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Electrification of a Tourist Village Using Hybrid Renewable Energy Systems, Sarakhiyeh in Iran

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A B S T R A C T

Tourism paves the way for employment and income development in many countries. In southern provinces of Iran, especially Khuzestan, however, despite their high potential, tourism is only restricted to Nowruz (New Year) and there is no appropriate conditions for tourism. The development of suitable tourist infrastructures and construction of recreational places can terminate the Nowruz monopoly of tourism to witness the extensive presence of visitors at all times of the year. According to the above notes and in line with the construction of a tourist settlement in Sarakhiyeh village and noting that different scenarios of hybrid renewable energies have not been used to electrification of a tourist village in Iran so far, this paper uses HOMER to study the electrification of this village using renewable energies wind, solar, biomass, and fuel cell. The studied parameters are net present cost (NPC), cost of energy (COE), the surplus electricity produced and the emissions produced during the year. Results indicated that in the most cost-effective, which was related to the biomass/solar cell scenario with a price/kWh of $ 0.339, 49% of energy requirement was provided by solar cells which seemed reasonable given the high radiation potential of Khuzestan province. The result of this study can accelerate the development of Khuzestan and other southern provinces of Iran with similar climate conditions.

1. Introduction

Certainly, today the tourism industry plays an important role in the economic development of the world and, along with the annual growth of the National Gross Product (NGP), export, and services, the share of tourism in the economic activities of the world is continuously increasing. Research indicates that rural tourism account for 10 to 20 percent of the tourism activities of the world [1]. One of the most important effects of growing trend in tourism is employment and economic growth [2, 3]. At the moment, domestic tourism, especially rural tourism, is of utmost importance and development of this kind of tourism may work as a tool for increasing the welfare of local communities which gives rise to the sustainable development of tourist receiving villages and their surrounding areas.

Equipping the tourist villages plays a baseline role in prosperity of the tourism industry. However, villages with tourist attraction capabilities are mostly located far away from the national grid. These villages situated in good climate or areas which are mainly remote, mountainous, or having particular natural features which renders their electrification through the main grid difficult and cost-intensive. This problem highlights the importance of off-grid electrification. Todays, electricity is a crucial factor in economic and welfare development [4], however, access to cheap electricity is one of the main concerns for remote and low-populated areas which are afflicted by inaccessibility to the main grid, and tourist villages are no exception. At the moment, many governments around the world, including Iran, are trying to achieve ambitious objectives regarding the production of cheap electricity from renewable energies and there is an increasing interest in off-grid generation using renewable energies [5-9]. In addition to cutting the costs, this method is more environmentally friendly and lower prices will result in the prosperity of tourist villages, higher number of tourists, and increasing tourist travels from summer to all times of the year. Off-grid hybrid power systems based on renewable energies are one attractive solution for electrifying tourist villages. Given the potentials of the desired area, these systems may use multiple technologies such as wind and hydro turbines, photovoltaic modules, and diesel/gas generators. The choice of technology and the optimal size of selected components will play an important role in the cost of generated electricity and return on capital [10]. Iran's geography and climate are highly suitable for the different forms of renewable energy technology but Iran currently is only producing 0.2% of its energy from renewable sources [11]. In the following, a review of recent works on using renewable energies for electrification of tourist areas is discussed.

Ciriminna et al. [12] examined the electrification planning and removing large-scale obstacles to the potentials of using renewable energies in Sicily islands, Italy, remote from the main grid. They decided that electrification was economically efficient and promoted tourism industry in these areas in summer. Furthermore, from environmental perspective, less pollution was produced.

Diab et al. [13] investigated the choice of the most optimal city in terms of suitability for constructing a tourist village among 5 cities of Aswan, Qena, Alexandria, Giza, and Luxoe, in Egypt. This choice was based on COE, NPC, and Greenhouse Gasses (GHGs). Given that the simulation results obtained from HOMER Pro ®, Alexandria was the most suitable city for using hybrid solar cell /wind/diesel/battery systems. While Aswan City is the most economically appropriate for hybrid solar cell/diesel/battery system. Even so, for a diesel/battery system, there was no difference in economic terms among 5 cities. Considering the emission of GHGs from a solar/wind/diesel/battery system and by including the ambient temperature effects, Qena was the most optimal. In case of entering GHGs emission penalties, Aswan was the optimal city. Furthermore, if both ambient temperature effects and GHGs emission penalties were taken into account, Alexandria became the optimal city. It is worth noting that the effects of ambient temperature and GHGs emission penalties on combinations of solar cell/ diesel/battery, wind/ diesel/battery, and diesel/battery were studied. In order to enhance the potential of using renewable energies and reducing GHGs emission, Diab et al. [14] used HOMER Pro ® to conduct an enviro-economic analysis on a net zero energy (NZE) tourist village in Alexandria, Egypt. They hybrid solar cell/wind/diesel/battery system in this study was selected as the optimal system for this tourist village. The optimal renewable energy system included: solar panels-1600 kW (58.09% of total generation), wind turbines-1000 kW (41.34% of total generation), convertor-1000 kW, diesel generator-200 kW (0.57% of total generation), and 2000 batteries each with a capacity of 589 Ah. Levelized cost of energy for this system was 0.17 $/kWh and total NPC of that was $ 15,383,360. In addition, the renewable energy share was 99.1% and GHGs emission of only 31,289 kg/year which was a negligible figure compared with other systems so that the system could be regarded as a green one.

