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Emergency Power Supply for NICU of a Hospital by Solar-Wind-Based System, a Step Towards Sustainable Development

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Abstract

Equipping hospitals with emergency power supply is crucial. This is especially critical for important wards of the hospital, such as the NICU, ICU, and CCU. Due to the importance of this issue, the present study, for the first time, studies the power supply of vital devices of the neonatal ward in one of the hospitals in Iran. Techno-econo-enviro studies have been performed using HOMER software on 20-year average data. The case study of this article is the Social Security Hospital in Farrokhshahr, located in the Chaharmahal and Bakhtiari province, Iran, where the system under study uses tree-shaped wind turbines, solar cells, diesel generators and batteries. The use of real data for the electrical consumption of the devices, use of wind and sun data in the form of 20-year averages, and use of up-to-date costs of equipment and consumed fuel, as well as the use of a new generation of the wind turbine, are the advantages of the present study. The results showed that the use of solar energy is superior to the use of wind energy, both economically and environmentally. The cheapest simulated system among 17640 possible scenarios, with the price of each kWh equal to 0.636$, was able to use 18% of the solar energy. In contrast, the cheapest wind turbine-based system was able to use 10% of the wind energy, with the price of every kWh wind electricity equal to 0.917$. The diesel generators are used in all optimal scenarios, which indicates that either the price of solar cells and wind electricity are high compared to the diesel generator, or the intensity of sunlight or wind speed are not high enough. Moreover, compared to the conventional system only consisting of diesel generator, the optimal scenarios of using solar cells and wind turbine, benefit from a reduction in produced pollutants equal to 4.8 and 4 tones/yr, respectively. The authors hope the results of this study could help in providing a perspective for the Iranian energy policymakers.

Keywords: HOMER software; Hospital; Solar energy; Wind energy.

1. Introduction

Renewable energy, and specifically solar and wind energies, has gained increasing popularity in Iran [1] and their high potential for energy production and reduction of greenhouse gas emission has been presented in numerous studies by researchers [2,3]. Therefore, the use of these energy resources can lead to the development of the country [4]. The present work is focused on using two en ergy resources. Figure 1 demonstrates the latest status of utilizing renewable power plants in Iran, for April 2020 in which the solar and wind energies have the highest share in Iran's renewable energy, with 44% (63 power plants) and 34% (20 power plants), respectively [5].

Stability and reliability of the power grid are two significant factors, such that in some systems, low values of these two factors can impose irreparable

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damages on the system. In Iran, the shortage of water resources has made it difficult for thermal power plants to generate electricity. Lack of new power plant capacities equal to electricity consumption has already raised concerns about sustainable electricity supply in the coming years [6], where some places such as hospitals may be subject to compulsory shutdowns [7].

Nomenclature

NICU	Neonatal Intensive Care Unit	ρ_0	Air density at standard pressure and temperature equal to 1.225
ICU	Intensive Care Unit	ρ	Actual air density (kg/m^3)
CCU	Critical care unit	η_{gen}	Electrical efficiency of generator (%)
NPC	Net present cost ($)	P_{gen}	Electricity produced by diesel generators (kW)
LCOE	Levelized cost of energy ($)	$\dot{m}_{fuel}$	Fuel consumption of generator in units/hr
yr	Year	P_{WTG}	Power output of wind turbine
AM	Ante meridiem	$P_{WTG, STP}$	Power output of wind turbine at standard pressure and temperature
PM	Post meridiem	LHV_{fuel}	Lower heating value of the fuel (MJ/kg)
L	Liter	$C_{ann,total}$	Total annual cost ($)
Y_{PV}	Output power of solar cell under standard conditions (kW)	i	Annual real interest rate
f_{PV}	Derating factor (%)	N	Number of day in the year
$\overline{G_T}$	Incident radiation on the cell's surface on a monthly basis (kW/m^2)	$E_{load\ served}$	Real electrical load by system (kWh/yr)
$\overline{G_{T,STC}}$	Incident radiation on the cell's surface under standard conditions (1 kW/m^2)	AC	Alternating current
P_{PV}	Output power of PV cells (kW)	DC	Direct current

Since power outages may result in the death of patients in critical wards of the hospital such as ICU, CCU, and NICU, thus using a system that can overcome this issue is inevitable.

