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Development of Rural Tourism in Iran Using PV-Based System: Finding the Best Economic Configuration

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ABSTRACT

Rural tourism is an important factor in achieving economic, social, and cultural development. Given that villages in Iran do not have access to permanent electricity or are associated with high power outages, the provision of sustainable electricity through renewable energy can cause more tourists to choose these villages as their ultimate goal. Therefore, in this paper, for the first time, a hybrid system has been evaluated based on solar energy in 10 tourism target villages in Iran using HOMER software. This study investigated the design of the system with real and up-to-date data on equipment and fossil fuel prices taking into account transportation costs as well as a comprehensive study of energy-economic-environmental with electricity generation approach to the development of rural tourism. The results demonstrated that for the studied stations, the LCOE parameter was in the range of $ 0.615-0.722, the percentage of power supply by solar cells was in the range of 90-99 %, and the prevention of pollutants was 33.9-277 kg/year. According to the results, Meymand village is the most suitable and Mazichal village is the unsuitable station in the field of energy supply required by solar cells. The production pollution in the studied stations is mainly CO_2 and results from the operational phase of the project and its amount is 979.5 kg/year. Given that the rural tourism has grown and become a solution for development, the authors hope that the present work results can be used as a perspective to help energy and rural tourism decision-makers.

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1. INTRODUCTION

Concerns about rising global energy demand, greenhouse gas emissions, attention to health, and environmental impacts from the production of non-renewable energy are important reasons that motivate countries to promote renewable energy sources [1-3]. Forecasts show that global demand for primary energy will increase by 37 % until 2040 [4]. One of the solutions for communities is to use renewable energy as a sustainable, free, accessible, and clean source [5-7]. Global statistics show the rapid energy growth in the coming decades and the use of renewable sources should increase in energy production. The renewable energy industry is now expanding more rapidly in developing countries in the face of rapid economic growth and severe energy shortages [8]. Middle Eastern countries, which are the heart of the world's fossil fuel reserves, plan to increase the use of renewable sources by 16 % up to 2035 [9]. The average annual growth of renewable energy sources is estimated at 7.6 % [10]. Among renewable energy sources, wind and solar are estimated to have the greatest potential [11], with photovoltaic and wind energy capacity growth of 28.3 % and 16 % in 2014, respectively [12]. Research shows that using systems that combine these two energies (solar photovoltaic-wind) is also an attractive solution for generating electricity, especially in places with solar and wind energy [13-15].

Nowadays, rural tourism is one of the most important forms of tourism, because it is a valuable source of income and job creation and can be an important tool for the social and economic development of rural communities. In order to protect the environment, which is a necessary condition for tourism, the use of renewable resources helps reduce the level of dependence on imported energy, guarantee energy supply, and increase the potential for regional development [16]. Solar energy provides an opportunity for the tourism industry to continue to expand as its impact on the environment diminishes. In tourism, there are important issues such as accommodation and the comfort of tourists who need a lot of electricity. With proper planning and the use of sustainable energy sources such as solar energy, sustainable development can be achieved.

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The following examples illustrate the research conducted in the field of rural tourism and sustainable rural development in recent years.

In 2018, Shams et al. studied the sustainable development of rural tourism with emphasis on the role of valuable tissues using the SWOT model in Hamadan province located in Iran [17]. Based on the results, it was stated that rural revitalization and renewal strengthened the role of rural tourism. Also, if rural tourism is properly planned and managed, it can act as a stimulus in achieving sustainable development in rural areas and the tourism industry.

Rinaldi et al. [18] analyzed the economic feasibility and optimization of hybrid renewable energy systems in Peru. They employed HOMER software and their goal was to supply electricity to a village outside the national grid. Three stations in different weather conditions and seven different configurations were examined. The results showed that the wind turbine-solar cell-diesel generator system was the most economical. The lowest LCOE for these stations was \$ 0.478, \$ 0.460, and \$ 0.504 per kWh. The use of renewable energy for these stations was estimated between 94 and 97 %.

Hoque et al. [19] proposed an energy engineering-based approach for farmers in rural Bangladesh to reduce the impact of COVID-19 on food safety. The system under study included solar cell, battery, and diesel generator and analyses were performed using HOMER software. The results showed that for small, medium, and large farms, the LCOE was \$ 0.451, 0.467, and \$ 0.508 per kWh, respectively. Also, the solar cell-diesel generator-battery system had a lower total NPC than the solar cell-battery-diesel generator systems and it drastically reduced greenhouse gas emissions.