2. Homer software

HOMER energy analysis software is a free and powerful software for designing and analysis of hybrid power systems which may by a combination of ordinary power generation systems, combined heat and power (CHP), wind turbine, solar cells, batteries, fuel cells, biomass and other inputs. This software can model both grid-connected and off-grid systems. Actually, HOMER enables the user to determine the extent to which renewable energies like solar and wind can be used to be combined with her/his system. In the following, the relations used in the software to estimate the size and quantity of components in the hybrid systems and also the calculation of costs are presented [15].

2.1. Solar cells

To calculate the output power of PV cells, Homer uses the following relation:

$$P_{pv} = Y_{pv} f_{pv} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}}\right)\left[1 + \alpha_p\left(T_c - T_{c,STC}\right)\right] \qquad (1)$$

where Y_{pv} is the output power (kW) of solar cell under standard conditions, f_{pv} is derating factor, $\overline{G_T}$ is the incident radiation on the cell's surface on a monthly basis (Kw/m²), $\overline{G_{T,STC}}$ is the incident radiation on the cell's surface (1 Kw/m²), under standard conditions, α_p is temperature coefficient of power (%/°C), T_c is the cell's surface temperature (°C) at each time interval, $T_{c,\ STC}$ is the cell's surface temperature under standard conditions (i.e. 25 °C). Due to the fact that the selected cell does not include the temperature effect in the simulations, α_p has a value of zero in the present study.

2.2. Wind turbine

Using the power and wind speed curve at hub height, HOMER calculates the output power of wind turbines. Notice that the power curve generally captures the wind turbine performance under standard temperature and pressure conditions. In order to calculate it for real world conditions, as it is shown in the following relation, the software multiplies the power curve output by the air density ratio.

$$P_{WTG} = \frac{\rho}{\rho_0} \times P_{WTG,STP} \quad (2)$$

where ρ is the real air density (kg/m³), ρ_0 is the air density under standard temperature and pressure conditions which is equal to 1.225, and $P_{WTG,STP}$ is the wind turbine output power under standard conditions.

2.3. Batteries

In each time step, HOMER calculates the maximum amount of power that the storage bank can absorb. The maximum charge power varies from one time step to the next according to its state of charge and its recent charge and discharge history. HOMER imposes three separate limitations on the battery's maximum charge power. The first limitation comes from the kinetic battery model which is calculated by the following relation:

$$P_{batt,cmax,kbm} = \frac{kQ_1 e^{-k\Delta t} + Qkc(1-e^{-k\Delta t})}{1-e^{-k\Delta t} + c(k\Delta t - 1 + e^{-k\Delta t})} \quad (3)$$

where Q_1 is the available energy (kWh) in the battery at the beginning of the time step, Q is the total amount of energy (kWh) in the battery at the beginning of the time step, c is battery capacity ratio, k is the battery rate constant (1/h), and Δt is the length of the time step (h).

The second limitation relates to the maximum charge rate of battery which is given by:

$$P_{batt,cmax,mcr} = \frac{(1-e^{-\alpha_c \Delta t})(Q_{max} - Q)}{\Delta t} \quad (4)$$

where α_c is the battery's maximum charge rate (A/Ah), Q_{max} is the total capacity of the battery (kWh). The third limitation relates to the battery's maximum charge current, according to the following equation:

$$P_{batt,cmax,mcc} = \frac{N_{batt} I_{max} V_{nom}}{1000} \quad (5)$$

where N_{batt} is the number of batteries, I_{max} is the battery's maximum charge current (A), and V_{nom} is the battery's nominal voltage (V). According to the following relation, HOMER sets the maximum battery charge power equal to the least these three values.

$$P_{batt,cmax} = \frac{\text{Min}\,(P_{batt,cmax,kbm}, P_{batt,cmax,mcr}, P_{batt,cmax,mcc})}{\eta_{batt,c}} \quad (6)$$

where $\eta_{batt,c}$ is the batteries charge efficiency.

2.4. Diesel generator

By entering the fuel curve inputs, HOMER draws the corresponding efficiency curve. The fuel curve describes the amount of fuel that the generator consumes to produce electricity. HOMER assumes that the fuel curve is a straight line. The following relation gives the generator's fuel consumption in units/hr as a function of its electrical output:

$$\dot{m}_{fuell} = F_0 Y_{gen} + F_1 P_{gen} \quad (7)$$

where F_0 is the fuel curve intercept coefficient (units/hr.kW), F_1 is the fuel curve slope (units/hr.kW), Y_{gen} is the rated capacity of the generator (kW), and P_{gen} is the electrical output of the generator (kW). The generator's electrical efficiency, which is defined as the electrical energy coming out divided by the chemical energy of the fuel going in, is calculate by the following relation in HOMER:

$$\eta_{gen} = \frac{3.6\, P_{gen}}{\dot{m}_{fuel} LHV_{fuel}} \quad (8)$$

where LHV_{fuel} is the lower heating value of the fuel (MJ/kg).