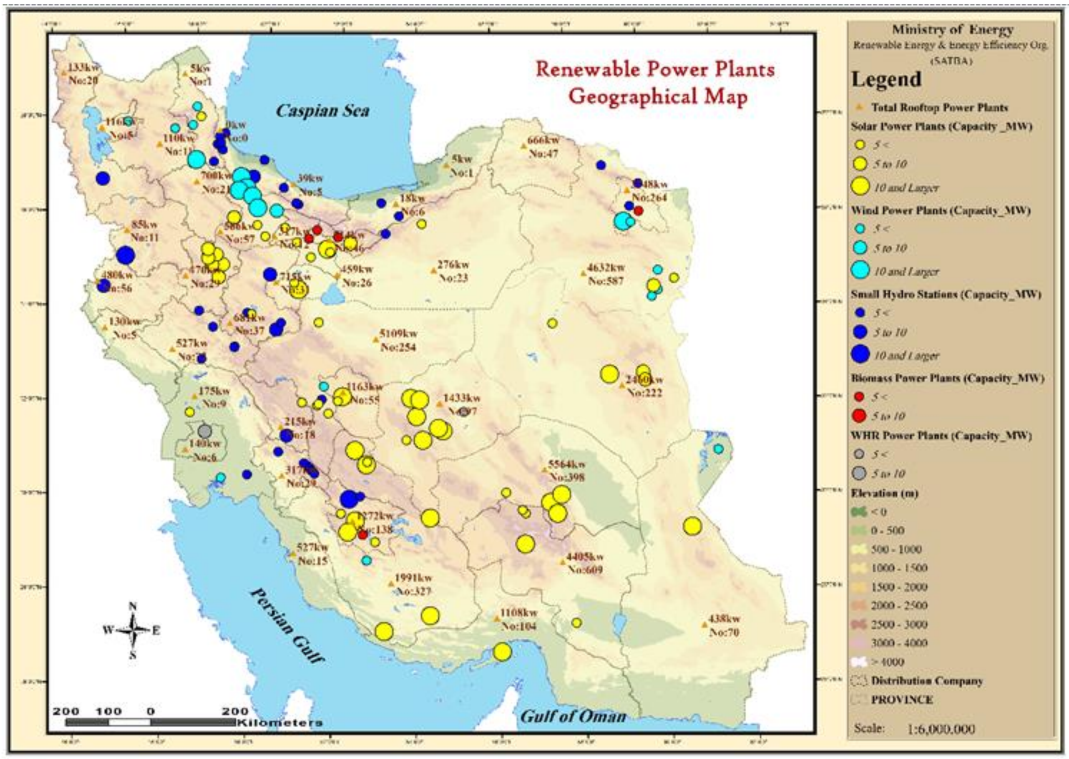


Figure 1. Geographical location map of renewable power plants in Iran [5].

Recent studies in the literature regarding the electricity supply of hospitals, clinics, healthcares or medical cares that have used renewable energies are discussed in the following.

In 2019, Faraji et al. [8] performed a comparative study between a generator-based system and a system based on renewable energies to supply the electricity of a clinic in Tehran, Iran. The results of that study imply lower values of Total NPC and COE in the system based on renewable energy connected to the grid, compared to the conventional diesel generator-based system. In addition, the diesel generator based system, produced 2115kg more CO_2 compared to the other system, annually.

In 2019, Cetinbas et al. [9] designed, analyzed, and optimized a hybrid microgrid using HOMER software at the university hospital of Eskisehir Osmangazi. The system under study included a solar cell, battery, and a diesel generator while connected to the power grid. In the optimal case, including a 2500 kW solar cell and a 110 kWh battery, the price of each kWh of the generated electricity was 0.05 $, where solar energy could provide for 43.7% of the required electricity.

In 2019, Alotaibi et al. [10] investigated the solution of smart energy for a hospital in the NEOM green city in Saudi Arabia. Analyzing the supply of 250 kWh/day with a peak value of 45.76 kW was performed using data from NASA's website and the HOMER software in the case where the system is connected to the grid. The solar cell-battery-biogas cofire generator system with the price of 0.21 $/kWh and fuel consumption of 5819 L/yr, and a renewable energy percentage equal to 78.4% was chosen as the optimal system.