Anwar et al. [20] evaluated the feasibility and sensitivity of the system including wind, solar, biogas, fuel cell, diesel generator, and battery for a village outside the national grid in India using HOMER software. Seven different scenarios were examined and the results showed that without government support, the minimum LCOE would be \$ 0.207 per kWh. With government support and fines set for pollutants, the LCOE was estimated at \$ 0.12 per kWh. In addition, the results of sensitivity analysis showed that total NPC was the most sensitive to load changes and the least sensitive to wind speed.

Nebey et al. [21] used Matlab and HOMER software to design a combined power generation system for rural areas in Ethiopia. The optimal system included a solar cell, wind turbine, and hydropower that provided 13, 52, and 35 % of the required electricity, respectively. Then, in MATLAB software, they designed a control system in which the result obtained from combining resources showed that supply and demand were balanced. A fuzzy logic control system was also designed to manage demand and available resources.

Sharma et al. [22] used HOMER software to economically evaluate a renewable energy system in the rural areas of India. They used biomass from agricultural waste and photovoltaics. The purpose was to meet the needs of cooking, water pumping, and street lighting at a rate of 510 kWh per day. The results showed that the optimal system had a total NPC of \$ 76837 and the price per kWh of energy produced was \$ 0.032. The optimal system had 0.5 kW solar cell, 40 kW diesel generator, and 40 batteries of S460 model and it was a 35-kW electrical converter. Overall, the accuracy of HOMER software is sufficient to show the optimized solution for the changing needs of electricity and to confirm the economic feasibility.

A review of the present article is important from two perspectives:

1. Iran is a country with various potentials and attractions, which can play an effective role as a pole in the development of tourism in the country. Rural areas are also one of the most important tourist destinations in this country, but Iran faces serious challenges in this area, such as management, energy supply, and environmental protection. The pristine, attractive, and clean environment of most tourist villages in Iran is in conflict with fossil fuels. Since the preservation of the environment and responsible circulation in nature is the essence of this type of tourism, the use of clean and renewable energy while having the positive effects of rural tourism also prevents threatening the clean environment of the village.

2. Iran is one of the richest countries in the world in terms of various energy sources and in addition to extensive sources of fossil and non-renewable fuels such as oil and gas, it has a great potential for renewable energy such as wind, solar, biomass, and geothermal. However, Iran is completely dependent on fossil fuels for the industrial, residential, and transportation sectors [23]. Fossil energy carriers provide more than 98 % of energy in Iran. However, according to studies by Aghahseni et al. [24], renewable energy systems are a reliable and low-cost option for Iran in the medium-term future. In this paper, for the first time, 10 special and attractive tourist villages in Iran are selected and the superior features of each are expressed. Then, the possibility of creating an independent solar-diesel generator hybrid system in these villages is investigated using HOMER software. The parameters studied in the present work are the price of kWh for electricity produced, total net present cost, amount of pollutants produced due to the use of diesel generators, determining the percentage of electricity production by solar cells, and investigating the amount of losses in the optimal economic system. The authors of this article hope that the results of the present work are used in the optimal use of rural tourism potentials for the development of rural areas in all economic, socio-cultural, and environmental dimensions.

2. SOLAR ENERGY IN IRAN

Iran is one of the most suitable countries in the world in terms of receiving solar energy and the average annual hours of sunshine are more than 2900 hours [11]. In the central part of Iran, due to its hot and dry climate, it is estimated at 3200 hours per year [25] and this shows that solar energy constitutes a significant part of the country's energy consumption in the future. Iran currently has the world’s 14th largest solar power plant and the total potential of the country to produce solar energy is estimated at 40,000 GWh [11]. Figure 1 shows the average annual radiation in Iran on the horizontal surface [26].

The ten specific villages of Iran, which are shown in Figure 2, are Sar Aqa Seyyed village, Sarakhiyeh village, Makhunik village, Ab Ask village, Abyaneh village, Kandovan village, Meymand village, Hawraman village, Mazichal village, and Nusha village. The locations of the studied villages are shown in Figure 2.

3. HOMER SOFTWARE AND REQUIRED DATA

HOMER Software is one of the best-specialized software for designing microgrid power networks [32, 33], used to model and optimize hybrid renewable energy systems. One of the most important features of HOMER Software is the possibility of accurate simulation of the examined system over different time periods and the possibility of estimating the final cost and the degree of optimization of the system [34, 35]. The optimization performed by HOMER software is that the various configurations are examined using the available equipment and the configurations with the lowest total NPC value are selected as the optimal systems [36, 37].

