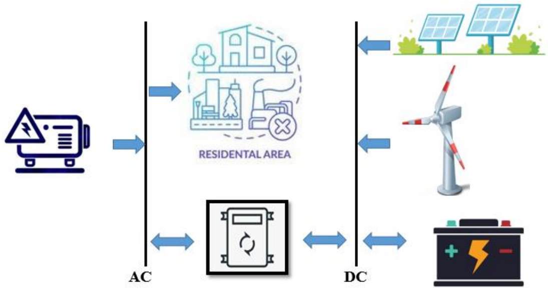
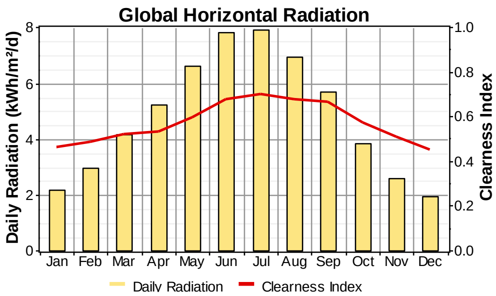
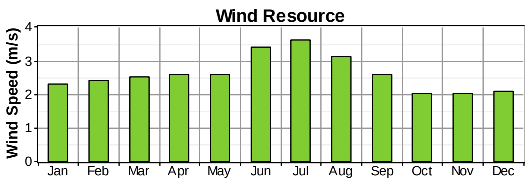


Figure 3. Schematic of the system investigated in the present work

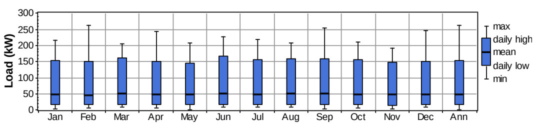


(a)

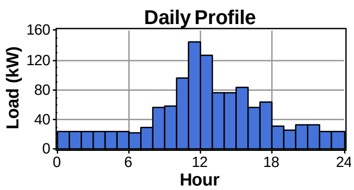


(b)

Figure 4. Diagram of a) Average monthly solar radiation b) Average monthly wind speed



(a)



(b)

Figure 5. Profile of electricity consumption during the year (Figure a) and during 24 hours (Figure b)

Figure 4b indicates that the wind speed has a yearly average of 2.6 m/s and a monthly peak of 3.6 m/s in July. The electricity demand that needs to be satisfied is the key simulation output, which is presented in Figure 5. The daily electricity demand is 1190 kWh/day on average, and a 15% factor for daily fluctuations and a 20% factor for hourly fluctuations are applied to account for randomness.

5. Results and Discussion

Table 4 presents the results of three scenarios that involve renewable energies and compares them with the conventional scenario of using a diesel generator for power supply. The results of Table 4 show that the most economical scenario is the first one, which demonstrates the advantage of solar energy over wind energy in the economic aspect for the region under investigation. According to the results, the price per kWh of the wind-diesel system is about 3.18 times the price per kWh of the solar-diesel system. The second scenario has a lower initial purchase cost, but it has a much lower share of renewable energy, so it requires about 9.3 times more diesel generator usage than the first scenario and thus has a higher net present value of the total cost. The main reason for the higher operational cost of the system in the second scenario compared to the first one is the maintenance cost of the diesel generator, which is used more frequently in the second scenario than the first one. The third scenario, which utilizes both wind and solar energy, has the largest proportion of renewable energy use with 93%. The electricity generation cost per kWh of this scenario is 1.31 times higher than the best economic scenario (the first scenario). Due to the increased use of renewable energies, about 590 liters of diesel are saved. The higher operational cost of the system in the third scenario compared to the first one is attributed to the maintenance cost of the wind turbine, which is an additional expense.

Using a diesel generator in the fourth scenario results in a very low initial cost (only 6% of the optimal scenario cost) but a very high operational cost (over 20 times higher). This is the most costly scenario at 4.088 $/kWh, and it uses 400298 liters more diesel than the third scenario, which is the most environmentally friendly. As shown in Table 4, the lowest-cost electricity production has a price of 0.426 $/kWh, which is approximately 2.7 times higher than the global average electricity price [42] and about 8.7 times higher than the national grid electricity price in Turkey [42]. However, it should be mentioned that the scenarios under investigation had surplus electricity that could be sold to the grid and lower the system costs considerably. Moreover, by imposing a penalty for pollutants, which was not considered in this study, the costs could be further reduced.

Additional information on the three renewable energy-based scenarios is given in Table 4. The payback period is measured against the fourth scenario. The payback period for all three scenarios is under one year, much shorter than the conventional diesel generator scenario. Table 4 reveals that the second scenario, which employs a wind turbine, does not generate any surplus electricity. However, the first and third scenarios, which utilize solar cells, produce a large amount of excess electricity. The wind turbine's low capacity factor also indicates the poor performance of wind energy in the region under investigation. The diesel generator in the second scenario has a high usage rate, which reduces its lifespan compared to the other scenarios. The second scenario also has the greatest battery losses and the smallest converter losses. The third, first and second scenarios are the most, second most and least eco-friendly scenarios, respectively, in terms of pollutant emissions. The third scenario emits the least amount of pollutants, at 46952 kg/year.