So far, very few technical-economic-environmental studies have investigated the power supply of a hospital or a ward in a hospital in Iran. Thus there is a need for further research and studies in this regard. Therefore, the present study investigates a system separate from the electricity grid based on solar cells and a tree-shaped wind turbine with the support of a diesel generator to supply the electricity of vital devices in the neonatal ward of Farrokhshahr's social security hospital. The use of real data regarding the electricity consumption of the devices, use of wind and solar data in the form of 20-year averages, use of up-to-date prices for the equipment and fuel, as well as the use of a new generation of wind turbine are the advantages of the present work.

2. The location under study

The social security hospital located in Farrokhshahr, is chosen as the case study of this research. Figure 2 shows the location of Farrokhshahr which has a longitude of 50º 58' E and latitude of 32º 17' N, and at a height of 2101m above sea level and is one of the cities in the Chaharmahal and Bakhtiari province, located at a distance of 12km from Shahrekord (the capital of the province). The population of the city, based on the 2016 census is 31739, making it the fourth most populated city of the Chaharmahal and Bakhtiari province [11]. Farrokhshar has a quite mountainous climate with extremely cold winters and mild summers.

Figure 2. The location of the hospital under study on the map of Iran.

3. The used Software

HOMER software provided by NREL Co. is used as a simulator for renewable energy hybrid systems. The unique feature of this software is the simple presentation of the systems' cost function. The cost function includes installation and setup costs, reconstruction costs, maintenance costs, pollutant costs, etc. [12, 13]. By examining all possible cases of required load supply, the software provides a list of solutions from the lowest to the highest values of total NPC [14, 15].

4. Required Data

The most important data required by the software is the power consumption data for a period of 24 hours. The neonatal ward of the hospital under study contains 10 phototherapy devices and 4 incubators, with their consumed kWh during the day, equal to 1.08, and 10.76, respectively [16]. In Fig. 3, the annual electricity required for this ward, taking day-by-day and hour-by-hour random variability coefficients into account, were calculated 15%, and 20%, respectively [17]. As seen in Fig. 3, the highest need for electricity occurs at 5 AM in March, with a value of 4.362 kW.

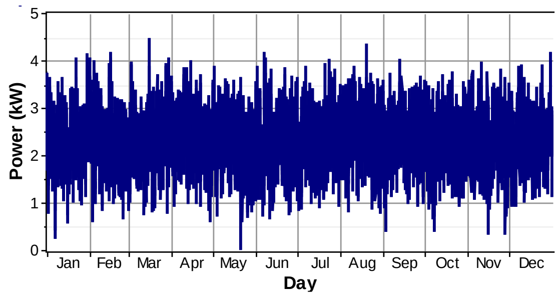


Figure 3. The graph of annual required electricity consumption.

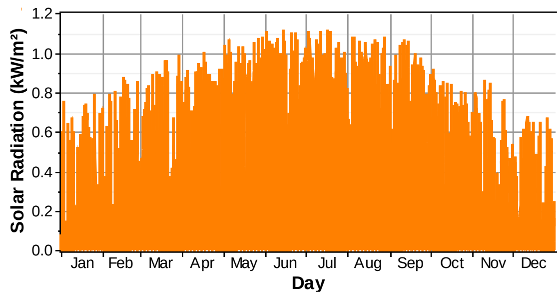


Figure 4. The annual solar radiation intensity diagram at the station under study.

Other essential data are the wind speed in m/s, and the intensity of the sun's radiations in kW/m^2, which were available in the form of 20-year average data for the area under study, and were obtained from NASA's website, as shown in Figs. 4 and 5. It should be noted that by including the radiation data, the air clearness index is calculated by the software based on the latitude of the location under study [18, 19].