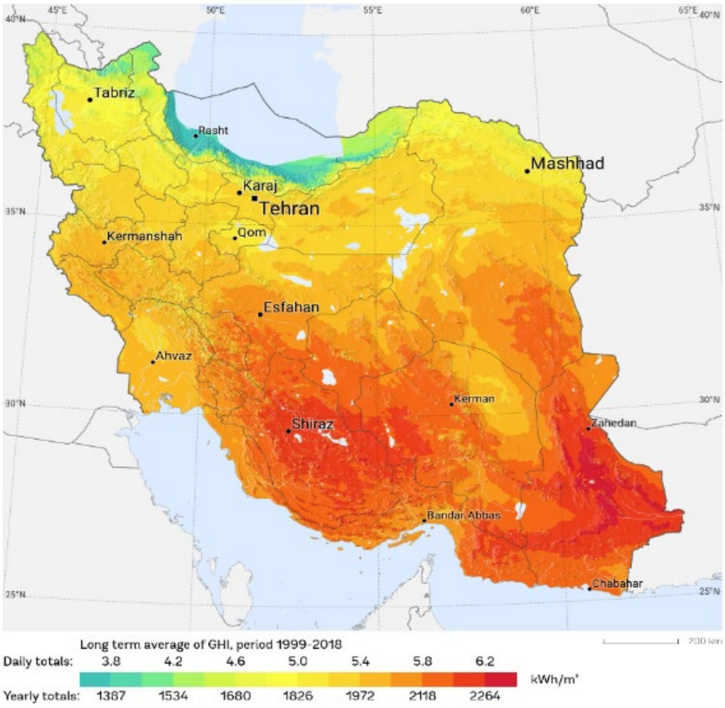

Figure 1. Average annual radiation on the horizontal surface

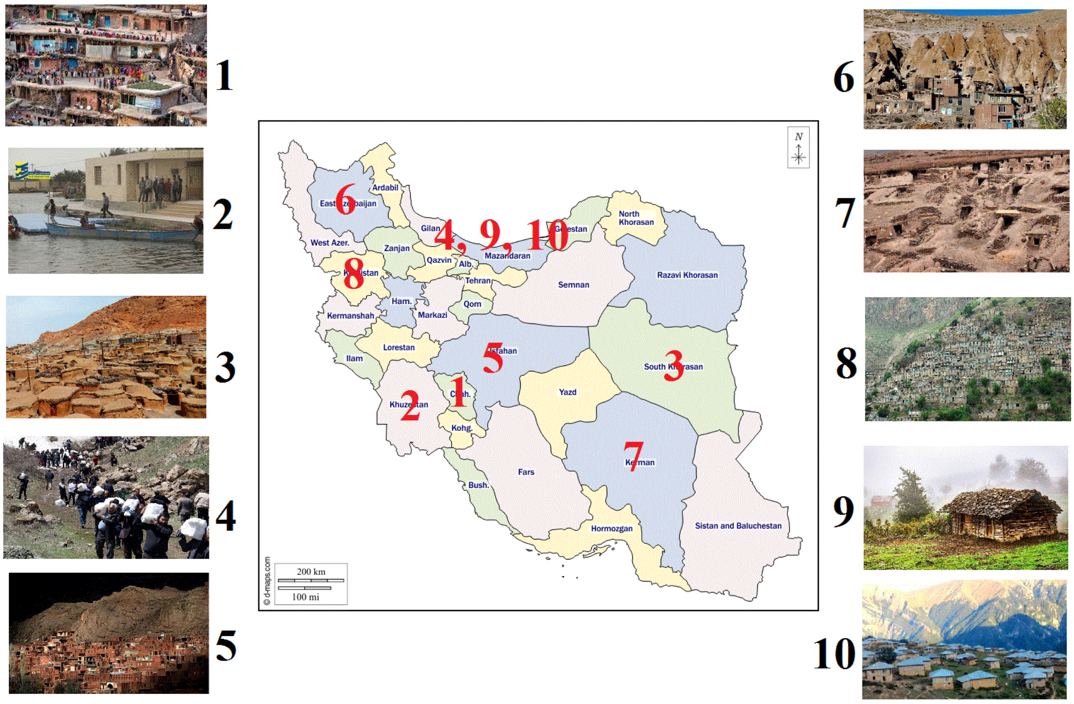

Figure 2. Location of the studied stations

In the present study, the annual interest rate is 10 %, project lifetime is 25 years, pollutants' penalties are zero, fuel prices are $ 0.19214 per liter. In addition, altitude as well as geographical and climatic information are listed in Table 1 and Table 2 and daily electricity consumption is 5.9 kWh with a peak value of 806 W. Considering that both installation and disposal phases affect the total production pollutants, it should be noted that the production pollutants in the present work result from the operational stage and the consumption of diesel fossil fuel by diesel generators.

