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Management and Environmental Assessment of Simultaneous Production of Solar Electricity and Heat (Case Study: Sar Agha Seyed Rural Health Center)

Mashallah Valikhani Dehaghani[1], Mohsen Khalili Samani[2,*], Daryosh Mohamadi Janaki[3]

[1] Faculty of Management, South Tehran Branch, Islamic Azad University, Tehran, Iran
[2] Department of Management, Dehaghan Branch, Islamic Azad University, Dehaghan, Iran
[3] Faculty of Engineering, Shahrekord University, Shahrekord, Iran
*Corresponding author; mo.khalili@std.iaushk.ac.ir; mohsen_khalili@dehaghan.ac.ir

Abstract

The future belongs to institutions and organizations that use all their potential and actual potentials to face new challenges. The impact of administrative processes on energy services is significant. When the existing institutions and administrative systems only maintain the status quo or act poorly in the face of these changes, the results of the quantitative and qualitative part of the provision of energy services are not satisfactory. Since electricity is considered the center of development, special attention to rural electricity supply and also solving possible problems of important rural centers in the areas of reliable electricity supply and lighting can pave the way for sustainable development in rural areas. In this regard, one of the main priorities of the government is to provide services to villages, hamlets, and deprived areas, as well as increase the quality of services provided to these areas and, of course, for sensitive uses in the villages. Due to the importance of the above, in the present work, for the first time, the simultaneous production of solar electricity and heat for a public health center located in the village of Sar Agha Seyed in Chaharmahal and Bakhtiari province has been evaluated. The reason for choosing this village and this government health service center to investigate is that in winter and autumn, with snow and rain, the region's electricity is cut off. In addition, it is very important and necessary to pay attention to continuous and stable electricity supply due to the sensitivity of medical centers in providing services. Technical, economic, environmental, optimization, and sensitivity analysis assessments are performed by HOMER commercial software over a period of one year. Another purpose of this article is to study the different organizational dimensions of the use of renewable energy in rural public health centers.

Keywords: Managerial and environmental assessment, Solar energy, Load fluctuations, Simultaneous supply of electricity and heat, HOMER software.
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1. Introduction

Energy and the environment are the two main concerns of our future, and the development of sustainable renewable energy technologies is becoming more and more essential. Among all renewable sources, solar energy is the most promising source due to its abundance and environmentally friendly nature [1, 2]. The G8 leaders at their 2007 meeting in Heiligendamm called on countries to "take the tools and measures to significantly increase the combined heat and power (CHP) share of electricity generation" [3]. CHP systems, as the name implies, can be powered by fossil-based or renewable sources and provide heat and electricity to the energy system [4]. CHP technique is promoted worldwide as one of the most effective low carbon technologies to increase the efficiency of thermal power plants [5]. CHP systems have received scientific attention since the 1970s during the energy crisis. However, the study of CHP systems with renewable energy (RE) energy has attracted considerable scientific attention only since the 2000s [6].

CHP systems, as well as energy storage technologies, can be a great help in balancing and improving the efficiency of renewable energy systems [7, 8]. CHP systems are not only an excellent alternative to conventional systems characterized by distinct heat and power generation but also improve energy efficiency and energy saving capabilities of systems [9]. In addition, the hybridization of CHP systems with renewable energy sources increases their stability in relation to reducing greenhouse gas emissions. Figure 1 shows a classification of the main existing CHP technologies and the main areas of their application.

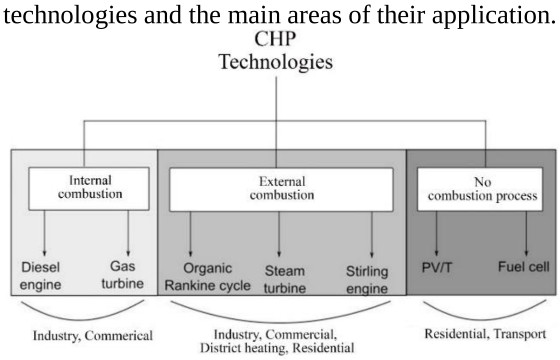


Fig. 1. Main CHP technologies and their application areas.

Solar photovoltaic (PV) systems are used worldwide to generate clean electricity [10, 11]. Electricity generation from solar PV increased by 156 TWh (23%) to 821 TWh in 2020. However, the zero-emission scenario by 2050 shows an average annual growth of 24% between 2020 and 2030, which is equivalent to a 630 GW increase in net power in 2030 (Figure 2) [12]. To solve the problems of reliability and accessibility of solar energy, hybrid power generation is widely used [13]. One of the main ways to increase the efficiency of solar systems is to extend them to CHP [14]. Solar CHPs can reduce greenhouse gas emissions much faster than conventional solar energy devices and maximize the economic and environmental value of solar energy [15].

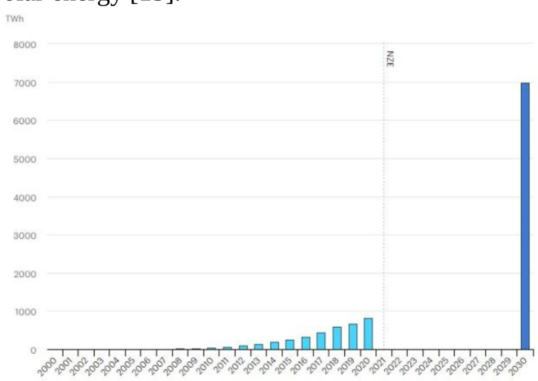


Fig. 2. Solar PV power generation, 2000-2030 [12].

The following is a review of recent studies on renewable hybrid CHP systems in the world.

Pahlavan et al. (2019) [16] investigated the effect of heat return coefficient on the simultaneous production of electricity and heat in distributed generation by solar cells in Isfahan. HOMER software was used for simulation. The results showed that the use of solar cells as hybrids with generators and boilers had a higher cost, but fuel consumption and CO_2 emissions were much lower.

Kim et al. (2017) [17] used HOMER software to investigate the possibility of simultaneous generation of electricity, heat, and cold (CCHP) for a building using solar cells. The study area was Atlanta in Canada. The studied parameters were energy consumption, costs of electricity and heat production, reduction of pollutants, and reduction of water consumption. The results showed that for a residential building, using this system reduces energy consumption by 48.8%, costs by 5.6%, and water consumption by 48.6%.

Gbadamosi and Nwulu (2020) [18] examined the optimal power distribution for combined heat and power (CHP), wind, PV, and battery systems for agricultural applications. The results showed that a 48% reduction in energy costs could be achieved by considering a combined CHP, wind, PV, and battery system compared to the CHP power supply.