2.5. Converter

The inverter efficiency determines how much of the DC power is converted to AC power. Converter may be a synchronous inverter (with AC generator) or a switched inverter. Rectifier efficiency is defined as the ratio of DC power to the applied AC power. It should be mentioned that HOMER assumes constant values for inverter and rectifier efficiencies. While most solid-state converters are less efficient at lower loads due to standing losses.

2.6. Hydrogen tank

To model a system that produces its required hydrogen from the surplus electricity hydrolysis, there must be a hydrogen tank to store hydrogen for fuel cell consumption. Hydrogen tank autonomy is defined as the ratio of the energy capacity of the hydrogen tank to the electric load which is given by:

$$A_{htank} = \frac{Y_{htank} LHV_{H_2} (24\frac{h}{d})}{L_{prim,ave}\ (3.6\frac{Mj}{kWh})} \quad (9)$$

where Y_{htank} is the rated capacity of the hydrogen tank (kg), LHV_{H_2} is the lower heating value of hydrogen (120 Mj/kg), and $L_{prim,ave}$ is the average of the primary load (kWh/day).

2.7. Hydrogen tank

Electrolyzer efficiency is the efficiency with which the electrolyzer converts electricity into hydrogen and is equal to the energy content (due to the higher heating value) of the hydrogen produced divided by the amount of electricity consumed.

2.8. Cost computations

Discount rate is used to convert one-time costs into equivalent annual costs. HOMER uses interest rate to give discount factor and calculate the annual costs from NPCs. To calculate annual real interest rate (i) from nominal interest rate (i′), HOMER uses the following equation:

$$i = \frac{i' - f}{1 + f} \quad (10)$$

where f is the annual inflation rate. HOMER assumes a constant inflation rate for all costs. The total NPC is captured by dividing total annual cost by capital recovery factor. HOMER calculates the capital recovery factor (CRF) by:

$$CRF = \frac{i\,(1+i)^N}{(1+i)^N - 1} \quad (11)$$

In addition, the price per kWh of electricity produced is obtained by total annual costs divided by the real cost of electrical load.

3. Studied area

Sarakhiyeh is a village located in Khuzestan Province. A village in the middle of which water passes and people use boats to move around. This is the Iranian Venice, however, except for water there is no similarity with Venice. This village is located near the Shadegan wetland, Naseri rural district, Khanafereh district, Shadegan County, and it is introduced as one of the tourist attractions of Khuzestan. Having a traditional texture, Sarakhiyeh village is of research value in Khuzestan. Anthropologically, this village is of utmost importance and represents part of the native culture of this region. Residents are Arab and they speak Arabic. Commuting within the village and to other adjacent villages is the same as Venice, Italy. The houses and architectures are natives hand-made which increase their importance. This architecture is an extension of the region’s traditional architecture and residents build their houses using such materials as clay, mud, or straw which they provide from the wetland. Providing tourist services is one of the residents’ jobs. They take visitors to boat trips and show them different places. Figures 1 and 2 show some views of this village and the Shadegan’s location on Iran’s map, respectively. Despite its numerous endowments and capacities, Shadegan wetland has never enjoyed a significant development and rehabilitation and all the plans designed for this wetland has remain so far as a dream or wish. While due to the unique conditions of this wetland, even foreign investors have expressed their interest in its development recently. In this regard, Missan Culture and Art group with the collaboration of Khuzestan’s provincial government have started the construction of a tourist village in Sarakhiyeh, Shadegan County. In this study, the electrification of this village using renewable wind, solar, biomass and fuel cell energies is simulated by HOMER software.

4. Solar and wind resource

Figures 3 and 4 illustrate the contours of annual average radiation and annual average wind speed. Wind speed and sun radiation data are 20-year-average [16] taken from NASA website. Figure 3 reveals that the highest radiation occurs at south-eastern part of Khuzestan province (Behbahan and Hendijan), while the radiation intensity is reduced toward the north-west (Andimeshk and Shush).

Figure 1. Views of Sarakhiyeh village.

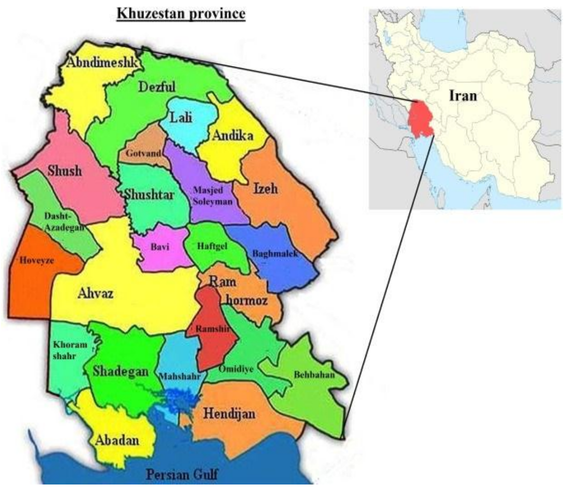

Figure 2. The location of Shadegan on Iran’s map.