Figure 6 shows the weight and type of the parameters under study. The weights in Figure 6 are derived from the average opinion of 10 experts and then normalized and shown in Figure 6. Among the 6 parameters under investigation, the CO_2 Emission parameter has the greatest weight and the Losses and Renewable fraction parameters have the smallest weight. Non-Beneficial parameters are those that have a more negative impact as they increase. Beneficial parameters are those that improve the situation as they increase. Of the 6 parameters under investigation, COE, Losses, Return on investment and CO_2 Emission are Non-Beneficial and the others are Beneficial.

Table 4. The technical-economical-energy-environmental results of the scenarios examined in this work

scenario	Equipment	Total NPC ($)	COE ($/kWh)	Initial Capital ($)	Operating Cost ($)	Ren. Frac. (%)	Diesel (L)
1	PV, DG, Batt.	1,892,883	0.426	993,200	87910	92	17959
2	Wind, DG, Batt.	6,021,492	1.355	910,900	499365	7	166882
3	PV, Wind, DG, Batt.	2,481,023	0.558	1,513,500	94538	93	17370
4	DG	18,172,416	4.088	60,000	1,769,795	0	417668

Continue the Table 4

scenario	Time coming back Fund (year)	Electricity Extra (kWh/year)	Capacity factor (%)	Generator lifetime (year)	Losses Battery (kWh/year)	Losses converter (inverter, rectifier) (kWh/year)	Production pollutants (CO_2, CO, NO_x, SO_2)
1	0.556	164081	PV 17.8	26.6	26893	45605, 4483	47292,117,1042,95
2	0.667	0	Wind 4.05	5.49	33636	21648, 37992	439456,1085,9679,883
3	0.87	200479	PV 17.8, Wind 4.05	27.3	23348	45757, 4402	45740,113,1007,91.9
4	-	395461	-	1.71	-	-	1099858, 2715, 24225, 2209

Table 5. Forming the normal matrix of data used for simulation by considering the weight of each parameter

Scenario	COE ($/kWh)	Renewable Fraction (%)	Losses (kWh/year)	Emissions (kg/year)	Excess electricity (kWh/year)	Return on investment (year)
1	0.1313	0.2202	0.1658	0.0559	0.2317	0.1891
2	0.4177	0.0168	0.2091	0.5193	0.0000	0.2269
3	0.1720	0.2226	0.1648	0.0195	0.2832	0.2960

Table 6. Calculation of parameters V^+ and V^-

Parameters	COE($/kWh)	Renewable Fraction (%)	Losses (kWh/year)	Emissions (kg/year)	Excess electricity (kWh/year)	Return on investment (year)
V^+	0.1313	0.2226	0.1648	0.0195	0.2832	0.1891
V^-	0.4177	0.0168	0.2091	0.5193	0.0000	0.2960

Table 5 presents the normalized matrix for the 6 output data of the simulations, considering the weight of each parameter, using equations 7 and 8. This matrix is employed to compute the V^+ and V^- parameters (step 3 of section 3.2). The type of parameter under investigation (Beneficial or Non-Beneficial) should be taken into account when calculating the V^+ and V^- parameters in Table 6.

Table 7 presents the Si^+ and Si^- parameters computed using equations 9 and 10. The final score of each scenario is then obtained using equation 11. The results in Table 7 indicate that the first scenario is the optimal one. Considering that the first scenario is only the best choice in terms of COE and Return on investment parameters and the third scenario is better in the remaining four parameters, and also that Emissions has the highest weight and the third scenario has a better value in it, the need for ranking in choosing the best scenario becomes more evident.

Since the best scenario is the first scenario, more details of this scenario are discussed below. Figure 7 displays the costs of the optimal economic scenario over the project's 25-year useful life. The results reveal that the main cost, which was for the equipment, was incurred in the first year and then battery replacement costs were present in the ninth and eighteenth years and solar cell replacement costs were imposed on the system in the twentieth year. There is a steady cost of maintenance and repair of the generator during the 25 years. Also, the replacement of the electric converter in the tenth and twentieth years will increase the system cost. At the end of the twenty-fifth year, there is a salvage cost of about 440000 $, which is added positively to the system.

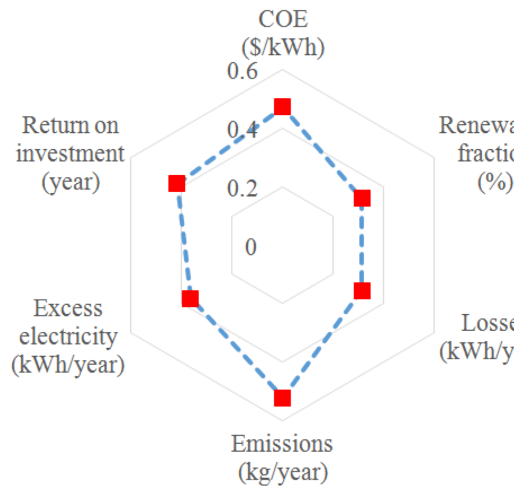


Figure 6. Weight and type of parameters considered for ranking

Table 7. Ranking of different scenarios

Scenario	Si^+	Si^-	Pi	Rank
1	0.0630	0.6365	0.9099	1
2	0.6766	0.0690	0.09268	3
3	0.1143	0.6593	0.8522	2