Schematics of the simulated system and the amount of power required for 24 hours are shown in Figures 3 and 4, respectively. The prices of the equipment used in this project and their other specifications for power supply are given in Table 3 [38-43].

Table 1. Geographical information of the studied stations

Station	Longitude	Latitude	Elevation (m)
Sar Aqa Seyyed	49 52	32 40	2100
Sarakhiyeh	48 32	30 41	3.01
Makhunik	60 24	32 27	1600
Ab Ask	52 8	35 52	1852
Abyaneh	51 35	33 35	2222
Kandovan	46 14	37 47	2232
Meymand	55 22	30 13	2213
Hawraman	46 15	35 15	1417
Mazichal	51 6	36 31	2600
Nusha	50 38	36 36	2006

Table 2. Climatic information of the studied stations

Station	Parameter	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
Sar Aqa Seyyed	Solar (kWh/m^2-day)	2.970	3.910	4.640	5.550	6.740	7.740	7.310	6.850	5.910	4.450	3.220	2.670	5.169
	Clearness index	0.542	0.578	0.547	0.550	0.607	0.674	0.649	0.657	0.656	0.613	0.560	0.526	0.606
Sarakhiyeh	Solar (kWh/m^2-day)	3.260	4.370	4.830	5.620	6.670	7.590	7.330	6.720	5.770	4.150	3.070	2.830	5.187
	Clearness index	0.562	0.620	0.556	0.552	0.600	0.664	0.652	0.640	0.629	0.552	0.506	0.523	0.597
Makhunik	Solar (kWh/m^2-day)	3.240	4.090	4.900	5.690	6.450	6.970	6.930	6.700	5.790	4.630	3.520	2.960	5.161
	Clearness index	0.588	0.602	0.576	0.563	0.580	0.607	0.615	0.642	0.641	0.636	0.608	0.579	0.604
Ab Ask	Solar (kWh/m^2-day)	2.750	3.580	4.450	5.520	6.390	7.310	6.910	6.370	5.390	3.970	2.890	2.390	4.832
	Clearness index	0.557	0.570	0.548	0.557	0.576	0.633	0.612	0.618	0.619	0.583	0.553	0.528	0.586
Abyaneh	Solar (kWh/m^2-day)	3.090	4.100	4.940	5.830	6.640	7.340	6.960	6.620	5.780	4.430	3.360	2.850	5.166
	Clearness index	0.580	0.619	0.589	0.581	0.598	0.638	0.617	0.636	0.648	0.621	0.600	0.580	0.612
Kandovan	Solar (kWh/m^2-day)	2.550	3.380	4.450	5.320	6.480	7.420	7.210	6.440	5.260	3.770	2.650	2.170	4.765
	Clearness index	0.552	0.565	0.564	0.544	0.586	0.641	0.638	0.630	0.617	0.577	0.539	0.517	0.591
Meymand	Solar (kWh/m^2-day)	3.570	4.550	5.210	5.980	6.920	7.280	7.040	6.750	5.940	4.940	3.890	3.280	5.450
	Clearness index	0.607	0.639	0.596	0.586	0.623	0.637	0.627	0.643	0.645	0.652	0.633	0.598	0.624
Hawraman	Solar (kWh/m^2-day)	2.590	3.370	4.420	5.330	6.810	7.870	7.610	7.030	5.940	4.130	2.940	2.270	5.034
	Clearness index	0.513	0.529	0.540	0.536	0.614	0.682	0.674	0.680	0.677	0.599	0.551	0.490	0.607
Mazichal	Solar (kWh/m^2-day)	1.800	2.410	3.320	4.440	5.600	6.590	6.140	5.620	4.820	3.400	2.270	1.590	4.007
	Clearness index	0.373	0.390	0.413	0.450	0.505	0.570	0.544	0.546	0.557	0.506	0.443	0.360	0.490
Nusha	Solar (kWh/m^2-day)	2.320	3.030	3.910	4.910	5.980	6.750	6.320	5.880	4.970	3.500	2.480	2.000	4.343
	Clearness index	0.482	0.491	0.487	0.498	0.540	0.584	0.560	0.572	0.575	0.522	0.485	0.455	0.531