In 2009 [19], Pierce explored the potential of establishing a distribution network of PV and CHP hybrid systems to increase the level of PV penetration in the United States. The results showed that a hybrid system of PV and CHP not only has the potential to drastically reduce energy loss in the current electric and heating systems but also allows the share of solar PV to increase up to about five times.

2. Management of Iran's energy resources

Iran's economy is based on natural resources and its energy consumption is inefficient. The government has tried to implement inefficiency policies in the energy sector at various times. The facts show that inefficiency in Iran's energy sector is a serious issue and the phenomenon of collapse is seen in energy policies [19]. Natural gas is one of the most widely used energy carriers in the administrative, domestic, and industrial sectors of Iran. Iran's gas consumption is 6.7 times higher than the world's per capita consumption, and the government pays about $ 82 billion to $ 83 billion in energy subsidies annually [20]. According to the study, the average global price of natural gas in June 2021 was $ 0.060 per kWh for home users and $ 0.048 per kWh for commercial users. It is noteworthy that the cheapest price of natural gas among the countries in the world in both domestic and commercial sectors has been recorded for Iran [21].

Iran's electricity sector was the largest consumer of natural gas with 32% in 2020 [22]. Certainly, the transition to renewable energy is the key to sustainable development [23]. Iran has one of the highest potentials for the use of solar energy in the world, with more than 1648,000 km^2 of suitable area and 300 sunny days per year, and more than 2200 kWh/m^2 of radiation. As can be seen in Figure 3, most parts of Iran have a very good potential for utilizing sunlight. However, achieving the goals of renewable energy development according to the Iran Roadmap faces various obstacles [24]. According to the operational plan for the development of renewable energy infrastructure in Iran, investment in the construction of solar sites is the main focus of the programs of the Renewable Energy and Energy Efficiency Organization (SATBA) of Iran [25]. By the end of 2019, 299 public and private companies in Iran were eligible to build solar sites with a total capacity of 2685 MW, of which only 365 MW were installed [26]. In fact, the potential capacity of 2320 MW is still in the understudy phase [27].

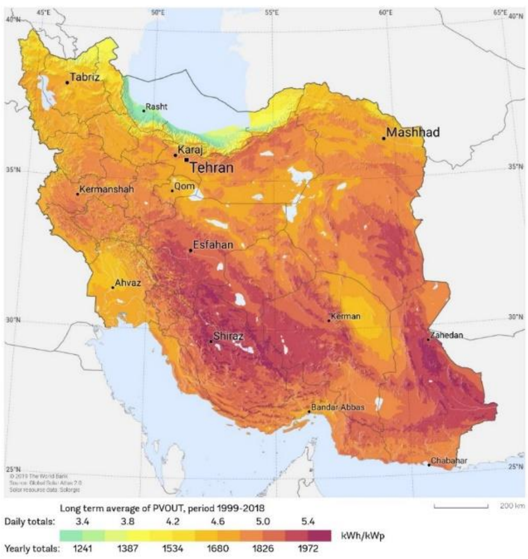


Fig. 3. Potential of PV electricity in Iran [28].

According to a 1995 Cabinet decision, government ministries, institutions, companies, and public non-governmental organizations are required to provide at least 20% of their buildings' electricity consumption from renewable energy sources within two years, but unfortunately, less than 10 MW have been implemented so far. Renewable energy plants can be built in government offices in all parts of the country, such as PV power plants, in the form of production on site. Not only can these power plants provide a significant portion of the electricity needed by offices, especially during peak consumption, but they can also achieve part of the Ministry of Energy's 10,000 MW renewable energy development goal over the next four years without the use of limited guaranteed purchase resources.

The impact of administrative processes on the provision of energy services is significant, and when the existing institutions and administrative systems, only maintained the status quo or reacted poorly to these changes, the quantitative results of the provision of energy services are not satisfactory. In communities where there are strong and flexible administrative institutions and organizations, the results have been much better. As shown in Figure 4, creating employment, reducing pollutants, raising public awareness and social acceptance, creating economic efficiency, and reducing energy consumption are the most important effects of using renewable energy in government centers. Iran faces many economic, technical, managerial, and legal challenges and obstacles in the development and use of renewable energy sources. The development of the use of renewable energy in Iran, in addition to international obstacles, faces many problems. These problems include the lack of macro-management policies and development plans, the lack of national and local administrative laws on renewable energy, the unfamiliarity of national planners and managers with the function of this type of energy resources, weakness in management Human resources, and barriers to technology transfer.

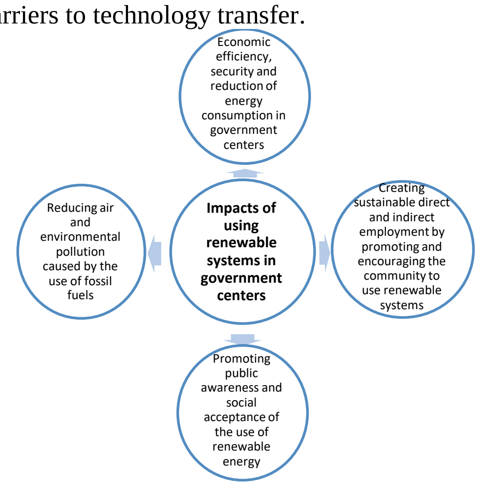


Fig. 4. Impacts of the use of renewable systems in government centers.

3. The place understudy

Sar Agha Seyed or one of the old villages of Koohrang in Chaharmahal and Bakhtiari province, which like Masuleh and some villages in Iran, the roof of each house is the courtyard of the upper house. If this village is properly considered, it will become one of the most prominent manifestations of nature tourism in Iran with a global status (Figure 5). Rural houses usually have no windows and have thick walls and flat roofs made of stone, mud, and wood. In addition to security aspects (wildlife attacks, theft, etc.), it seems that due to the cold winters and frosts in the region, the principles of optimizing fuel consumption have been observed better than today.

The region has a population of 2500 people, at a distance of 45 km from Koohrang city and 130 km from Shahrekord (the center of the province), and at 2500 m above sea level has a mountainous climate with very cold and snowy winters [9]. When there is heavy snowfall in Sar Agha seyed village, it is not possible to access this area and during some periods of the winter season, the connection between this village and the outside is cut off. The main consumption of the villagers in this area is fossil fuels with high pollution such as oil, diesel, and firewood. This village lacks the necessary facilities for a normal life and it seems that one of the important priorities in creating the well-being of the residents and tourists of this area is the implementation of energy systems separate from the grid.