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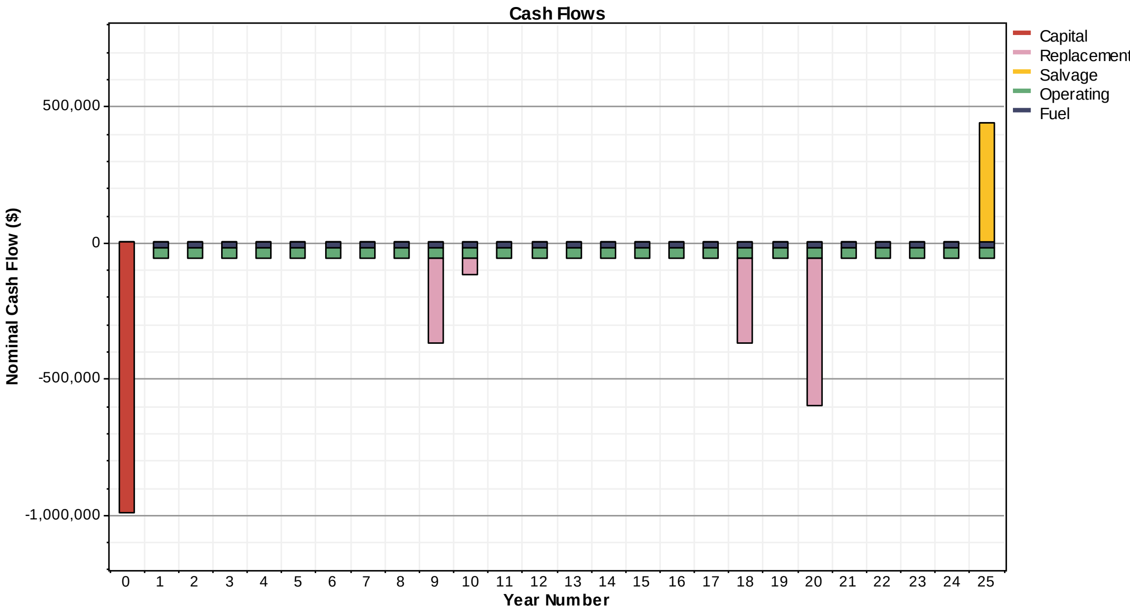

Figure 7.Costs of the top economic scenario during the 25 years of the useful life of the project

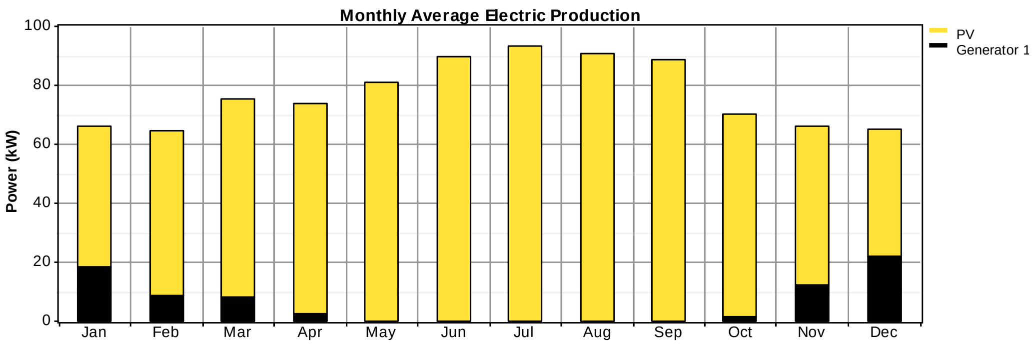

Figure 8.Average monthly electricity generation for the top economic scenario

Figure 8 illustrates the average monthly electricity production under the optimal economic scenario. The figure reveals that the diesel generator operates only in the cold season (mainly December and January), whereas the solar cells provide all the required electricity from May to September (5 months). The solar cells generate approximately 622 MWh of electricity annually, while the diesel generator consumes about 54 MWh/year.

Figure 9 displays the contour of the solar cell performance during the year. The figure indicates that the electricity production ranges from 0 to 450 kW and occurs from 7 AM to 6 PM during the year. The mean output of the solar cells is 71 kW and the capacity factor is 17.8%, with a total of 4380 hours of operation per year.

Figure 10 shows the contour of the output of the diesel generator, indicating a maximum performance of 100 kW during the 6 cold months of the year, resulting in a capacity factor of 6.14%. The useful life of 26.6 years and the number of 27 starts/year are other performance data. In total, the diesel generator consumes 18000 liters/year of gasoline.

As shown in Figure 11, the battery charge contour varies throughout the year. The figure reveals that the battery charge reached 90% to 100% for about 24% of the year. The annual battery losses amounted to about 27000 kWh.