From Figure 4, it is also clear that the highest and lowest wind speeds are associated with the Northern (Dezful and Lali) and south-western (Abadan, Shadegan, Khoramshahr) parts of the province. As it can be observed from Figures 3 and 4, and according to the results of previous research

[17], given its geographical location, Sarakhiyeh village is in a better position in terms of radiation than wind speed. Notice that Sarakhiyeh is considered to be in a desirable situation in terms of radiation, but it is evaluated as weak from the wind speed viewpoint.

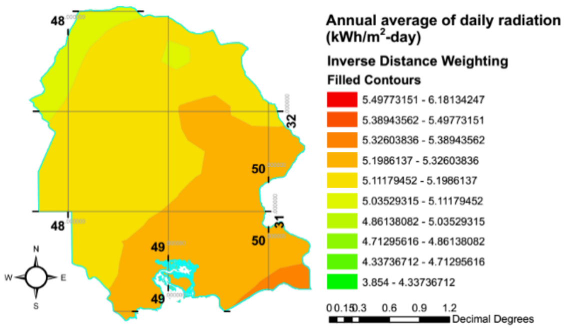

Figure 3. Annual average global horizontal irradiation (GHI) contour in Khuzestan province.

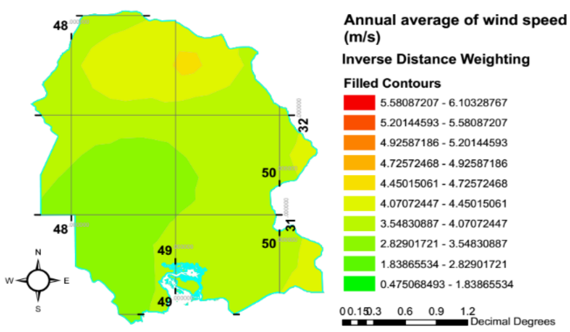

Figure 4. Annual average wind speed contour in Khuzestan province.

5. Homer input data

Given the geographical position of Sarakhiyeh, which is located at 30° 40´ Northern latitude and 48°32´ Eastern longitude, NASA website data regarding radiation and clearness index were used which is observable in Figure 5.

As it is observed, having radiations of 7.409 kWh/m^2-day and 2.976 kWh/m^2-day, June and December have the highest and lowest rate of radiation, respectively. The sun radiation received on earth varies with time and depends on the region's climate. To predict the amount of sun radiation received on a horizontal surface, first the clearness index should be calculated.

In this study, the daily average clearness index was calculated using sun radiation data on an average daily basis measured by NASA. As it is obvious in Figure 5, September (0.675) and December (0.55) have the highest and lowest values of clearness index, respectively. Annual average sun radiation and annual average clearness

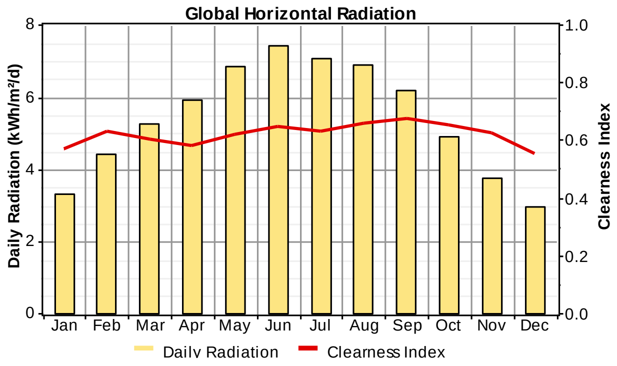

Figure 5. Monthly daily average radiation and clearness index.

index are 5.424 kWh/m^2-day and 0.624, respectively. Figure 6 indicates the wind speed for a year (m/s). This figure shows that the highest wind speed occurs at June and July with an average speed of 4 m/s and the lowest wind speed is related to October and December with an average of 2 m/s. It should be noted, based on the fact that accurate wind speed data were not available for Sarakhiyeh, wind speed average data of Ahvaz and Abadan were used since this village is located in the middle of these two cities. Subsidized price of diesel is about $ 0.19214 per liter in Iran. Given the upsurge in prices over the last years, an annual growth rate of 15% for a project life of 25 years was considered. The most important input data was the amount of electricity requirement during 24 hours for various months which is obvious in Figure 7. Annual average electricity requirement of 35.7 kWh/day was calculated and daily random variation of 15% was taken into account. The prices, sizes, lifetime, and other useful information related to the used components are listed in Table 1.

6. Results & Discussion

The equipment used in each 9 scenarios are shown in Tab. 2. Scenarios 1 to 3: based on biomass generator, 4 to 6: based on fuel cell, 7 and 9: based on diesel generator, and 8: based on wind and solar. Tab. 3 reveals the details of superior scenarios. Results of Tab. 3 indicates that wind alone cannot meet the electricity requirement of Sarakhiyeh station. Also, in cases where wind energy has been incorporated in hybrid systems, only a maximum of 3% of the generated electricity has been produced by wind turbines. The highest and lowest electricity generation are related to wind/solar systems (38,818 kWh/y) and biomass generator alone (14,612 kWh/y), respectively. Moreover, given Tab. 3 and as it was expected, fossil fuel-based systems (diesel generator) produce large amounts of emission which has an adverse effect on environment.