In this article, to evaluate the simultaneous production of electricity and solar heat for a public health service center located in one of the impassable villages of Koohrang city located in Chaharmahal and Bakhtiari province has been selected. The reason for choosing this village is the problems caused by the transfer of the national energy network to this area and the frequent power outages during the cold seasons. One of the centers in this village that suffers the most from these power fluctuations and lack of energy is the only public health service center in this village. Figure 6 shows the location of the village as well as a schematic of the studied system (CHP and PV) in this village.

4. Methodology

A) Software used

HOMER software is research software that is used globally as a guide for the optimal planning and evaluation of grid-independent [30-33] and grid-connected [34-37] energy systems. This software has been used in several energy studies due to its reliability, coherent scheduling, and user-friendly interface [38-42].

B) Flowchart of performance

As shown in Figure 7, the technical-economic-energy-environmental analysis of the present work consists of 3 parts. In the first part, based on the planned strategy, the required electric and thermal load profiles, equipment prices, and climatic data are evaluated. The output of this section, due to design limitations, is to select the appropriate technology to meet the load demand. In the second part, where the optimization is done, the modeling is done. In this section, the software builds various hybrid renewable energy systems and examines whether each of them can provide the energy needed for years. The output of this section is the various configurations of renewable energy systems on which 3E analysis has been performed. In the third section, each existing optimal configuration is evaluated based on economic, energy, and environmental parameters.

Fig. 5. Sar Agha Seyed steppe village in winter and summer

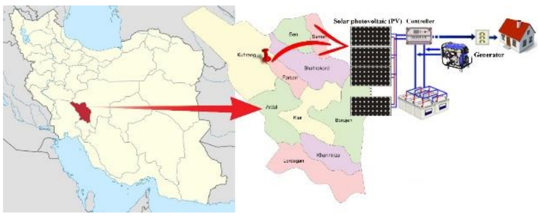


Fig. 6. Schematic of using CHP and PV system in Sar Agha seyed village.

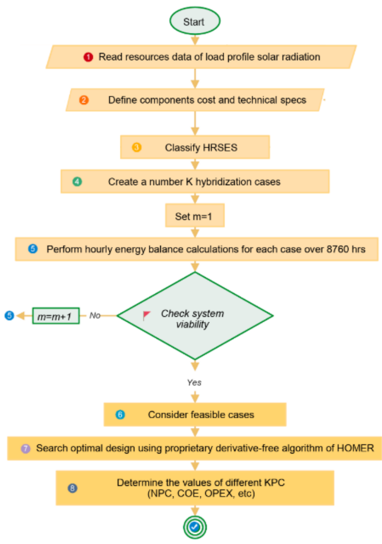


Fig. 7. Simulation software performance diagram

C) Governing equations

Table 1 shows the equations governing the various parts of the renewable energy system. The parameters used in Table 1 are described in the nomenclature.

D) Schematic of the understudy system

Figure 8 shows a schematic of the solar-biomass cogeneration system. It is clear from Figure 8 that using Dump Load, excess electricity is converted into heat.

Table.1.
Governing equations of simulation

Parameter	***Governing equation***	***Reference***
Solar cell production capacity	$P_{pv} = Y_{pv} \times f_{pv} \times \frac{\overline{H_T}}{\overline{H_{T,STC}}}$	[43]
Biomass generator efficiency	$\eta_{Biog.gen.} = \frac{3.6\ P_{Biog.gen.}}{\dot{m}_{Biog.}\ LHV_{Biog.}}$	[44]
Maximum battery power	$P\_(batt.cmax) = (Min\ (P\_(batt.cmax.kbm), P\_(batt.cm\ /\eta\_(batt.c)$	[45]
Total net present cost (NPC)	$Total\ NPC = \frac{C_{ann,total}}{\frac{i\ (1+i)^N}{(1+i)^N - 1}}$	[46]
Levelized cost of energy (LCOE)	$LCOE = \frac{C_{ann,total}}{E_{Load\ served}}$	[47]

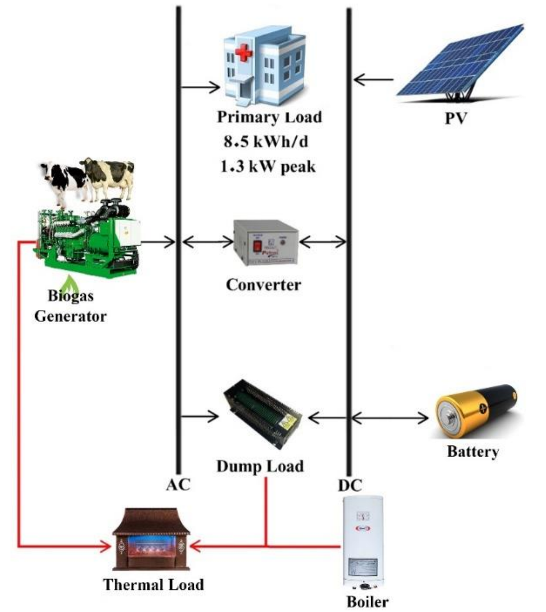


Fig. 8. Understudy system schematic

5. Input data

The building under study is a clinic located in Sar Agha Seyed village with coordinates 32° 39' N and 49° 52' E. Figure 9 shows the radiation on the horizontal surface as well as the air clearness index for the study site, which is an average of 20 years [48] and obtained from the NASA website. According to the figure, the average annual radiation is 5.17 kWh/m2-day and the average air clearness index is 0.606. Consumption price of diesel equal to 0.01 $/L [49], price of animal waste used as biomass 192 $/ton, annual interest rate in Iran 18% [50], project lifetime is 25 years [51], and based on the number of livestock, the average amount of animal waste is 500 kg/day per month.

Given that the effect of ambient temperature on the performance of solar cells is considered in the present work, Figure 10 shows the data duration diagram for the ambient temperature parameter. According to the results of Figure 10, the average annual ambient temperature is 10 ° C and the minimum ambient temperature is -3 °C and the maximum is about 23 °C. Also, about 2160 hours during the year, temperature is zero or below zero. Information on the properties and pollutants of diesel and biomass used, as well as penalties for pollutants produced, are given in Table 2.