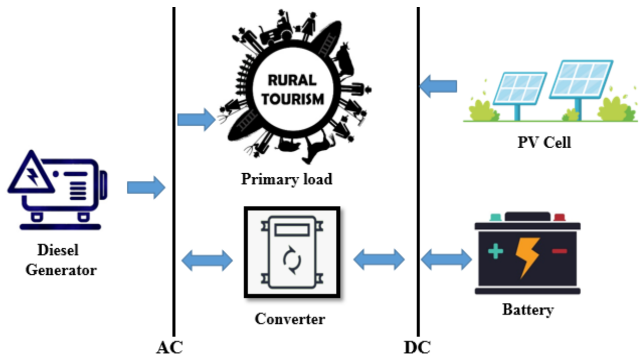

Figure 3. Schematic of the simulated system

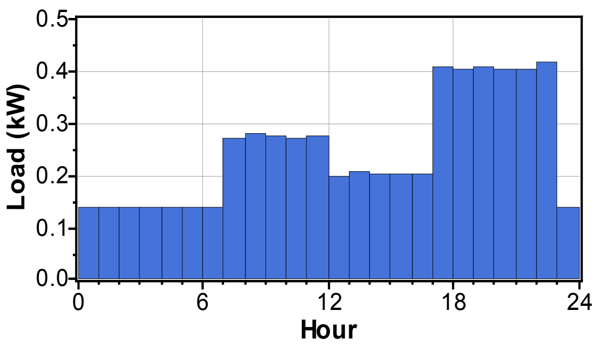

Figure 4. The amount of electricity required within 24 hours

Table 3. Technical and economic information of the equipment used in the solar-diesel system

Equipment	Cost ($)			Size (kW)	Other information
	Capital	Replacement	O & M		
PV [38]	3200	3000	0	0-4	Lifetime: 20 years, Derating factor: 90 %, Ground reflectance: 20 %
Battery T-105 [39]	174	174	5	0-20	Nominal Voltage: 6, Nominal capacity: 225 Ah, Lifetime throughput: 845 kWh
Diesel generator [40, 41]	200	200	0.5	0-2	Lifetime: 15000 hr, Minimum load ratio: 30 %, Max. Efficiency: 31 %
Converter [42, 43]	200	200	10	0-2	Lifetime: 10 years, Efficiency: 90 %

HOMER software uses the following equation to calculate the production capacity of solar cells [44]:

$$P_{pv} = Y_{pv} \times f_{pv} \times \frac{\overline{H}_T}{\overline{H}_{T,STC}} \tag{1}$$

In the above equation, Y_{pv} is the rated capacity of photovoltaic cells in kW, f_{pv} the derating factor, $\overline{H}_T$ the solar radiation hitting the cell surface in operating conditions in terms of kW/m^2, $\overline{H}_{T,STC}$ solar radiation that hits the surface under standard test conditions and is equal to one kW/m^2, and P_{pv} the output power of photovoltaic cells in kW.

The efficiency of the diesel generator is obtained by the following equation [45]:

$$\eta_{gen} = \frac{3.6\ P_{gen}}{\dot{m}_{fuel} \times LHV_{fuel}} \tag{2}$$

In this equation P_{gen} is the electricity produced by diesel generators in kW, $\dot{m}_{fuel}$ is the fuel consumption in liters per hour, and LHV_{fuel} is the low calorific value of fuel in MJ/kg.

Battery performance is calculated as follows [46]:

$$P_{batt.cmax} = \frac{\mathrm{Min}\ (P_{batt.cmax.kbm}, P_{batt.cmax.mcr}, P_{batt.cmax.mcc})}{\eta_{batt.c}} \tag{3}$$

In this equation, $P_{batt,\ cmax}$ maximum is battery charge capacity in kWh, $\eta_{batt,c}$ battery charging efficiency in percentage, $P_{batt,\ cmax,\ kbm}$ maximum battery charging capacity based on kinetic battery model in kWh, $P_{batt,\ cmax,\ mcr}$ maximum battery charge capacity based on maximum charge rate, and $P_{batt,\ cmax,\ mcc}$ the maximum battery charging capacity based on maximum charging current in kWh.

The total net present cost is calculated using the following equation [47]:

$$NPC = \frac{C_{ann,total}}{CRF\ (i, R_{proj})} \tag{4}$$

while $C_{ann,total}$ is the total annual cost, CRF return factor of investment, i real interest rates, and R_{proje} the lifetime of the project. The return factor of investment, which represents the return on investment during N years, is calculated using the following equation [48]:

$$CRF = \frac{i\ (1+i)^N}{(1+i)^N - 1} \tag{5}$$

Also, during the useful lifetime of the project, the cost per kWh of energy is obtained by HOMER software through the following equation [49]:

$$COE = \frac{C_{ann,total}}{E_{Load\ served}} \tag{6}$$

In the above equation, $E_{Load\ Served}$ is the actual electric charge by the hybrid system in kWh/year.