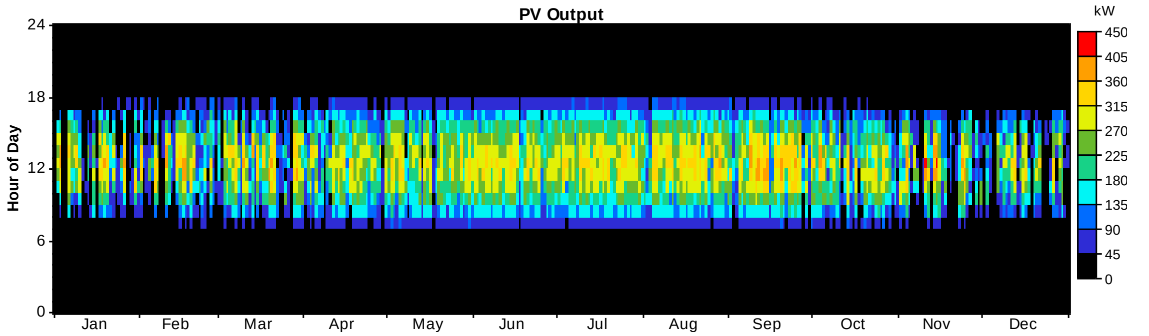

Figure 9.Solar cell performance contour over the year

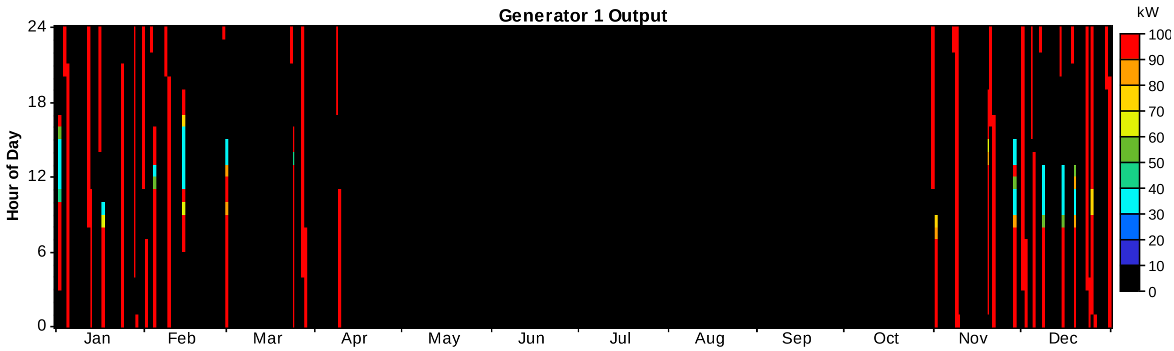

Figure 10.Output contour of diesel generator

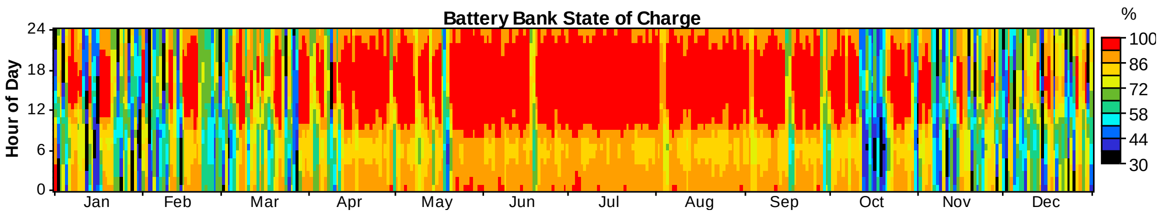

Figure 11.Contour of battery charge

Figure 12 displays the annual performance contours of the inverter and the rectifier. The results show that the inverter had a peak capacity of 270 kW at noon and the rectifier had a maximum capacity of 90 kW during the night hours. A noteworthy aspect of the rectifier performance is that it converted AC to DC in the rectifier during the months when the diesel generator was operational (6 cold months of the year). The inverter and the rectifier operated for 8280 hours and 479 hours, respectively, resulting in losses of 45.6 MWh in the inverter and about 4.5 MWh in the rectifier.

In Table 8, the adjusted prices of generating each kilowatt of renewable electricity from systems similar to the present work have been compared. From the results, it can be seen that the order of prices is consistent, and the very slight difference is due to the use of different systems and different equipment prices in different years. Also, different scales of electricity supply, different types of wind turbines, and different solution assumptions are other factors that have led to this minor difference. Overall, considering Table 8, the results of the present work are valid.

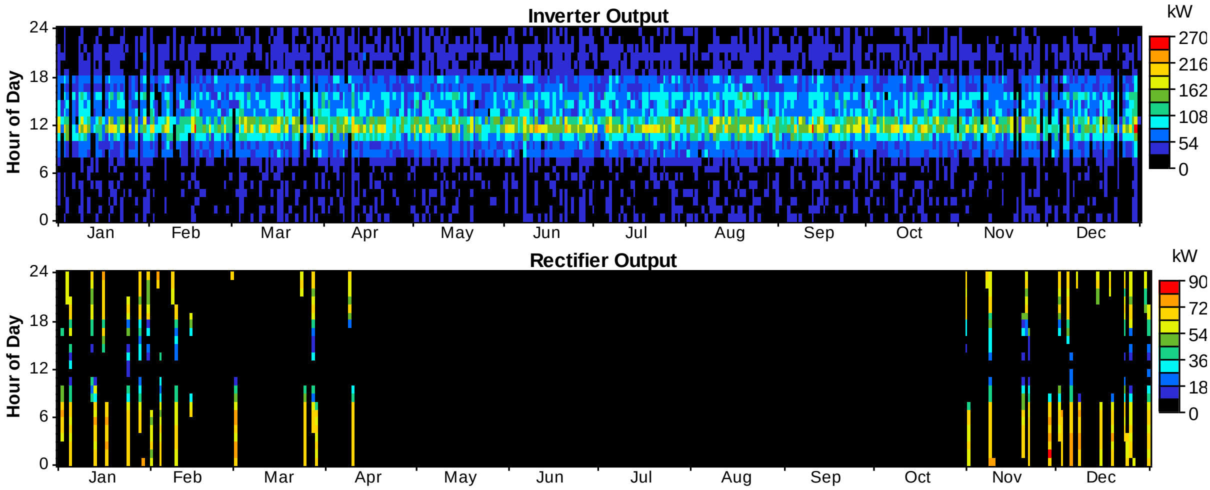

Figure 12.Contour of Inverter and rectifier performance

Table 8. Comparison of the adjusted price of generating each kilowatt of renewable electricity from systems similar to the present work in Turkey