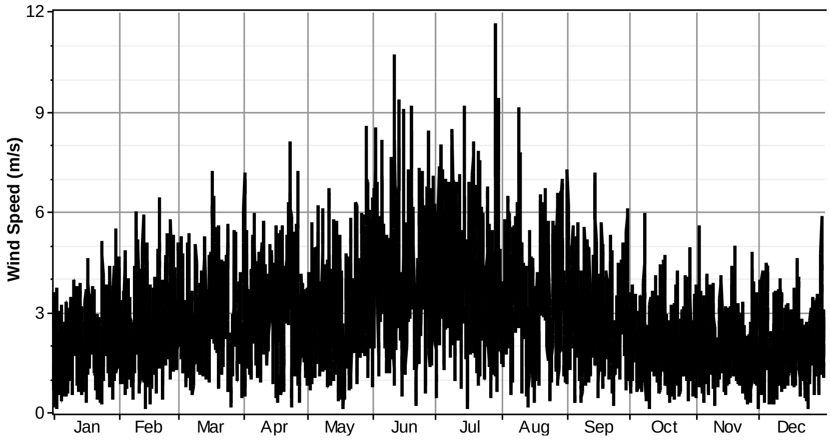

Figure 6. Wind speed (m/s) in Sarakhiyeh.

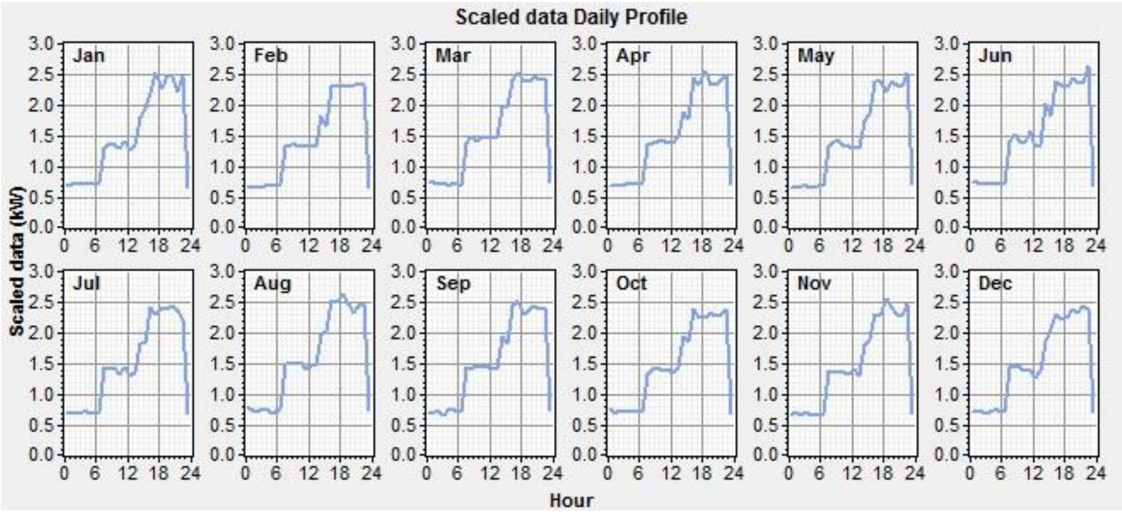

Figure 7. The amount of mean daily electricity requirement for each month a year.

Table 1. Data of simulated hybrid power-plant.

Components	Lifetime	O & M ($)	Replacement ($)	Capital ($)	Other information
PV [18]	20 year	0	3000	3200	No Tracking
Battery [18]	845 kWh	5	174	174	Trojan T-105 model
Converter [18]	10 year	10	200	200	-
Diesel generator [18]	15000 h	0.5	200	200	Diesel price 0.19214 $
Wind turbine [18]	20 year	100	3650	5725	Hub height 25 m
Biomass generator [4]	15000 h	0.023	3000	3500	Available biomass 1 t/d
Fuel cell [4]	40000 h	0.1	2500	2500	DC generation
Hydrogen tank [4]	25 year	0	1200	1200	-
Electrolyzer [4]	15 year	0	1500	1500	DC generation, efficiency 85%