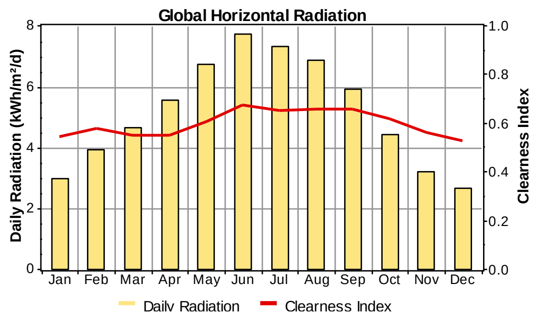


Fig. 9. Average monthly radiation and air clearness index for the study area

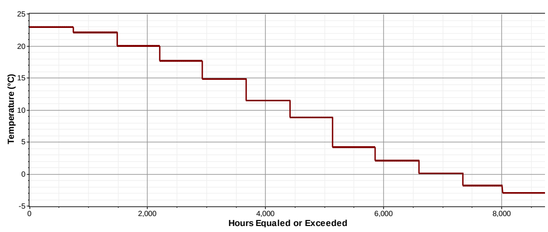


Fig. 10. Data duration diagram for ambient temperature at the study site

Table.2.
Fuel information and pollutants fines

Item	Properties	Emission factor
Diesel [52]	Lower heating value: 43.2 MJ/kg Density: 820 kg/m^3 Carbon content: 88% Sulfur content: 0.33% Boiler efficiency: 85%	Carbon monoxide: 6.5 g/m^3 Unburned hydrocarbons: 0.72 g/m^3 Particulate matter:0.49 g/m^3 Fuel sulfur converted to PM: 2.2 % Nitrogen oxide: 58 g/m^3
Biomass [52]	Lower heating value: 5.5 MJ/kg Carbon content: 5% Gasification ratio: 0.7	Carbon monoxide: 16.5 g/m^3 Unburned hydrocarbons: 0.72 g/m^3 Particulate matter: 0.1 g/m^3 Fuel sulfur converted to PM: 2.2 % Nitrogen oxide: 15.5 g/m^3
Emission penalty [53]	Carbon dioxide: 3.1 $/t Carbon monoxide:57 $/t Sulfur dioxide: 560 $/t Nitrogen oxides: 184 $/t	-

Figures 11 and 12 show the amount of seasonal electricity and heat loads of the space under study, respectively. The required electric charge is 8.5 kWh/day with a maximum of 1.3 kW in August and the required thermal charge is 115 kWh/day with a maximum of 34.2 kW in February.

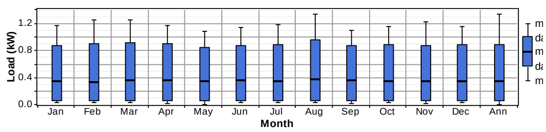


Fig. 11. Seasonal electricity profile

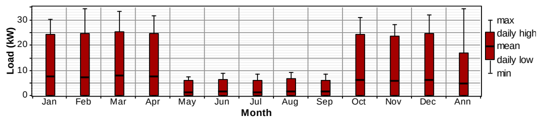


Fig. 12. Seasonal heat profile

Table 3 provides information on the price of equipment used, their size and other technical characteristics. It should be noted that this equipment has been selected based on access to the Iranian market and the limitation in the number of available equipment has been due to economic issues.

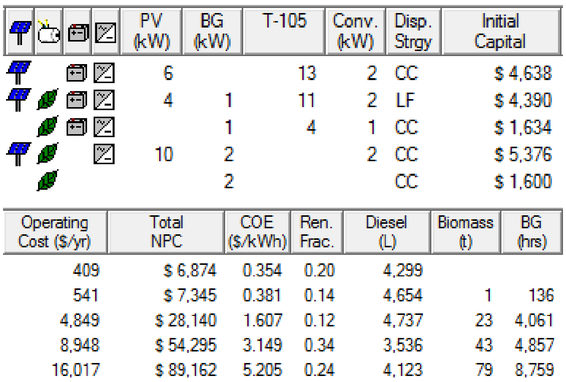
6. Results

E) Technical analysis

Figure 13 details 5 possible scenarios. From the results of Figure 13, it can be seen that the best-case scenario, which could have the lowest total NPC, includes 6 kW of solar cells, 13 batteries and 2 kW of electrical converters. In this scenario, the cycle charging strategy is used. The second superior scenario is the combination of a 1 kW biomass generator with 4 kW solar cell that uses 11 kW batteries and 2 kW electric converter. In the second top scenario, the load following strategy is used. In the third superior scenario, the solar cell is no longer used and a 1 kW biomass generator, 4 batteries and a 1 kW electric converter are used using the cycle charging strategy. In the fourth superior scenario, which differs from the second superior scenario by removing the battery from the system configuration, the strategy was changed by removing the battery, and the cycle charging strategy was used. Also, due to the removal of the battery, 6 kW of solar cells and 1 kW of biomass generator has been added compared to the second superior scenario, which shows the necessity and importance of using the battery in the renewable CHP hybrid system. In the fifth superior scenario, where only the 2-kW biomass generator is used, the strategy used is cycle charging.

Table.3.
Information on renewable hybrid system equipment.

Equipment	***Cost ($)*** Capital	Replace	O&M	***Size (kW)***	***Other information***
Converter [54]	138	138	10	0-5	Lifetime: 15 y Inverter Efficiency: 95% Rectifier Efficiency: 95%
PV [54]	350	350	10	0-5	Lifetime: 25 y Derating factor: 85 % Temp. Coeffic. of power: -0.38 %/ºC Nominal operating cell temp.: 45 ºC Efficiency at std. test condition: 16.25 %
Battery Trojan T-105 [55]	174	174	5	0-5	Lifetime: 845 kWh Nominal specs: 6V, 225 Ah
Biogas generator [55]	800	700	0.001	0-5	Lifetime: 15000 h Max. efficiency: 30% Intercept coefficient: 2.66 kg/hr/kW rated Slope: 1.52 kg/hr/kW output



PV (kW)	BG (kW)	T-105	Conv. (kW)	Disp. Strgy	Initial Capital
6		13	2	CC	$ 4,638
4	1	11	2	LF	$ 4,390
	1	4	1	CC	$ 1,634
10	2		2	CC	$ 5,376
	2			CC	$ 1,600

Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Biomass (t)	BG (hrs)
409	$ 6,874	0.354	0.20	4,299		
541	$ 7,345	0.381	0.14	4,654	1	136
4,849	$ 28,140	1.607	0.12	4,737	23	4,061
8,948	$ 54,295	3.149	0.34	3,536	43	4,857
16,017	$ 89,162	5.205	0.24	4,123	79	8,759

Fig. 13. Simulation results for existing conditions

F) Energy analysis

In the first superior scenario, 20% of the total required thermal and electrical load is supplied by solar cells. According to Figures 14 and 15, which show the power and heat supply for this scenario, respectively, the total 3100 kWh/year of electricity required is supplied by solar cells and the remaining 6334 kWh/year of excess generated electricity is converted to the heat by dump load. According to Figure 15, 85% of the required heat, ie 35956 kWh/year, is supplied by a diesel boiler. Figure 16 shows the power output of solar cells. During the day, the average output power is 26.8 kWh and the capacity factor is 18.6%. Solar cells generate 4384 hours of electricity during the year and the maximum output according to Figure 16 is 5.91 kW. Figure 17 also shows the boiler power output. The boiler operates 3072 hours during the year and has an average output of 11.7 kW and a maximum output of 32 kW. Based on the performance of the batteries in Figure 18, the lifetime of the batteries is 8.65 years and their annual losses are 194 kWh. About 32% of the time, the batteries are 100% charged, which is during the hours of sunshine, and the minimum battery charge is 30%. Figure 19 shows the inverter performance, which operated 8740 hours during the year and also lost 163 kWh/year. The maximum output of the inverter is 1.33 kW and its capacity factor are 17.7%.