Ref.	Year	The system under study	Application	Adjusted price of producing each kWh of renewable electricity
[43]	2023	PV, Wind turbine, Diesel generator	Survey of EV charging stations based on renewable energies in big cities	0.441-0.542
[44]	2023	PV, Wind turbine, Diesel generator	Electrification of an area with 100 households	0.3-1.6
[45]	2022	PV, Wind turbine, Hydropower	Rural electrification	0.224-0.374
[46]	2021	PV, Wind turbine, Fuel cell, Hydropower	Rural electrification	0.427-0.974
[47]	2020	PV, Wind turbine, Diesel generator	Electrification of Yalova University campus	0.145-0.490
[48]	2021	PV, Wind turbine, Diesel generator	Electricity supply to an area with 100 villas	0.258-0.276
[49]	2023	PV, Wind turbine, Diesel generator	Electrification of a household in 21 provinces	0.198-0.346
Present work	2024	PV, Wind turbine, Diesel generator	Electricity supply to the area affected by natural disasters	0.426-1.355

6. Conclusions

This study focuses on Gaziantep, a Turkish city situated in an earthquake-prone area. The city seeks to improve the reliability of its energy networks by utilizing renewable sources such as wind and solar for electricity generation. The advantages of employing renewable sources in earthquake-prone area include reducing the likelihood of power interruptions, increasing the safety of energy production and transmission, and mitigating the negative impacts on the local ecosystem. Furthermore, these actions help to preserve the environment and decrease greenhouse gas emissions. Based on these considerations, we applied the TOPSIS ranking method to assess the performance of three different scenarios that rely on wind and solar sources with battery and diesel generator backup. The technical-economic-energy-environmental analyses were conducted by HOMER v2.81 software on 20-year data of solar radiation and wind speed obtained from NASA website. The three scenarios under examination are solar cell-diesel generator-battery (scenario one), wind turbine-diesel generator-battery (scenario two), and solar cell-wind turbine-diesel generator-battery (scenario three). The main findings are as follows:

- The cheapest solar electricity with a price of 0.426 \$/kWh and the shortest payback period of 0.556 years belong to scenario one.
- The highest percentage of renewable energy fraction, the lowest amount of losses, the lowest amount of pollutants, and the highest excess electricity are respectively 93%, 73507 kWh/year, 16952 kg/year, and 200479 kWh/year for scenario three.
- Among the six independent parameters under study, the amount of pollutants produced had the highest weight and the losses and renewable energy fraction had the lowest weight.
- The best scenarios using the TOPSIS method were first, third, and second, respectively. Scenario three, despite its superiority in four parameters out of six, could not be the best scenario and this issue showed the necessity of ranking more than before.

Nomenclature

i	Annual interest rate (%)
RO	Reverse osmosis (-)
RE	Renewable energy (-)
P_{gen}	Electricity produced by diesel generators (kW)
$\dot{m}_{fuel}$	Fuel consumption of generator (units/hr)
LHV_{fuel}	Lower heating value of the fuel (MJ/kg)
$\eta_{batt,c}$	Batteries charge efficiency (%)
N	Useful life-time (year)
PV	Photovoltaic
NPC	Net present cost (\$)
COE	Levelized cost of electricity (\$/kWh)
P_{WTG}	Power output of wind turbine (kW)
$P_{WTG,STP}$	Power output of wind turbine at standard pressure and temperature (kW)
$P_{batt.cmax}$	Maximum power of battery (kWh)
X_{ij}	Matrix containing input data (-)
$\overline{X}_{ij}$	Normalized Matrix (-)
V_{ij}	Weighted normalized matrix (-)
W_j	Weight of j^{th} criterion (-)
ρ	Actual air density (kg/m^3)
ρ_0	Air density at standard pressure and temperature equal to 1.225 kg/m^3
$P_{batt,cmax,kbm}$	Maximum battery charge power based on kinetic battery model (kWh)
$P_{batt,cmax,mcc}$	Maximum battery charge power based on maximum charge current (kWh)
$P_{batt,cmax,mcr}$	Maximum battery charge power based on maximum charge rate (kWh)
$\overline{H_{T,STC}}$	Incident radiation on the cell's surface under standard conditions (1 kW/m^2)
$\overline{H_T}$	Incident radiation on the cell's surface on a monthly basis (kW/m^2)
Y_{PV}	Output power of solar cell under standard condition (kW)
f_{PV}	Derating factor (%)
P_{PV}	Output power of PV cells (kW)
η_{gen}	Electrical efficiency of generator (%)
$C_{ann,total}$	Total annual cost (\$)
$E_{load\ served}$	Real electrical load by system (kWh/year)
V^+	Maximum value of V_{ij} (-)
V^-	Minimum value of V_{ij} (-)
S_i^+	Euclidean distance for ideal best (-)
S_i^-	Euclidean distance for ideal worst (-)
P_i	Performance score (-)