The framework of software performance is shown in Figure 5 [50]. Considering that the penalty for pollutants produced by fossil fuel-based systems in Iran is zero, the optimization of the present work is purely economic and the optimal system is a system that has the lowest total NPC and is not necessarily the system that produces the least pollutants. Another limitation of optimization by HOMER software is that voltage changes and fluctuations cannot be taken into account, power interruptions cannot be simulated, and fluctuations and changes in electrical load in less than an hour cannot be simulated. Also, the limitation in the number of available and accessible equipment is another limitation of optimization by this software.

The limitations of optimization are related to the limitations of software and those of search space to find the optimal configuration. Resizing systems can be about examining different configurations using available equipment and have nothing to do with optimization constraints.

4. RESULTS AND DISCUSSION

The results of the simulations for the studied stations are given in Table 4. The important point that can be seen from the results is that in all the studied villages, the use of solar energy is cost effective. In all villages, according to the electricity required, 2 kW of solar cells, 1 kW of diesel generator, and 1 kW electric converter have been used.

In the economic optimum results for each station, the difference between stations is in the amount of battery usage so that for villages with lower radiation intensity, fewer batteries have been used. The smallest number of batteries (11 batteries) is related to Sarakhiyeh and Meymand villages, while the largest number of batteries (15 batteries) belongs to Mazichal and Nusha villages. The villages of Meymand with \$ 12053 and Mazichal with \$ 14,166 had the lowest and highest net total costs, respectively, which resulted in a cost of \$ 0.615 and \$ 0.722 per kWh of generated electricity. Another important point that can be seen from the results of Table 4 is that the generated renewable electricity is cheaper than the generated fossil electricity.

According to the results, the highest and lowest percentages of the usage of renewable energy are 99 % (Makhunik, Abyaneh, and Meymand villages) and 90 % (Mazichal village), respectively. Due to the use of diesel fuel in diesel generators in all villages, annually, maximum of 277 kg of carbon dioxide (Mazichal village) and a minimum of 33.9 kg of carbon dioxide (Meymand village) are produced. According to the results, the highest usage of diesel generators is 341 hours per year which is related to Mazichal village, which leads to 105 liters of diesel consumption per year. The minimum use of diesel generators is 50 hours per year and is related to the villages of Meymand and Makhunik, which leads to the consumption of 13 liters of diesel per year. Based on the results, it can be seen that the Meymand village is most suitable from the economic-environmental point of view for the use of renewable hybrid systems. Therefore, Table 5 provides more details about the results of the optimal system for Meymand. Based on the results of Table 5, it can be seen that diesel generators are not needed to generate electricity in 9 months of the year and diesel generators are used only in March, April, and August. In total, annually, 3962 kWh of solar electricity is generated which is due to the 4388-hour operation of solar cells and 35 kWh of electricity is generated by diesel generators. During the year, there is about 34 % of surplus electricity (1360 kWh) which would significantly reduce electricity production if sold to the national grid. Regarding the evaluation of hybrid system losses in Meymand village, it should be noted that in batteries, inverters, and rectifiers, there will be 231, 239, and 3 kWh of annual losses, respectively.

Figure 6 shows a comparison of the optimal system (solar cell-diesel generator) with the traditional power generation system (diesel generator only). According to the results, the payback time for an optimal system investment is about 2 years and at the end of the project's useful lifetime (25-year), due to the cheaper solar power, there will be an economic saving of $ 101020.