Another important note observable from Table 3 is the low surplus electricity produced in case of using generator (diesel and biomass). While in the without-generator (diesel and biomass) scenario, a large amount of surplus electricity is produced and a significant reduction in initial and maintenance costs can be obtained through selling this surplus electricity to the grid. Table 4 presents the optimal results of analyses performed by HOMER for various scenarios. A comparison of results in Table 3 to that of Tab. 4 shows that at the most economically optimal state among nine scenarios (2nd scenario), where the price/kWh of electricity generated is $ 0.339, around 49% of the electricity is produced by solar cells and the remaining 51% is generated by biomass generator. The second scenario includes 4 solar cells (1 kW), 2 biomass generators (1 kW), 28 batteries, and 3 converters (1 kW), and it has a total NPC of $ 56,429. In this scenario, where 100% of energy requirement has been produced by renewable energies, the yearly run-time of biomass generator is 2.44% during which it consumes 7 tons of biomass. According to the results of Table 4, if the biomass alone system is used (third scenario), the price per kWh of electricity generated will be $0.372 and the system is consisted of 2 biomass generator (1 kW), 34 batteries and 3 power converters (1 kW). Here, with a consumption of 14 tons of biomass, the generator's yearly run time will be 83%. In case of using biomass/wind turbine system, the most economically optimal state includes the price per kWh of $0.416. This system is comprised of 1 wind turbine (1 kW), 2 biomass generators (1 kW), 41 batteries, and 3 power converters (1 kW). The yearly run time of biomass generator is 80.6% during which it consumes 14 tons of biomass. Another conclusion drawn from Table 4 is that in none of the scenarios and studied states, wind turbine alone cannot meet the demands. If we want to use only solar cells, the cheapest system in eighths scenario will include 21 solar cells (1 kW), 88 batteries, and 5 power converters (1 kW). With a total NPC of $ 10,1912, this system has a price/kWh of $ 0.862. For the diesel generator-based scenario, as it is shown in Tab. 4, they hybrid solar cell/ diesel generator system (seventh scenario) with a price/kWh of electricity generated of $ 0.561, entails the lowest cost. The next priority in economic terms is systems including diesel generator alone (9^{th} scenario) and wind turbine/diesel generator (9^{th} scenario) with price/kWh of $ 0.802 and $ 0.833, respectively. A general conclusion inferred from Tab. 2 through 4 is that biomass-based scenarios are most cost-effective which is because the biomass fuel is free and it has a higher efficiency. Also, fuel cell-based systems either cannot meet the electricity demand or are highly expensive which could be attributed to their low efficiency and the high cost of their equipment. An interesting note about various scenarios from Tabs. 3 and 4 is that, in case of not using battery for storing the surplus electricity generated, the cost/kWh will double which highlights the importance of applying batteries in hybrid systems. Furthermore, from the results it could be seen that solar cell-based system outperform wind turbine-based system from economic perspective which is due to the lower initial cost of solar cells compared to wind turbine. Another reason is that sun radiation is more favorable in the studied area than wind. The performance of various elements in the selected scenario (diesel generator/solar cell) is illustrated in Figures 8 to 11. As it is clear in Figures 8 and 9, and of course it was expected, when it is dark and solar cells cannot produce energy anymore, diesel generator has been used to generate electricity. However, at some sunny hours during the year a deficiency in electricity generation occurred during which the diesel generator was run (Figure 9). Figure 10 is related to the battery's charge content at various hours during the year. According to this figure, it is obvious that the highest battery charge is related to the peak of sunny hours which is between 12 up to 18. From Figures 11(a) and (b), which are concerned with converter's performance in converting DC to AC and vice versa, it is clear that mostly DC to AC has occurred, i.e. the electricity stored in battery has been consumed. To put it in exact terms based on the software output, the number of hours in which DC is converted to AC is 7680h and the number of hours in which the reverse has occurred is 1078 h.

7. Conclusions

Todays, the importance of rural tourism is well-recognized and development of tourism infrastructures of target villages is given priority in the programs of executive organs. In this regard, given the recreational and natural capacities of Sarakhiyeh village in Khuzestan province and considering the necessity of attracting investors to the private sector, this paper investigates the techno-economic potential of electrifying a tourist settlement in this village. Results revealed that:

- The highest and lowest electricity generation are related to wind/solar systems (38,818 kWh/y) and biomass generator alone (14,612 kWh/y), respectively.
- At the most economically optimal state among all scenarios (2nd scenario), where the price/kWh of electricity generated is $ 0.339, around 49% of the electricity is produced by solar cells and the remaining 51% is generated by biomass generator.
- In none of the scenarios and studied states, wind turbine alone or fuel cell-based systems cannot meet the demands.
- Biomass-based scenarios are most cost-effective.
- In case of not using battery for storing the surplus electricity generated, the cost/kWh will double which highlights the importance of applying batteries in hybrid systems.

Table 2. The equipment used in each scenario.

Scenario	PV	Wind turbine	Biomass generator	Diesel generator	Fuel cell	Battery	Converter
1	-	-	✓	-	-	✓	✓
2	✓	-	✓	-	-	✓	✓
3	-	✓	✓	-	-	✓	✓
4	-	-	-	-	✓	-	-
5	✓	-	-	-	✓	✓	✓
6	-	✓	-	-	✓	✓	✓
7	✓	-	-	✓	-	✓	✓
8	✓	✓	-		-	✓	✓
9	-	✓	-	✓	-	✓	✓

Table 3. Details of superior scenarios.

Scenario	Details	Electric production (kWh/yr)	Share of each components	Excess electricity (%)	Emissions (CO_2 kg/yr)
Based on Diesel generator (DG)	Only DG	15207	100% diesel generator	0	13230
	With wind turbine	15146	97% diesel generator, 3% Wind turbine	0	12757
	With PV	15807	30% diesel generator, 70% PV	3.23	4119
Based on biomass generator (BG)	Only BG	14612	100% biomass	0	2.46
	With wind turbine	14624	97% biomass generator, 3% Wind turbine	0	2.37
	With PV	15019	51% biomass generator, 49% PV	1.5	1.28
Based on fuel cell (FC)	Only FC	-	-	-	-
	With wind turbine	-	-	-	-
	With PV	33273	≈100% PV, ≈ 0% Fuel cell	52.7	0
Based on wind and solar	Only wind	-	-	-	-
	Only PV	38818	100% PV	59.5	0
	Hybrid Wind & PV	37466	99% PV, 1% wind turbine	58.1	0

Table 4. Optimal results of each scenario.