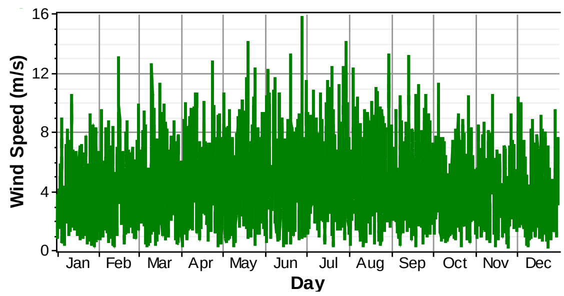
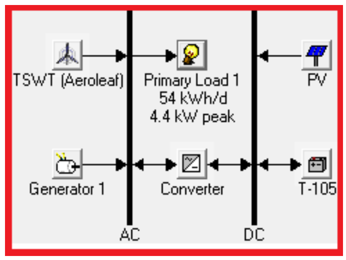


Figure 5. The annual wind speed diagram at the station under study.

Table 1: System information

Equipment	Cost ($)			Size (kW)	Other information	Schematic
	Capital	Replacement	O&M			
Converter [15]	200	200	10	0-5	Lifetime: 10 yr Inverter Efficiency: 90% Rectifier Efficiency: 85%	
PV [15]	3200	3000	0	0-4	Lifetime: 20 yr Derating factor: 90 % Tracking system: No	
Battery Trojan T-105 [15]	174	174	5	0-20	Lifetime: 845 kWh Nominal specs: 6V, 225 Ah	
Generator [15]	200	200	0.5	0-6	Lifetime: 15000 h Max. efficiency: 50%	
Tree shape wind turbine (TSWT) [23]	35000	35000	200	0-3	Lifetime: 19 yr Hub height: 6.8 m Rated power: 11.7 kW AC	

The price of the diesel used in the simulations is 0.02 $/L [20], while the useful life of the project was assumed to be 25 years [21], with an annual interest rate equal to 18% [22]. The prices and information of the equipment used in the simulations are presented in Table 1.

5. Equations used in the simulations

HOMER software uses Eqs. (1) and (2) for calculating the output power of solar cells and wind turbines, respectively [24]:

$$P_{pv} = Y_{pv} \cdot f_{pv} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right) \quad (1)$$

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

The efficiency of the diesel generator in the HOMER software is calculated as follows [25]:

$$\eta_{gen} = \frac{3.6\, P_{gen}}{\dot{m}_{fuel} \times LHV_{fuel}} \quad (3)$$

The economic calculations of the software, including the determination of Total NPC and COE parameters, are given by the following equations [26]:

$$\text{Total NPC} = \frac{C_{ann,total}}{\frac{i(1+i)^N}{(1+i)^N + 1}} \quad (4)$$

$$COE = \frac{C_{ann,total}}{E_{Load\ served}} \quad (5)$$

6. Results

The simulation results are presented in Table 2. The number of analyses performed by the software is 17640. The results in Table 2 show that the optimal system (the first scenario) includes a 3 kW solar cell, a 3 kW diesel generator, 14 batteries, and 4 converters. The lowest total net present cost was calculated to be 68257 $, which leads to a price of 0.636 $ per each kWh of the generated electricity. 18% of the required annual electricity is generated by solar cells, while the rest is generated by the diesel generator in 5945 hours, consuming 3446 L of diesel annually.

Table 2: Results of simulations

Scenario	PV	Wind	Generator	Battery	Converter	Total NPC ($)	COE ($/kWh)	Ren. Frac. (%)	CO_2 (kg/yr)	Diesel (L)	Generator (hrs)
1	3	-	3	14	4	68257	0.636	18	9073	3446	5945
2	-	1	3	20	2	98467	0.917	10	9816	3728	6327
3	2	1	3	16	3	98706	0.919	26	8264	3138	5469
4	-	-	4	-	-	99535	0.927	0	13868	5266	8759

Figure 6 demonstrates the cash flows diagram for the first scenario. As can be observed in the figure, the main costs in the first year were spent on purchasing the required equipment. There exists an almost fixed operating cost in all years which is due to the diesel fuel consumption. A relatively high cost also exists in the 20th year, which is spent on replacing the solar cells. Finally, a salvage cost is seen in the 25th year, because some equipment has a useful lifespan and can be sold afterward.