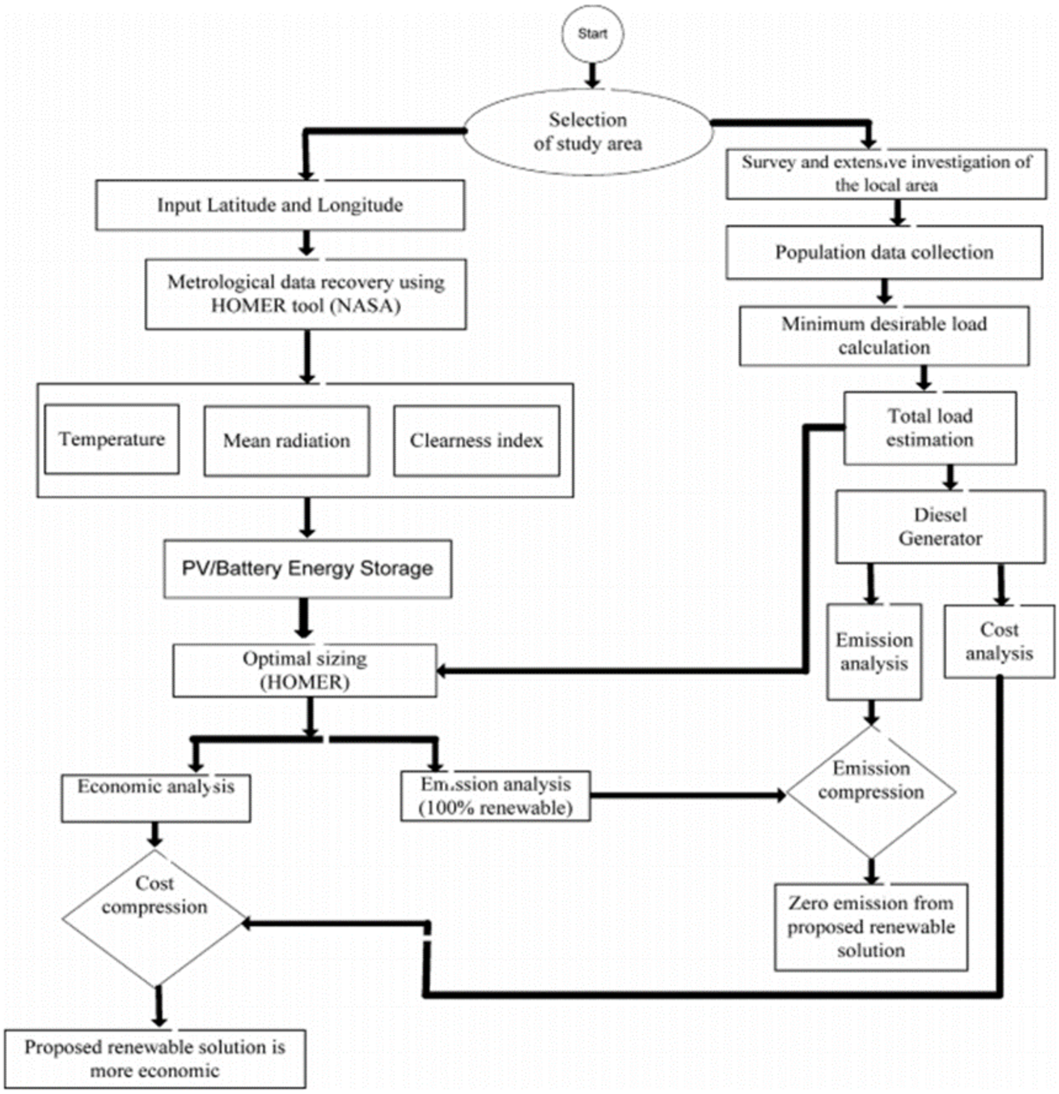

Figure 5. The framework of optimization performed by HOMER software [50]

Table 4. Optimal economic results for each station

Station					Total NPC ($)	COE ($/kWh)	Ren. Frac.	CO_2 (kg/yr)	Diesel (L)	Generator (hrs)
Sar Aqa Seyyed	2	1	12	1	12399	0.632	0.98	74.9	28	92
Sarakhiyeh	2	1	11	1	12529	0.639	0.97	115	44	153
Makhunik	2	1	12	1	12258	0.625	0.99	34.5	13	50
Ab Ask	2	1	13	1	12652	0.645	0.97	80	32	108
Abyaneh	2	1	12	1	12202	0.622	0.99	37.4	14	51
Kandovan	2	1	13	1	12720	0.649	0.97	97.2	37	122
Meymand	2	1	11	1	12053	0.615	0.99	33.9	13	50
Hawraman	2	1	13	1	12584	0.642	0.98	79.6	30	97
Mazichal	2	1	15	1	14166	0.722	0.90	277	105	341
Nusha	2	1	15	1	13392	0.683	0.95	150	57	192

Table 5. Results of the best scenario for Meymand village

Comp.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
PV array	0.398	0.455	0.452	0.452	0.473	0.475	0.471	0.487	0.488	0.467	0.425	0.380
Generator	0.000	0.000	0.027	0.010	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000