In the second superior scenario, 14% of the total thermal and electrical loads required are generated by renewable sources. In this scenario, according to Figure 20, 6531 kWh/year of electricity is generated by solar cells and only 52 kWh/year, ie about 1% of electricity is supplied by the biomass generator. According to Figure 21, 155 kWh of heat is supplied annually by the biomass generator, 3115 kWh of heat is generated by excess electricity and 38922 kWh of heat is generated by the boiler. According to Figure 22, the average output power of solar cells is 17.9 kWh, their capacity factor is 18.6% and their maximum output is 3.94 kW. According to Figure 23, which shows the output power of the biomass generator, in January, February, March, November and December, the biomass generator is used, which has a total operating time of 136 hours and a biomass consumption of 630 kg/year. The maximum output power of the biomass generator is 0.881 kW and the capacity factor are about 0.6%. According to Figure 24, which results from the consumption of 4654 liters of diesel by the boiler, it can be seen that the maximum boiler output for this scenario is 36 kW. Also, the boiler operating time in this scenario is 3152 hours.

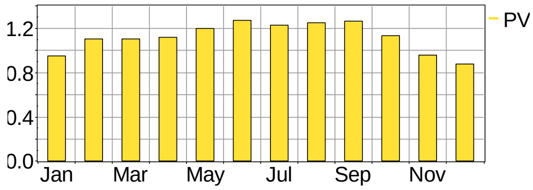


Fig. 14. Monthly Average Electric Production (Scenario 1)

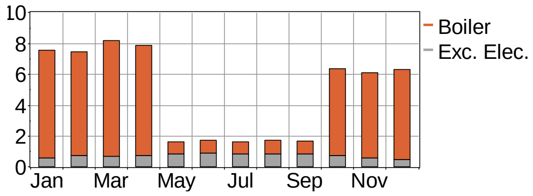


Fig. 15. Monthly Average Thermal Production (Scenario 1)

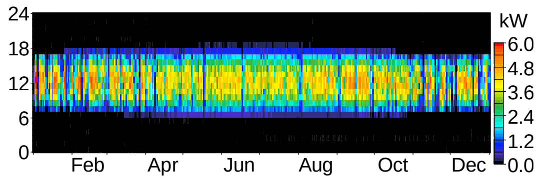


Fig. 16. PV Output (Scenario 1)

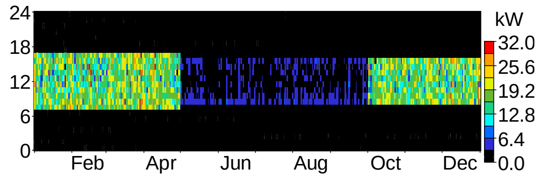


Fig. 17. Boiler Output (Scenario 1)

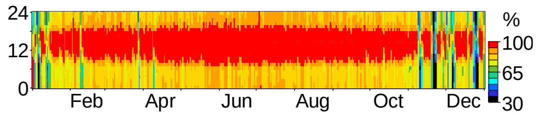


Fig. 18. Battery Bank State of Charge (Scenario 1)

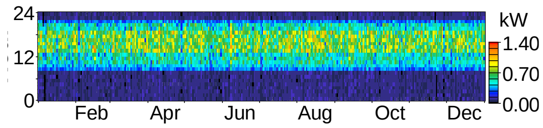


Fig. 19. Inverter Output (Scenario 1)

The charge level of the batteries in Figure 25 indicates that 22% of the time the batteries are fully charged. Battery losses in this scenario are 194 kWh/year and their lifetime is 7.01 years based on their performance. In the second scenario, because we have the conversion of AC to DC power (surplus electricity generated by the biomass generator), the rectifier has also entered into operation. The rectifier and inverter capacity factor is 0.1% and 17.5%, respectively. According to Figures 26 and 27, the maximum output of the inverter and rectifier is 1.33 kW and 0.24 kW, respectively, and the annual inverter and rectifier losses are 161 kWh and 1 kWh, respectively.

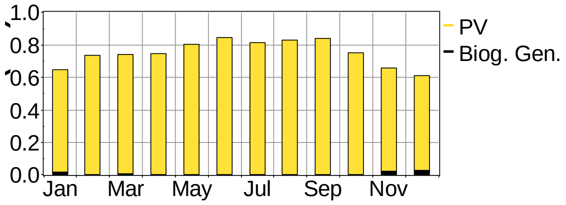


Fig. 20. Monthly Average Electric Production (Scenario 2)

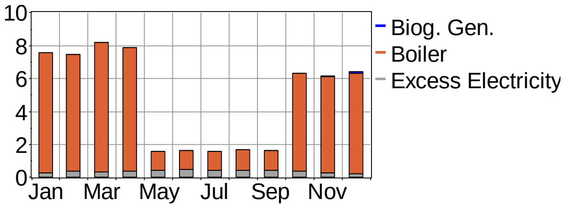


Fig. 21. Monthly Average Thermal Production (Scenario 2)

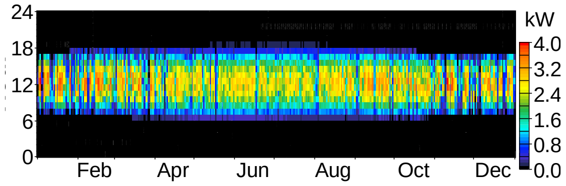


Fig. 22. PV Output (Scenario 2)

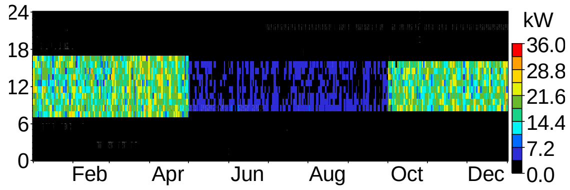


Fig. 23. Boiler Output (Scenario 2)