It is seen in Fig. 7 that in the first scenario, the need for diesel generators was at its highest in December and January, while the highest amount of electricity generation of the solar cells occurred between June and September.

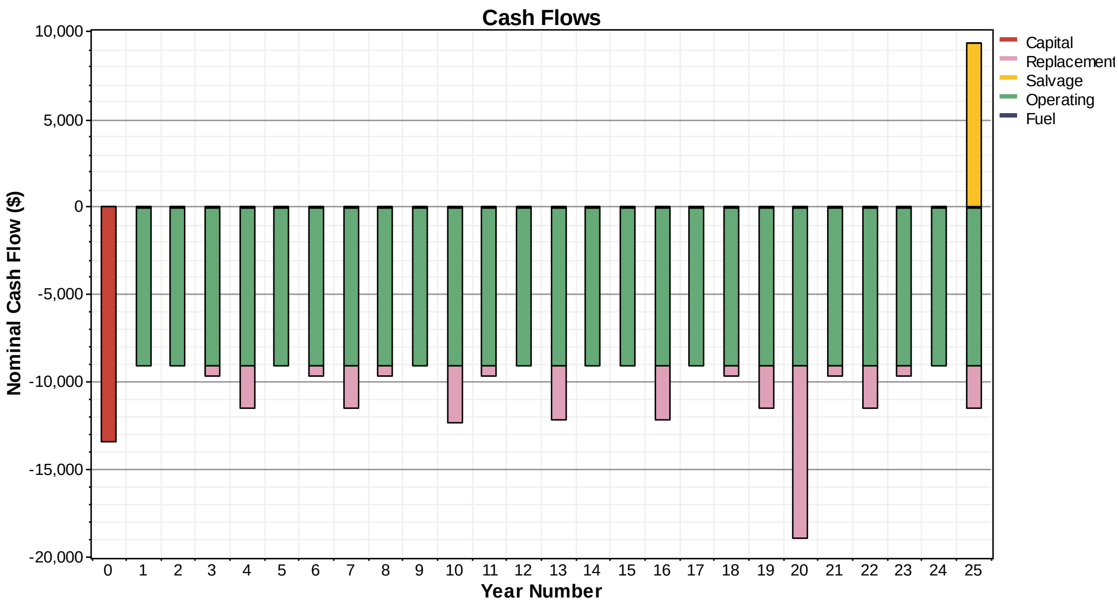


Figure 6. The cash flow diagram of the first scenario for the useful lifespan of the project.

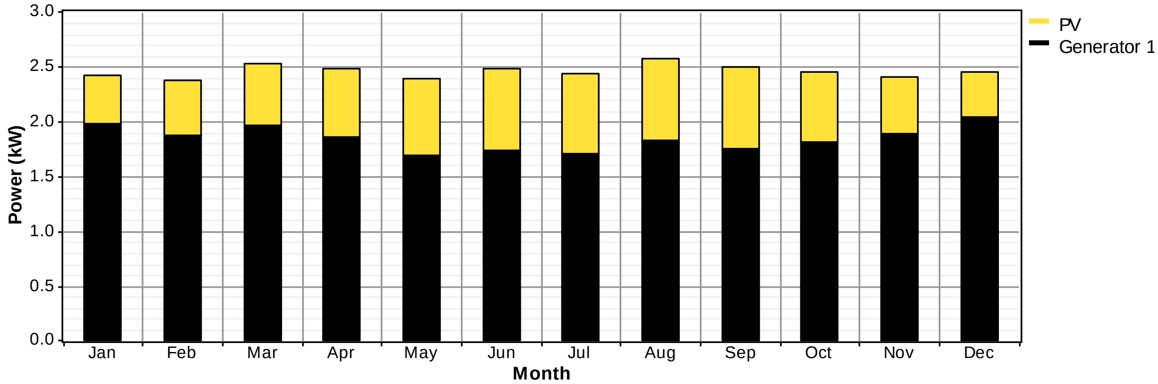


Figure 7. Monthly-average electricity generation in the first scenario.