Scenario 1 — Optimal modes

Biods (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Biods (hrs)
3	14	2	$ 13,336	4,025	$ 64,795	0.389	1.00	14	5,352
5			$ 17,500	9,314	$ 136,563	0.820	1.00	19	8,759

Scenario 2 — Optimal modes

PV (kW)	Biods (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Biods (hrs)
4	2	28	3	$ 25,272	2,437	$ 56,429	0.339	1.00	7	3,873
	3	28	2	$ 15,772	4,078	$ 67,909	0.408	1.00	15	5,093
6	4		3	$ 33,800	5,852	$ 108,608	0.652	1.00	12	6,729

Scenario 3 — Optimal modes

XL1	Biods (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Biomass (t)	Biods (hrs)
	2	34	3	$ 13,516	3,790	$ 61,965	0.372	1.00	14	7,306
1	2	41	3	$ 20,459	3,818	$ 69,260	0.416	1.00	14	7,064
1	4		1	$ 19,925	7,612	$ 117,232	0.704	1.00	16	8,759

4

Max. Cap. Shortage (%)	f.cel (kW)	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	f.cel (hrs)
0.0	—	—	—	—	—	—	—	—	—	—	—	—
5.0	—	—	—	—	—	—	—	—	—	—	—	—
10.0	—	—	—	—	—	—	—	—	—	—	—	—
15.0	—	—	—	—	—	—	—	—	—	—	—	—
20.0	—	—	—	—	—	—	—	—	—	—	—	—
25.0	—	—	—	—	—	—	—	—	—	—	—	—
30.0	—	—	—	—	—	—	—	—	—	—	—	—
35.0	—	—	—	—	—	—	—	—	—	—	—	—
40.0	—	—	—	—	—	—	—	—	—	—	—	—
45.0	—	—	—	—	—	—	—	—	—	—	—	—
50.0	—	—	—	—	—	—	—	—	—	—	—	—
55.0	—	—	—	—	—	—	—	—	—	—	—	—
60.0	—	—	—	—	—	—	—	—	—	—	—	—
65.0	—	—	—	—	—	—	—	—	—	—	—	—
70.0	—	—	—	—	—	—	—	—	—	—	—	—
75.0	—	—	—	—	—	—	—	—	—	—	—	—
80.0	—	—	—	—	—	—	—	—	—	—	—	—
85.0	—	—	—	—	—	—	—	—	—	—	—	—
90.0	—	—	—	—	—	—	—	—	—	—	—	—
95.0	—	—	—	—	—	—	—	—	—	—	—	—

5

PV (kW)	f.cel (kW)	T-105	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	f.cel (hrs)
18		103	6			CC	$ 76,722	2,076	$ 95,562	0.809	1.00	
18		103	6	10		CC	$ 91,722	2,420	$ 113,692	0.962	1.00	
18	10	103	6	10		CC	$ 116,722	2,173	$ 136,442	1.155	1.00	0

6

Max. Cap. Shortage (%)	XL1	f.cel (kW)	T-105	Conv. (kW)	Elec. (kW)	H2 Tank (kg)	Disp. Strgy	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	f.cel (hrs)
0.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—
30.0	—	—	—	—	—	—	—	—	—	—	—	—	—	—

7

PV (kW)	Label (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
6	3	54	3	$ 29,796	4,028	$ 66,360	0.561	0.64	1,564	1,604
	3	45	2	$ 8,830	9,698	$ 96,858	0.819	0.00	5,024	5,092
7	4		3	$ 23,800	14,456	$ 155,020	1.311	0.21	4,648	6,500

8

PV (kW)	XL1	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
21		88	5	$ 83,512	2,027	$ 101,912	0.862	1.00
20	1	89	5	$ 86,211	2,098	$ 105,259	0.891	1.00

9

XL1	Label (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
	3	31	2	$ 6,394	9,748	$ 94,875	0.802	0.00	5,024	5,093
1	3	28	2	$ 11,597	9,576	$ 98,522	0.833	0.00	4,844	4,924
1	4		1	$ 6,725	19,344	$ 182,313	1.542	0.00	6,403	8,759

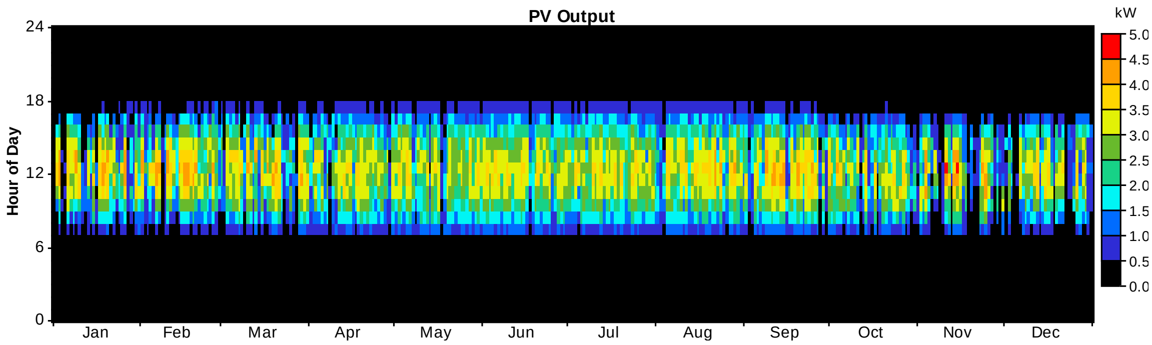

Figure 8. The electricity generated by solar cell.