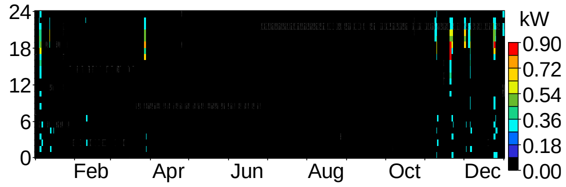


Fig. 24. Biogas Generator Output (Scenario 2)

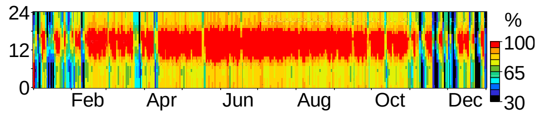


Fig. 25. Battery Bank State of Charge (Scenario 2)

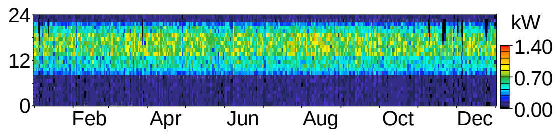


Fig. 26. Inverter Output (Scenario 2)

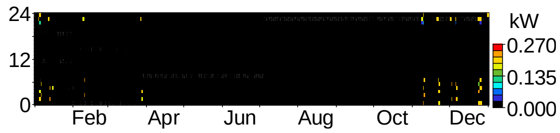


Fig. 27. Rectifier Output (Scenario 2)

In the third superior scenario, where 12% of the total load required is supplied by the biomass generator, according to Figures 28 and 29 all required electricity and 12% of the required heat (5234 kWh/year) are supplied by the biomass generator. In this scenario, there is no excess electricity to be converted to heat. The performance contour of the biomass generator in Figure 30 shows that there are 4061 hours of biomass generator operation during the year, which leads to the consumption of 22.7 tons of biomass. Based on this performance, the lifetime of the biomass generator is 3.69 years and its capacity factor is 38.3%. Boiler output power in Figure 31 shows that the boiler was on for 3160 hours during the year, which resulted in the consumption of 4737 liters of diesel. The performance of the battery charge in Figure 32 indicates that the maximum battery charge rate is 85%, which is about 7.5% of the year has this charge percentage. Another point that can be seen from Figure 32 is that unlike the previous two scenarios, the maximum charge is in the dark because the power consumption is less and the required heat is zero. This is clearly seen in Figures 33 and 34, which show the inverter and rectifier performance for this scenario, respectively. In this scenario, based on Figures 33 and 34 for the inverter and rectifier, the maximum power output is 0.77 and 0.29 kW, respectively, the capacity factor is 9.4 and 11.6%, respectively, and the annual losses are 43 and 54 kWh, respectively.

In the fourth top scenario, there is the highest percentage of electric and thermal charge supply with 34% by renewable energy. In this scenario, 16,329 kWh of electricity is supplied annually by solar cells and 2972 kWh of electricity is supplied by the biomass generator, of which 83.4% is surplus electricity. Figure 35 shows the proportion of 85% of electricity generated by solar cells and the rest by a biomass generator. Figure 36 shows the amount of heat supply by each equipment. It is known that with 52% of the heat produced, ie 29579 kWh/year, the boiler has the largest share. Then surplus electricity with 28% and biomass generators with 19% are in the next ranks. According to the results, there is 14553 kWh/year, which means 34.7% of excess heat. Figure 37 shows the output power contour of solar cells. The average output power is 44.7 kWh/day, the capacity factor is 18.6% and the number of hours of solar power generation is 4384 hours. Figure 38 shows the output power of the biomass generator, which often does not require a biomass generator during sunny hours. With a performance of 4857 hours per year and a capacity factor of 17%, the lifetime of the biomass generator is 3.09 years. Also, the maximum electricity output is 1.21 kW.

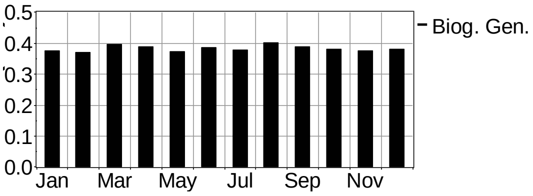


Fig. 28. Monthly Average Electric Production (Scenario 3)

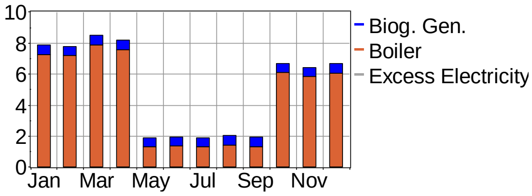


Fig. 29. Monthly Average Thermal Production (Scenario 3)

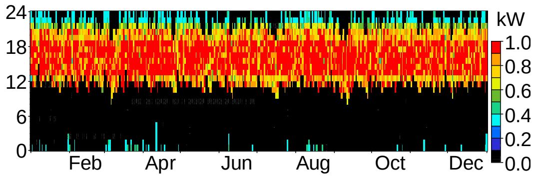


Fig. 30. Biogas Generator Output (Scenario 3)

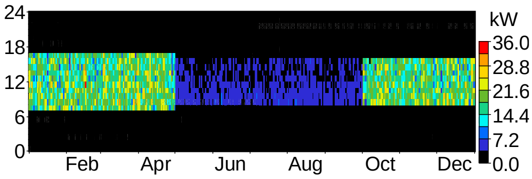


Fig. 31. Boiler Output (Scenario 3)

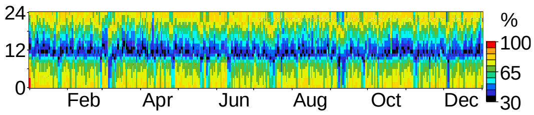


Fig. 32. Battery Bank State of Charge (Scenario 3)

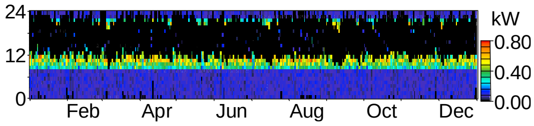


Fig. 33. Inverter Output (Scenario 3)

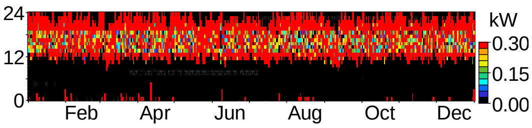


Fig. 34. Rectifier Output (Scenario 3)

Figure 39 shows the output power of the boiler, according to which the boiler works 2547 hours per year and consumes 3536 liters of diesel per year and has a maximum output of 31.2 kW. The inverter performance meter in Figure 40 shows that 4218 hours of DC to AC power conversion has occurred and the maximum output power of the inverter is 1.33 kW. Capacity factor and losses are 11% and 101 kWh/year, respectively.