Figs. 8 to 12 show the power generation contours of the solar cells and the diesel generator, battery charge status, and outputs of the inverter and the rectifier for the first scenario. It is seen from Fig. 8 that the energy production in solar cells occurs from almost 7 AM to 6 PM. The average output power of the solar cells was 0.62 kW, and they have generated 4384 hr/yr electricity and their LCOE is equal to 0.332 $/kWh. The performance contour of the diesel generator (Fig. 9) shows that the generator was almost not used in the hours that sun radiation existed, and the solar cells generated electricity, while in the rest of the hours, the diesel generator has generated electricity with its maximum capacity. In this scenario, the lifespan of the generator was 2.52 years, and it was started 422 times during the year, with a marginal generation cost of 0.0025 $/kWh. It is seen from Fig. 10 that the batteries are charging in the hours of radiation existence where the solar cells generate electricity, while they start discharging during the night hours. It is clear from the results that the loss of batteries is equal to 607 kWh/yr, their estimated lifespan is 3.08 yr, and their average energy cost is 0.003 $/kWh. Figs. 11 and 12 show that AC to DC conversion occurs mainly during the functioning hours of the solar cells, while the AC to DC conversion occurs during the time that the generator is functioning. The annual functioning hours of the invertor and rectifier were 4058h and 4696 h, respectively, with their losses equal to 742 kWh/yr and 477 kWh/yr, respectively.

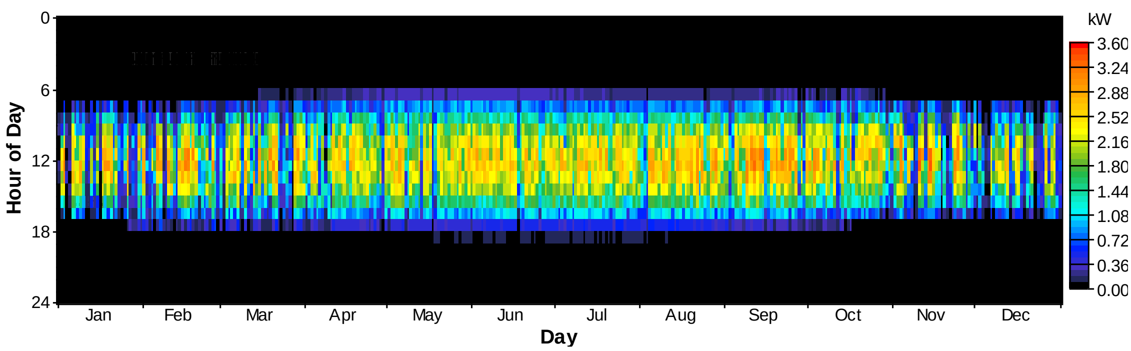


Figure 8. The generated solar electricity contour in the first scenario.

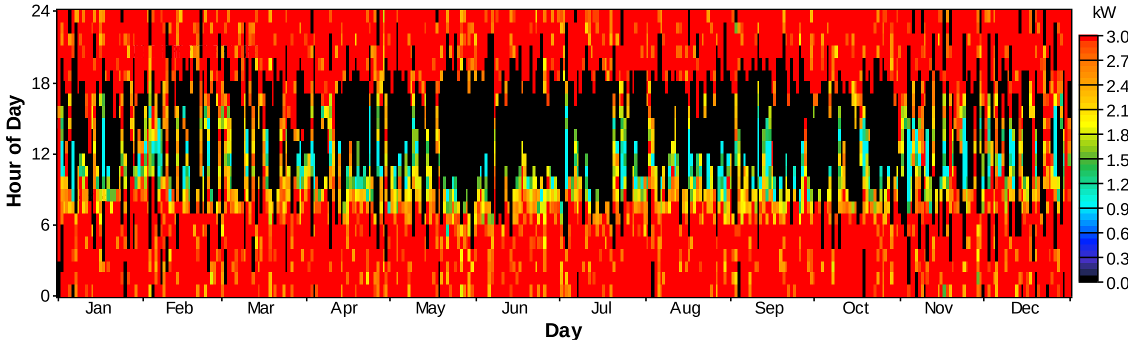


Figure 9. The generated diesel generator electricity contour in the first scenario.