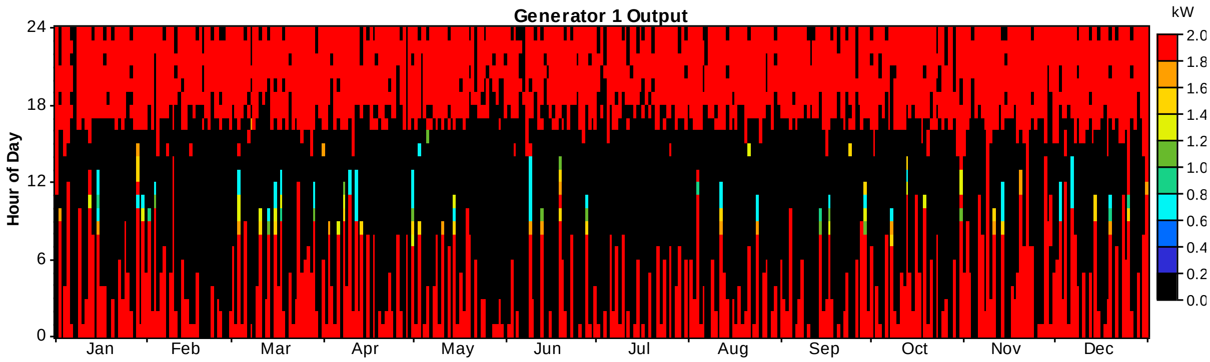

Figure 9. The electricity generated by generator.

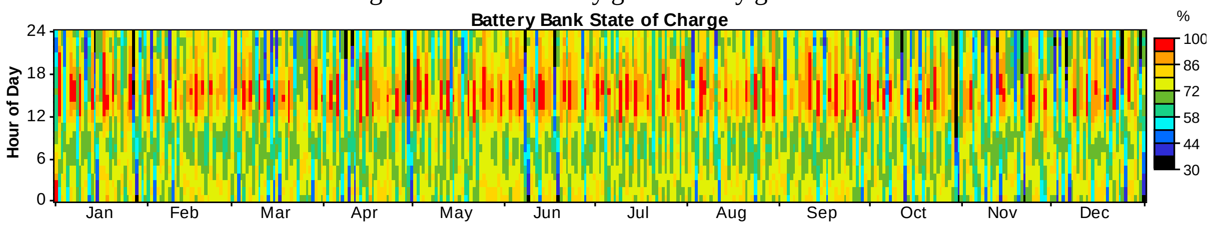

Figure 10. Battery charge content at various hours.

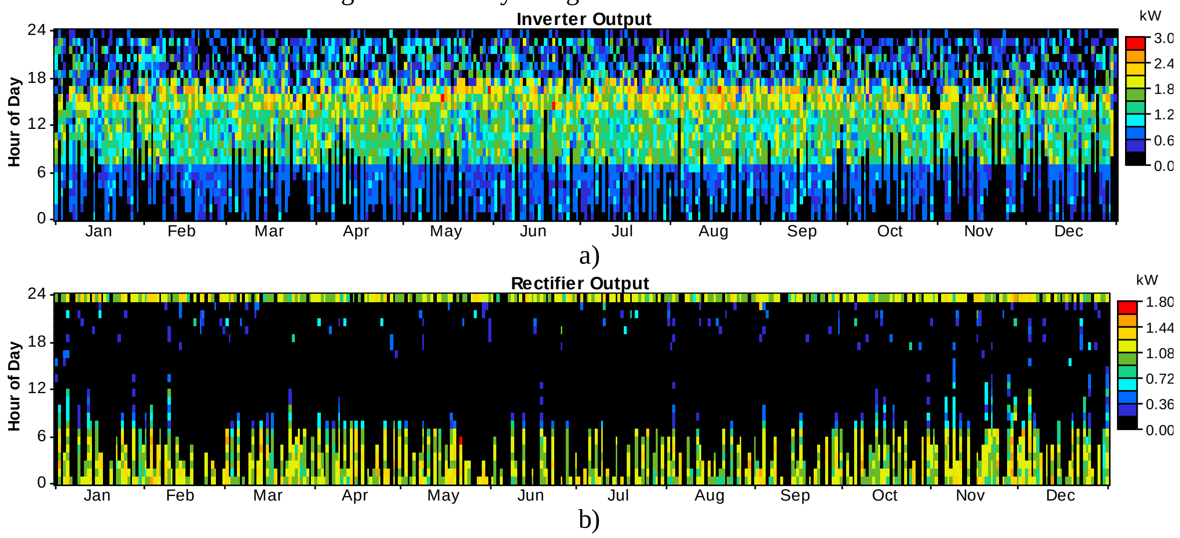

Figure 11. Performance of converter at various hours as (a) inverter, (b) rectifier.

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