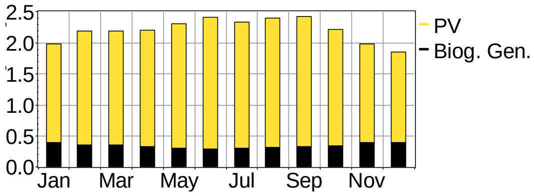


Fig. 35. Monthly Average Electric Production (Scenario 4)

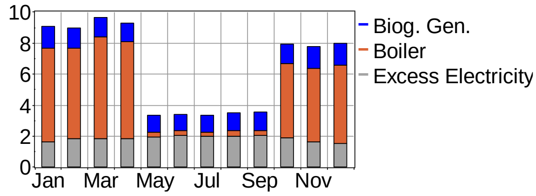


Fig. 36. Monthly Average Thermal Production (Scenario 4)

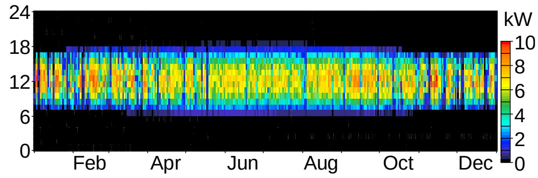


Fig. 37. PV Output (Scenario 4)

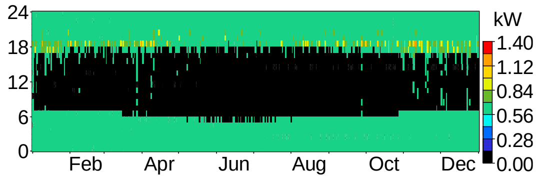


Fig. 38. Biogas Generator Output (Scenario 4)

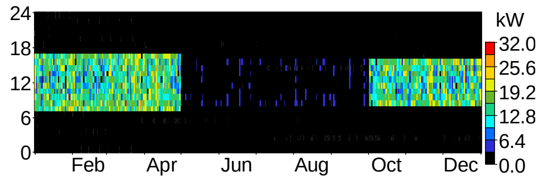


Fig. 39. Boiler Output (Scenario 4)

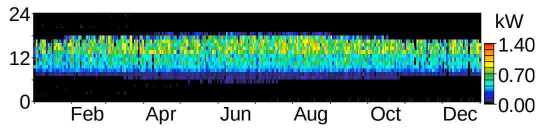


Fig. 40. Inverter Output (Scenario 4)

In the fifth superior scenario, 24% of the electrical and thermal needs are generated by the biomass generator. During the year, according to Figure 41, 5567 kWh/year of surplus electricity is generated, of which 2465 kWh is surplus and is converted to heat according to Figure 42. The rest of the required heat is generated by the boiler (34482 kWh/year) and the biomass generator (19639 kWh/year). In total, there is an annual excess heat of 14,610 kWh/year. Figure 43 shows the output power of the biomass generator, which shows the performance of 8759 hr/year, lifetime of 1.71 years, capacity factor of 31.8% and maximum output power of 1.33 kW. According to Figure 44, which shows the power of the boiler, the boiler worked 3114 hours during the year and consumed 4123 liters of diesel and the maximum output was 31.8 kW.

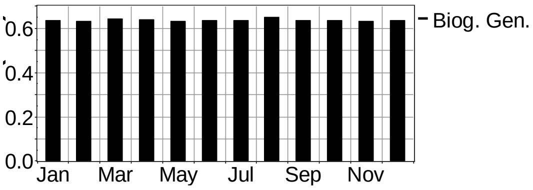


Fig. 41. Monthly Average Electric Production (Scenario 5)

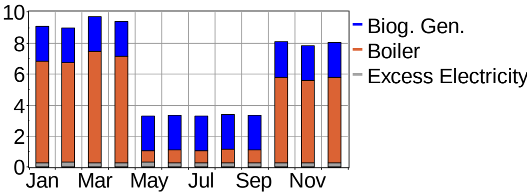


Fig. 42. Monthly Average Thermal Production (Scenario 5)

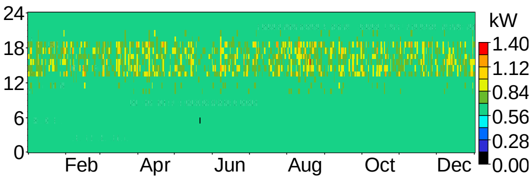


Fig. 43. Biogas Generator Output (Scenario 5)

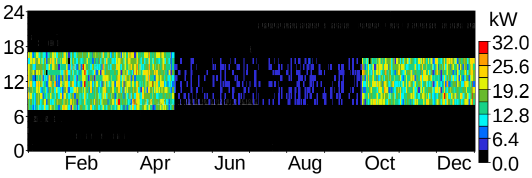


Fig. 44. Boiler Output (Scenario 5)

G) *Economic analysis*

The lowest cost per kWh of energy produced as shown in Figure 13 is for the first scenario, which is $ 0.354. For the next scenarios, respectively, 7.6%, 354%, 790% and 1370% of the cost price per kWh of energy production is more. In other words, it can be said that the first and second scenarios are cost effective and the other scenarios are not cost effective at all. As shown in Figures 45 and 46 for the first scenario, the main cost of the first scenario is for the battery ($ 3283) and then for the solar cells ($ 2428). Also, the main cost is related to the purchase of equipment ($ 4638) and then in the second place are maintenance costs ($ 1314). In the ninth and eighteenth years, two basic costs are imposed on the system, which are related to the replacement of batteries in this scenario. Figures 47 and 48 show the cost details for the second superior scenario. In this scenario, the cost of a biomass generator is almost equal to that of a solar cell, and the cost of batteries is still the highest. The noteworthy point in this scenario is the maintenance cost of the biomass generator, which is almost equal to the purchase cost. In the second superior scenario, in the eighth, fifteenth and twenty-second years, the lifetime of the batteries expires and therefore the cost of replacing them imposed a high financial load to the system.