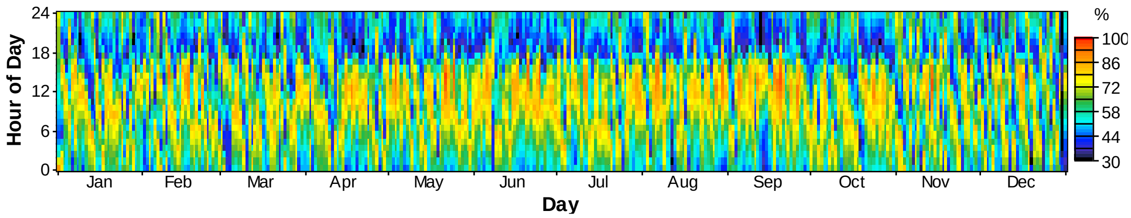


Figure 10. Battery charging status contour in the first scenario.

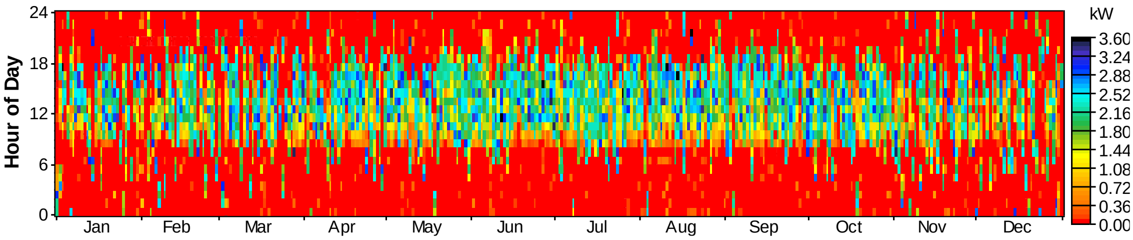


Figure 11. Invertor output contour in the optimal scenario.

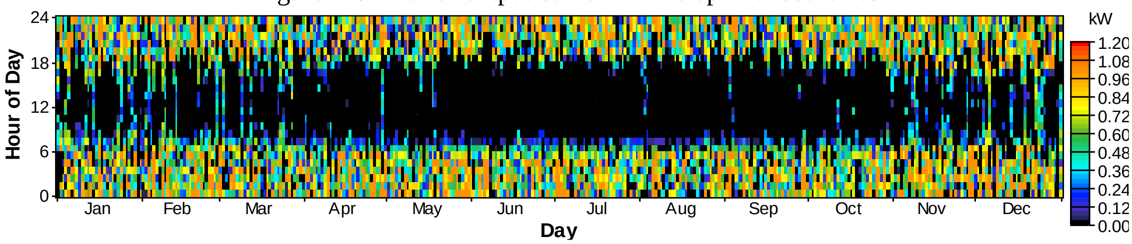


Figure 12. Rectifier output contour in the optimal scenario.

The amount of pollutants produced by the diesel generator in the first scenario is presented in Table 3. The highest amount of pollutant with 9.073 tons per year belongs to CO_2, followed by nitrogen oxide with 200 kg/yr. Due to the fact that there is no penalty for the production of pollutants in Iran, the aim of expressing the values in Table 3 is only to illustrate the environmental aspect of the first scenario. In addition, it is also important to note that considering penalties for the generated pollutants, will increase the price of each kWh of electricity produced in diesel-generator-based scenarios (scenarios one to four).

If we only want to use a diesel generator (the fourth scenario in Table 2), $31,278 more should be spent for the total net present cost, which increases the price of each kWh of the produced electricity by 0.291$. The important issue in this regard is that, with the production of 13.868 tons/yr of pollutants (according to Table 2), this scenario is not a suitable choice at all, especially for hospitals.