Comp.	Production (kWh/yr)	Excess electricity (kWh/yr)	Hours of operation (hr/yr)	Battery Losses (kWh/yr)	Inverter/Rectifier Losses (kWh/yr)
PV array	3962	1360	4388	231	239/3
Generator	35		50		

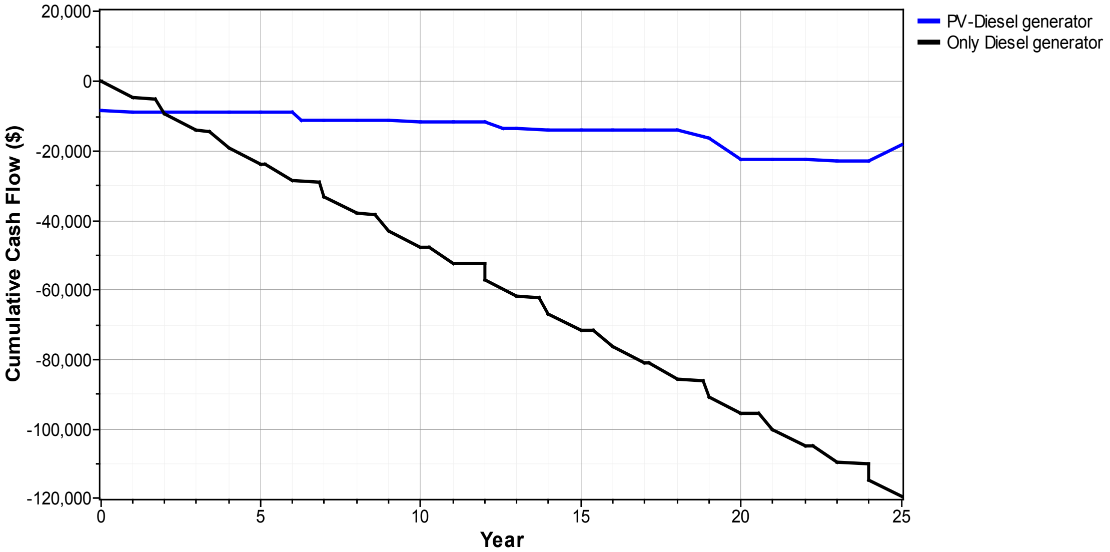

Figure 6. Comparison of the optimal system and the traditional system

5. CONCLUSIONS

Nowadays, rural tourism has become one of the most important economic sectors in many countries of the world and governments have implemented various policies to develop rural tourism on various scales, from local to national level.

Therefore, the purpose of this paper is to evaluate the feasibility of supplying electricity to a rural settlement in ten specific villages of Iran using a solar-diesel generator-battery hybrid system. Using the up-to-date equipment prices and average fuel prices in Iran (including transportation costs), Using 20 years of average solar radiation data, and technical-economic-environmental study of the solar-based hybrid system are other benefits of the present work. The results showed that:

- In all surveyed villages, the use of solar energy was cost effective.

-In the optimal economic results for each station, the difference between the stations was in the amount of battery usage.

- The villages of Meymand with $ 12053 and Mazichal with $ 14,166 had the lowest and highest net total costs, respectively, which yielded costs of $ 0.615 and $ 0.722 per kWh of generated electricity.

- In the studied villages, renewable electricity is cheaper than fossil electricity.

- The highest and lowest percentages of the usage of renewable energy are 99 % (Makhunik, Abyaneh, and Meymand villages) and 90 % (Mazichal village), respectively.

-Due to the use of diesel fuel in diesel generators in all villages, annually, maximum of 277 kg of carbon dioxide (Mazichal village) and a minimum of 33.9 kg of carbon dioxide (Meymand village) are produced.

-Meymand is the most suitable village from the economic point of view for using renewable hybrid systems.

- Only in March, April, and August in the village of Meymand, a diesel generator is needed to generate electricity.

- 3962 kWh of solar electricity and 35 kWh of fossil electricity are produced annually in Meymand village.

- During the year, there is about 34 % of surplus electricity (1360 kWh) in Meymand village.

- In Meymand village and in comparison with the traditional power generation system (diesel generator only), the payback time for an optimal system investment is about 2 years and at the end of the project's useful lifetime (25-year), due to the cheaper solar power, there will be an economic saving of $ 101020.

- Since many villages in Iran are very similar to these villages in terms of natural, cultural, social, and economic characteristics, the results of the present paper can be generalized to other villages.

The authors of this article hope that to create infrastructure services for accommodation facilities in the field of rural tourism, proper planning can improve the economic situation of the studied villages.

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