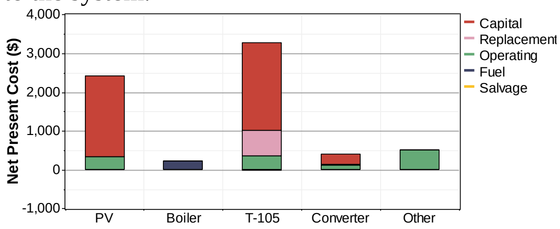


Fig. 45. Cash Flow Summary (Scenario 1)

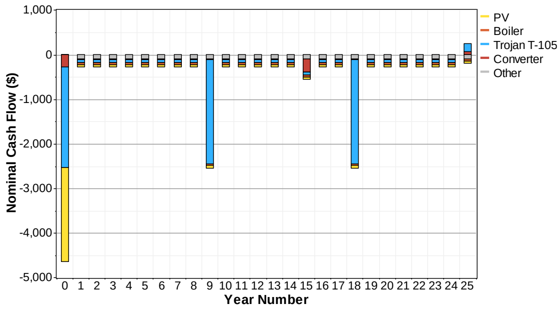


Fig. 46. Cash Flows (Scenario 1)

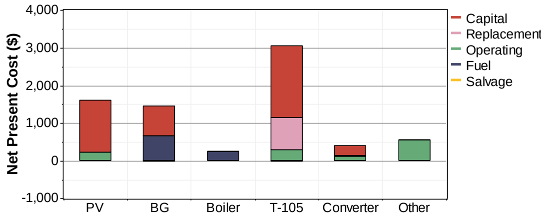


Fig. 47. Cash Flow Summary (Scenario 2)

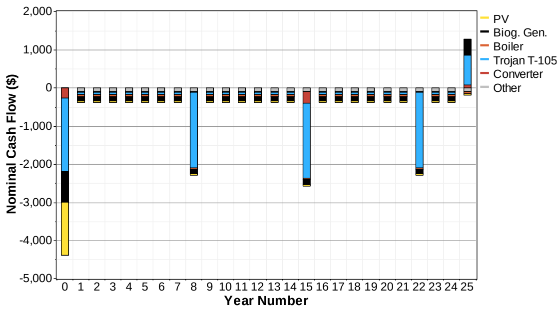


Fig. 48. Cash Flows (Scenario 2)

H) *Environment analysis*

The results of the emitted pollutants in the studied scenarios are given in Table 4. The results show that the major pollutant produced is carbon dioxide and then NOx is in the second highest emission.

Table.4.
Pollutants released in different scenarios by kg/year.

Scenario no.	*CO_2*	*CO*	*Unburned hydrocarbons*	*Particulate matter*	*SO_2*	*NO_x*
1	11321	27.9	3.1	2.11	22.7	249
2	12254	30.3	3.35	2.28	24.6	270
3	12477	31.2	3.43	2.32	25.0	275
4	9319	23.7	2.58	1.74	18.7	206
5	10869	28.1	3.02	2.03	21.8	240

The results of Table 4 show that the top three scenarios in terms of environment are the fourth, fifth and first scenarios, respectively. The low emission rate in the fourth scenario is related to the high use of renewable solar and biomass energies.

I) Sensitivity analysis

The results of the sensitivity analysis for the existing conditions (average electrical load required 8.5 kWh/day and average thermal load required 115 kWh/day) are shown in Figure 49. From the results, it is clear that for radiation less than 5 kWh/(m^2-day), the optimal system includes a solar cell-biomass generator-battery, and for radiation higher than this amount, the optimal system is a solar cell-battery. It is also observed that by increasing the amount of radiation that leads to increased solar energy production, the cost per kilowatt hour of energy production is reduced. Another point is that the heat recovery ratio has no effect on the optimal system and the price per kWh of energy produced.

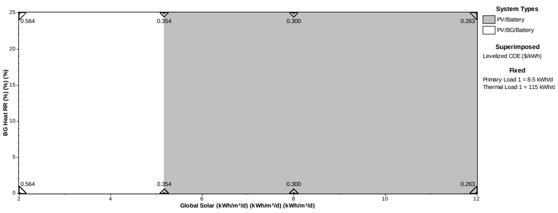


Fig. 49. Results of sensitivity analysis on solar radiation parameters and heat recovery ratio for current conditions

To investigate the uncertainties, the analyzes were repeated for three average electrical load values of 5, 8.5 and 12 kWh/day and three average thermal load values of 70, 115 and 160 kWh/day. The important point was that for all modes except the average electric charge equal to 5 kWh/day, for radiation less than 5 kWh/(m2-day) the optimal system is biomass generator-PV-battery and for more radiation the optimal system is PV-battery. For an average electric charge of 5 kWh/day as shown in Figure 50, the optimal system for all modes is PV-Battery, and the use of a biomass generator is in no way cost-effective.

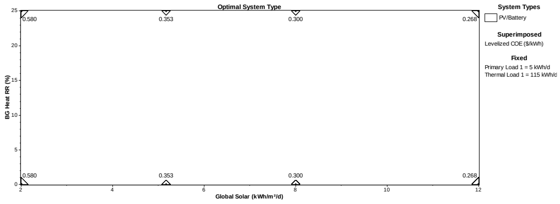


Fig. 50. Results of sensitivity analysis on solar radiation parameters and heat recovery ratio for variable conditions

7. Conclusion

Due to the importance of electricity supply to villages with special conditions that are cut off in winter due to snowfall and the management of renewable resources and increase social welfare, in the present work for the first time in Iran, technical-energy-economic-environmental analysis and Sensitivity analysis was performed. The software used was HOMER and the study site was Sar Agha Seyed village in Chaharmahal and Bakhtiari province. The system under study was responsible for the simultaneous supply of electricity and heat and included solar cells, biomass generator, battery and electric converter. Dump load was used to convert excess electricity into heat. Considering the penalties of pollutants produced by diesel fuel and considering the effect of temperature on the performance of solar cells and the use of up-to-date price data for equipment makes the results of the present work with high accuracy correspond to reality. Important results of the present work are:

- The optimal economic system includes 6 kW of solar panels, 13 batteries and 2 kW of electrical converters.
- The minimum cost per kilowatt hour of energy produced is $ 0.354.
- The optimal environmental system that has the highest percentage of renewable energy supply, includes 10 kW solar cells, 2 kW biomass generators and 2 kW electric converters.
- For radiation less than 5 kWh/(m2-day) is the optimal economic system PV-biomass generator-battery and for more radiation, PV-battery system is cost-effective.
- The results indicate the high role of dump load in heat supply so that the maximum heat supply by dump load with a rate of 16097 kWh/year is equivalent to 28% of the total heat required in the fourth scenario.
- The maximum battery charge is in the first scenario, so that 32% of the total time of the year, the batteries are 100% charged.
- The lowest rate of using the boiler to produce heat in the fourth scenario is 29579 kWh/year, ie 52% of the total heat required by the boiler.

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