Table 3. Pollutants produced in the optimal scenario

Pollutant	Emissions (kg/yr)
Carbon dioxide	9073
Carbon monoxide	22.4
Unburned hydrocarbons	2.48
Particulate matter	1.69
Sulfur dioxide	18.2
Nitrogen oxides	200

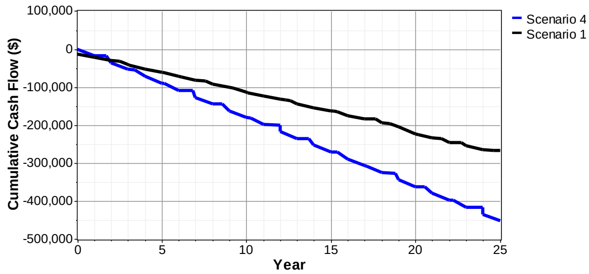
If a tree-shaped wind turbine is used (the second scenario in Table 2), the total net present cost would become 30210$ higher than the optimal case (the first scenario in Table 2), and the price of each kWh of the generated electricity would increase by about 44.2%. In this scenario, the tree-shaped wind turbine produces 10% of the required electricity, with its amount of annual electricity generation equal to 3503 kWh/yr and its LCOE equal to 1.94 $/kWh. The amount of CO_2 pollutant generation which is the most important pollutant with the highest value of generation is equal to 9816 kg/yr in this scenario.

The third scenario in Table 2 corresponds to the simultaneous use of solar cells and wind turbines. This scenario, which is the environmental friendly scenario, could produce 26% of the electricity from renewable energies, and thus has the lowest amount of fossil fuel consumption among the existing scenarios with 3138 L/yr. In this scenario, the amount of CO_2 produced is equal to 8264 kg/yr.

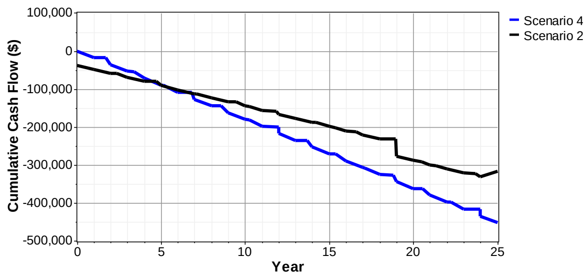
In Fig. 13a to 13c, the first, second, and third scenarios (which are based on renewable energies) are compared to the fourth scenario (based on fossil fuels). It is seen from these results that the fourth scenario is economically superior to the first one until the second year, where the costs of the first scenario become lower than the fourth and remain so until the end of the project. In the second scenario, it takes 4.5 years for wind energy to overcome the costs of using a diesel generator. This time span is five years in the third scenario.

7. Conclusion

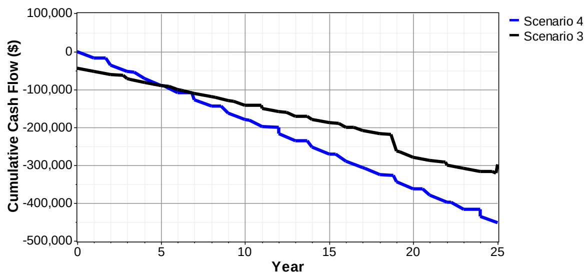
Emergency power systems, including solar panels and wind turbines, prevent the electricity of consumers, such as hospitals, from being cut out during power outages because of having batteries and electrical converters. Due to the high costs of emergency power supply for the entire hospital, only crucial wards and devices are supported by this emergency electricity. One of these sections is the neonatal ward, which has been studied in this research for the first time in the literature. The software used in this study was HOMER, and techno-econo-enviro analyses on the system consisting of solar cells, wind turbines, battery and diesel generator were all performed using this software. The case study of this research was the social security hospital of Farrokhshahr in Chaharmahal and Bakhtiari province. The main results are:



a)



b)



c)

Figure 13. Comparisons with the fourth scenario, a) the first scenario, b) the second scenario, c) the third scenario.

- The lowest cost per kilowatt-hour of the emergency power generation is $0.636, which corresponds to the solar cell-diesel generator-battery system.
- The lowest amount of annual pollution is equal to 8264 kg and occurs in the wind turbine- solar cell-diesel generator-battery system.

- The use of diesel generator alone is the last priority from an economic and environmental perspective.
- The use of solar cells has priority over the use of wind turbines, both economically and environmentally.
- Compared to the system consisting of a diesel generator, systems that are based on solar cells, wind turbines and simultaneous use of solar cells and wind turbines reach economic superiority after 2, 4.5, and 5 years, respectively.

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