References

[1] Okyere, M.A., Essel-Gaisey, F., Zuka, F.M., Christian, A.K. and Nunoo, I.K., 2023. Wading out the storm: Exploring the effect of flooding on energy poverty amidst disaster management strategies in Dar es Salaam. Environmental Science & Policy, 150, p. 103578. https://doi.org/10.1016/j.envsci.2023.103578

[2] Bhattacharya, R. and Bose, D., 2023. Energy and water: COVID- 19 impacts and implications for interconnected sustainable development goals. Environmental Progress & Sustainable Energy, 42(1), p. e14018. https://doi.org/10.1002/ep.14018

[3] Reddy, V.J., Hariram, N.P., Ghazali, M.F. and Kumarasamy, S., 2024. Pathway to Sustainability: An Overview of Renewable Energy Integration in Building Systems. Sustainability, 16(2), p. 638. https://doi.org/10.3390/su16020638

[4] Cabrera-Tobar, A., Grimaccia, F. and Leva, S., 2023. Energy Resilience in Telecommunication Networks: A Comprehensive Review of Strategies and Challenges. Energies, 16(18), p. 6633. https://doi.org/10.3390/en16186633

[5] Dalapati, G.K., Ghosh, S., Sherin, T., Ramasubramanian, B., Samanta, A., Rathour, A., Wong, T.K.S., Chakrabortty, S., Ramakrishna, S. and Kumar, A., 2023. Maximizing solar energy production in ASEAN region: opportunity and challenges. Results in Engineering, 20, p. 101525. https://doi.org/10.1016/j.rineng.2023.101525

[6] Amin, S.B., Chowdhury, M.I., Ehsan, S.A. and Iqbal, S.Z., 2021. Solar energy and natural disasters: Exploring household coping mechanisms, capacity, and resilience in Bangladesh. Energy Research & Social Science, 79, p. 102190. https://doi.org/10.1016/j.erss.2021.102190

[7] Setiawan, A.A., Sugiarto, S., Zhao, Y., Nayar, C.V., Wijaya, M.E., Melfiana, E., Negara, T.A., Utomo, B. and Assidiq, A.F., 2007, December. Development of sustainable power and water supply for remote areas and disaster response and reconstruction in Indonesia. In 2007 Australasian Universities Power Engineering Conference (IEEE), pp. 1-6. https://doi.org/10.1109/AUPEC.2007.4548051

[8] Setiawan, A.A., Zhao, Y. and Nayar, C.V., 2009. Design, economic analysis and environmental considerations of mini-grid hybrid power system with reverse osmosis desalination plant for remote areas. Renewable energy, 34(2), pp. 374-383. https://doi.org/10.1016/j.renene.2008.05.014

[9] Salehin, S., Zhang, H., Martinez, T.L., Papakokkinos, G., Upadhyay, G., Bowler, E. and Van Kasteren, J.M.N., 2011, November. Designing of an Emergency Energy Module for relief and refugee camp situations: Case study for a refugee camp in Chad-Sudan border. In 2011 World Congress on Sustainable Technologies (IEEE), pp. 9-14.https://doi.org/10.1109/WCST19361.2011.6114227

[10] Maghami, M.R., Maghoul, A., Dehkohneh, S.S., Gomes, C., Hizam, H. and Othman, M.L.B., 2016, October. Hybrid renewable energy as power supply for shelter during natural disasters. In 2016 IEEE International Conference on Automatic Control and Intelligent Systems (IEEE), pp. 34-39. https://doi.org/10.1109/I2CACIS.2016.7885285

[11] Yousefi, H. and Ghodusinejad, M.H., 2017. Feasibility Study of a Hybrid Energy System for Emergency Off-grid Operating Conditions. Majlesi Journal of Electrical Engineering, 11(3), pp. 7-14. https://journals.iau.ir/article_696267.html

[12] Faraji, J., Babaei, M., Bayati, N. and A. Hejazi, M., 2019. A comparative study between traditional backup generator systems and renewable energy based microgrids for power resilience enhancement of a local clinic. Electronics, 8(12), p. 1485. https://doi.org/10.3390/electronics8121485

[13] Sahrin, A., Utami, E. and Fathoni, M.A., 2021, August. Design of PV-Wind Turbine Mobile Container for Disaster Area Using Homer: A Case study in Cepu-Central Java. In 2nd Borobudur International Symposium on Science and Technology (BIS-STE 2020), Atlantis Press, pp. 93-98. https://doi.org/10.2991/aer.k.210810.015

[14] Rad, M.A.V., Shahsavari, A., Rajaee, F., Kasaeian, A., Pourfayaz, F. and Yan, W.M., 2020. Techno-economic assessment of a hybrid system for energy supply in the affected areas by natural disasters: A case study. Energy Conversion and Management, 221, p. 113170. https://doi.org/10.1016/j.enconman.2020.113170

[15] Al-Shareef, T., Erseçen, K., Al Mohammad, M., Dayioglu, E.A., Tanrıverdi, Y., Evci, B. and Haklıdır, F.S.T., The Benefits of Microgrid Energy Systems: A case study, ESEN 401 Report, Istanbul Bilgi university. https://www.researchgate.net/publication/362016315

[16] Jahangir, M.H., Abdi, A. and Fakouriyan, S., 2023. Energy demand supply of small-scale medical centers in epidemic conditions of Covid-19 with hybrid renewable resources. Energy Reports, 9, pp. 5449-5457. https://doi.org/10.1016/j.egyr.2023.04.362

[17] Barbui, C., Tedeschi, F., Acarturk, C., Anttila, M., Au, T., Baumgartner, J., Carswell, K., Churchill, R., Cuijpers, P., Karyotaki, E. and Klein, T., 2023. Risk factors for mental disorder development in asylum seekers and refugees resettled in Western Europe and Turkey: Participant-level analysis of two large prevention studies. International Journal of Social Psychiatry, 69(3), pp. 664-674. https://doi.org/10.1177/00207640221132430

[18] Akgul, B.A., Ozyazici, M.S. and Hasoglu, M.F., 2023. Estimation of optimal tilt angles and solar radiation collected by fixed and tracking solar panels for the Mediterranean region, Turkey. Indian Journal of Physics, pp. 1-14. https://doi.org/10.1007/s12648-023-02894-7

[19] Photovoltaic Electricity Potential, SOLARGIS, 2024. https://solargis.com/maps-and-gis-data/download/turkey [Accessed 26 January 2024]

[20] Turkey wind speed @ 100m, global wind atlas, 2024. https://globalwindatlas.info/en/area/Turkey [Accessed 26 January 2024]

[21] Mariño, F., Tibanlombo, V., Medina, J. and Chamorro, W., 2023. Optimal Analysis of Microgrid with HOMER According to the Existing Renewable Resources in the Sector of El Aromo and Villonaco, Ecuador. Engineering Proceedings, 47(1), p. 3.

https://doi.org/10.3390/engproc2023047003
[22] Jahangiri, M., Yousefi, Y., Pishkar, I., Hosseini Dehshiri, S.J., Hosseini Dehshiri, S.S. and Fatemi Vanani, S.M., 2023. Techno–econo–enviro energy analysis, ranking and optimization of various building-integrated photovoltaic (BIPV) types in different climatic regions of Iran. Energies, 16(1), p. 546. https://doi.org/10.3390/en16010546
[23] Ganjei, N., Zishan, F., Alayi, R., Samadi, H., Jahangiri, M., Kumar, R. and Mohammadian, A., 2022. Designing and sensitivity analysis of an off-grid hybrid wind-solar power plant with diesel generator and battery backup for the rural area in Iran. Journal of Engineering, 2022, p. 4966761. https://doi.org/10.1155/2022/4966761
[24] Jahangiri, M., Khalili Geshnigani, M., Beigi Kheradmand, A. and Riahi, R., 2023. Meeting the Hospital Oxygen Demand with a Decentralized Autonomous PV System: Effect of PV Tracking Systems. Iranian Journal of Science and Technology, Transactions of Electrical Engineering, 47(2), pp. 601-615. https://doi.org/10.1007/s40998-022-00564-8
[25] Mostafaeipour, A., Qolipour, M., Rezaei, M., Jahangiri, M., Goli, A. and Sedaghat, A., 2021. A novel integrated approach for ranking solar energy location planning: a case study. Journal of Engineering, Design and Technology, 19(3), pp. 698-720. https://doi.org/10.1108/JEDT-04-2020-0123
[26] Mostafaeipour, A., Jahangiri, M., Saghaei, H., RaiesiGoojani, A., Chowdhury, M.S. and Techato, K., 2022. Impact of Different Solar Trackers on Hydrogen Production: A Case Study in Iran. International Journal of Photoenergy, 2022, p. 3186287.https://doi.org/10.1155/2022/3186287
[27] Jahangiri, M., Mostafaeipour, A., Rahman Habib, H.U., Saghaei, H. and Waqar, A., 2021. Effect of emission penalty and annual interest rate on cogeneration of electricity, heat, and hydrogen in Karachi: 3E assessment and sensitivity analysis. Journal of Engineering, 2021, pp. 6679358.https://doi.org/10.1155/2021/6679358
[28] Coaston, A., Lee, S.J., Johnson, J.K., Weiss, S., Hoffmann, T. and Stephens, C., 2023. Factors associated with mobile medical clinic use: a retrospective cohort study. International Journal for Equity in Health, 22(1), p. 195. https://doi.org/10.1186/s12939-023-02004-3
[29] Shahgholian, S., Taheri, M. and Jahangiri, M., 2023. Investigating the Cost-Effectiveness of Solar Electricity Compared to Grid Electricity in the Capitals of Middle Eastern Countries: A Residential Scale Case Study. International Journal of Photoenergy, 2023, p. 8028307. https://doi.org/10.1155/2023/8028307
[30] Jahangiri, M., Yousefi, Y., Pishkar, I., Hosseini Dehshiri, S.J., Hosseini Dehshiri, S.S. and Fatemi Vanani, S.M., 2023. Techno–econo–enviro energy analysis, ranking and optimization of various building-integrated photovoltaic (BIPV) types in different climatic regions of Iran. Energies, 16(1), p. 546. https://doi.org/10.3390/en16010546
[31] Mostafaeipour, A., Qolipour, M., Rezaei, M., Jahangiri, M., Goli, A. and Sedaghat, A., 2021. A novel integrated approach for ranking solar energy location planning: a case study. Journal of Engineering, Design and Technology, 19(3), pp. 698-720. https://doi.org/10.1108/JEDT-04-2020-0123
[32] Keshavarzi, R., Jahangiri, M., 2024. Synergizing wind, solar, and biomass power: ranking analysis of off-grid system for different weather conditions of Iran. Energy Engineering, 121(6), pp. 1381-1401. https://doi.org/10.32604/ee.2024.050029
[33] Jahangiri, M., Rezaei, M., Mostafaeipour, A., Goojani, A.R., Saghaei, H., Dehshiri, S.J.H. and Dehshiri, S.S.H., 2022. Prioritization of solar electricity and hydrogen co-production stations considering PV losses and different types of solar trackers: a TOPSIS approach. Renewable Energy, 186, pp. 889-903. https://doi.org/10.1016/j.renene.2022.01.045
[34] Aziz, A.S., Tajuddin, M.F.N., Adzman, M.R., Azmi, A. and Ramli, M.A., 2019. Optimization and sensitivity analysis of standalone hybrid energy systems for rural electrification: A case study of Iraq. Renewable energy, 138, pp. 775-792. https://doi.org/10.1016/j.renene.2019.02.004
[35] Moein, M., Pahlavan, S., Jahangiri, M. and Alidadi Shamsabadi, A., 2018. Finding the minimum distance from the national electricity grid for the cost-effective use of diesel generator-based hybrid renewable systems in Iran. Journal of Renewable Energy and Environment, 5(1), pp.8- 22. https://doi.org/10.30501/jree.2018.88377
[36] Badakhshian, S.E. and Baharvand, M., 2023. Preliminary assessment of using solar-based systems in the facade of building in Abadan: A sustainable development approach. International Journal of Smart Electrical Engineering, 12(02), pp. 151-156. https://doi.org/10.30495/ijsee.2022.1959496.1204
[37] Valikhani Dehaghani, M., Khalili Samani, M. and Mohamadi Janaki, D., 2022. Management and Environmental Assessment of Simultaneous Production of Solar Electricity and Heat (Case Study: Sar Agha Seyed Rural Health Center). International Journal of Smart Electrical Engineering, 11(04), pp.

191-203. https://doi.org/10.30495/ijsee.2022.1957192.1195

[38] Pishkar, I. and M Beigi, S., 2024. A Comprehensive Evaluation of Renewable Energy Systems with a Backup to Provide a Part of Electrical Needs of a Hospital: A Case Study in Grid-connected Mode. Iranica Journal of Energy & Environment, 15(1), pp. 1-9. https://doi.org/10.5829/ijee.2024.15.01.01

[39] Jahangiri, M., Haghani, A., Heidarian, S., Mostafaeipour, A., Raiesi, H.A. and Alidadi Shamsabadi, A., 2020. Sensitivity analysis of using solar cells in regional electricity power supply of off-grid power systems in Iran. Journal of Engineering, Design and Technology, 18(6), pp. 1849-1866. https://doi.org/10.1108/JEDT-10-2019-0268

[40] Diesel prices, liter, 04-July-2023, Global Petrol Prices, 2023. https://www.globalpetrolprices.com/diesel_prices[Accessed 04 July 2023]

[41] Interest Rate | Europe, Trading Economics, 2023. https://tradingeconomics.com/country-list/interest-rate?continent=europe[Accessed 04 July 2023]

[42] Electricity prices, December 2023, Global Petrol Prices, 2024. https://www.globalpetrolprices.com/electricity_prices/

[43] Güven, A.F. and Yücel, E., 2023. Application of HOMER in assessing and controlling renewable energy-based hybrid EV charging stations across major Turkish cities. International Journal of Energy Studies, 8(4), pp. 747-780. https://doi.org/10.58559/ijes.1324236

[44] Pürlü, M., Andiç, C., Aydın, E. and Solak, B., 2023. Optimal Design of Hybrid Renewable Energy System for a Region in Turkey Using HOMER. Turkish Journal of Electrical Power and Energy Systems, 3(3), pp. 146-155. http://doi.org/10.5152/tepes.2023.23021

[45] Pürlü, M., Beyarslan, S. and TÜRKAY, B., 2022. On-grid and off-grid hybrid renewable energy system designs with Homer: A case study of rural electrification in Turkey. Turkish Journal of Electrical Power and Energy Systems, 2(1), pp. 75-84. http://doi.org/10.5152/tepes.2022.21013

[46] Purlu, M., Beyarslan, S. and Turkay, B.E., 2021, November. Optimal design of hybrid grid-connected microgrid with renewable energy and storage in a rural area in Turkey by using HOMER. In 2021 13th International Conference on Electrical and Electronics Engineering (ELECO), pp. 263-267. https://doi.org/10.23919/ELECO54474.2021.9677788

[47] A. Kiliç, G., Al, K., Dağtekin, E. and Ünver, Ü., 2020. Technical, economic and environmental investigation of grid-independent hybrid energy systems applicability: a case study. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 379(2), pp. 1-16. https://doi.org/10.1080/15567036.2020.1825565

[48] Polat, S. and Sekerci, H., 2021. The determination of optimal operating condition for an off-grid hybrid renewable energy based micro-grid: A case study in Izmir, Turkey. EMITTER International Journal of Engineering Technology, 9(1), pp. 137-153. https://doi.org/10.24003/emitter.v9i1.597

[49] Polat, S. and Sekerci, H., 2021. The determination of optimal operating condition for an off-grid hybrid renewable energy based micro-grid: A case study in Izmir, Turkey. EMITTER International Journal of Engineering Technology, 9(1), pp. 137-153. https://doi.org/10.24003/emitter.v9i1.597