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Research Article

Utilization of Animal Solid Waste for Electricity Generation in the Northwest of Iran 3E Analysis for One-Year Simulation

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Today, the use of renewable energy is increasing day by day. The most susceptible to renewable energy is biomass energy because it depends directly on the size of the population and does not have the problems of other renewable energies such as lack of access day and night and constant change throughout the year. For this reason, animal solid waste has been used in the research to supply electrical energy to the study area. In this regard, the amount of animal waste is considered as a source of biomass input energy. HOMER software was used to simulate the system under study. To better compare the competitiveness of this energy, photovoltaic systems and wind turbines have been used as different scenarios of electrical energy production in the study area. The results of scenario analysis showed that in all designed systems, the highest amount of energy production was in July and was related to the hottest season of the year. Among hybrid systems, the biomass system has a higher priority than other systems due to the minimum cost of energy production and total net present cost (NPC). The amount of exhaust gas from the biomass system reached 53.5 kg/yr and the biomass-wind and biomass-wind-solar systems reached 52.5 kg/yr and 52.2 kg/yr, respectively. The surplus generated electricity also increases from 2.91% to 6.65% from the biomass-wind system to the biomass-with-solar system.

1. Introduction

Limited energy resources and problems caused by the consumption of fossil fuels in the current situation have led all countries, especially developed countries, to consider replacing traditional energy sources with renewable alternatives [1, 2]. Implementing hybrid renewable energy systems (HRES) in geographically varied locations where grid expansion is not an economically viable option might boost the use of renewables [3, 4]. Additionally, the hybridization of different energy resources addresses the intermittent nature of renewables, ensuring effective exploitation of available resources [5, 6]. However, the proper sizing of the HRES is critical for the model's economic rationale [7].

Several recent HRES-based investigations undertaken by different scholars throughout the world yielded useful findings [8–12]. El-Sattar et al. [13] investigated three different HRES integrating a biomass system with a photovoltaic (PV), wind turbine (WT), and battery (BAT) components for a remote area Abu-Monqar village, Egypt. They applied different optimization techniques to ensure that all load demand is met at the minimum cost of energy (COE). Tiwary et al. [14] investigated the utilization of domestic biowaste in HRES for community-scale operations both in the UK as well as Bulgaria. According to their research, biogas generators provide a significant proportion of electricity generation, accounting for up to 60–65 percent of the total. Al-Najjar et al. [15] examined PV, biomass, and a grid-based HRES to electrify a residential zone in Gaza City. The HRES's net present cost (NPC) and cost of energy (COE) were reported to be \$2.30 million and \$0.438/kWh, respectively. Al-Buraiki and Al-Sharafi and Al-Buraiki [16] investigated PV, wind, and battery-integrated HRES in different areas of Saudi Arabia. Li et al. [17] investigated the technoeconomic feasibility assessment of an off-grid HRES integrated with WT/PV/BAT/biomass for remote village electrification in China. Their investigation revealed that the proposed HRES yields an optimized COE of \$0.201/kWh. Ramos-Suáreza et al. [18] investigated the possibility of building a biogas project in the Canary Islands using 546 numbers of animal farms. They reported that the potential greenhouse gas emissions savings could reach up to 55,745.1 tCO_2/year. Gonzalez et al. [19] conducted economic and environmental assessments on a grid-connected PV-WT-biomass-based HRES, as well as multi-objective genetic algorithm optimization. Suresh et al. [20] examined off-grid HRES comprising of a solar-wind-biomass-biogas-fuel cell and a battery for electricity in a rural region of Karnataka, India. The HRES was shown to be very sensitive to changes in biomass price, ranging from 0.3 to 0.5 \$/ton, with the least COE deviating between 0.214 and 0.215 \$/kWh. Murugaperumal et al. [21], on the other hand, demonstrated the optimal design and techno-economic assessment of HRES based on PV-WT-biogas for rural electrification in India's remote Korkadu area. Their analysis found that the investigated HRES delivers an optimal COE of Rs13.71/kWh under combined dispatch methods.

Biomass-based power generation has gained a lot of traction in recent years in a number of countries [22]. Biogas generated from waste-derived biomass is a feasible renewable energy source that can be efficiently used in HRES to generate electricity. It can easily be produced by anaerobic fermentation of common biomass resources such as animal waste, agricultural residues, municipal solid waste, and industrial waste compounds. Biogas is ecologically benign owing to its minimal emission concerns, and it is typically constituted of CO_2 (35%), CH_4 (65%) and trace gases such as H_2S, N_2, and H_2 [23].

The total amount of agricultural waste is assessed to be 24.3 million tons that can be considered potential feedstock to produce 6,542 million m^3 of biogas, 2,443 million liters of biobutanol, and 2,082 million m^3 of biohydrogen. In addition, the biogas potential from livestock and slaughter wastes is estimated to be 11,523.84 and 16,026 million m3/year, respectively. The findings indicated that there is considerable potential for bio-power generation in Iran [24]. Biogas generation from animal waste might be a suitable choice for Iran because it offers several environmental and economic advantages. In this regard, Afazeli et al. studied Iran's biogas generation potential from livestock and slaughterhouse wastes [25]. They estimated that animal dung could generate 8,600 million m^3 of the biogas per year, whereas slaughterhouse waste could generate 54 million m^3 of the biogas per year.

Electricity generation from bioresources is an excellent option for transforming Iran's vast amount of waste into clean and usable energy. Despite the enormous potential for using biogas energy in the development of HRES, it is yet to be explored in Iran. In this research, an appropriate model for the exploitation of biomass resources with the priority of animal waste has been considered. To the best of the author's knowledge, the integration of biogas energy, the solar, wind, and battery-based HRES has not been thoroughly investigated. This study describes the development of a biogas generator, PV, WT, and battery-based HRES for a neighbourhood in Bile Savar, Iran. To achieve this purpose, the proposed HRES has been constructed with the studied area's environment and the types of accessible local animals in mind. The HOMER software has been utilized for optimal sizing of the system.

The aim of this study is to achieve an economically optimal hybrid system with high reliability and to consider environmental constraints from an operational point of view. The cost of the system is the sum of the cost of the photovoltaic system, the cost of the wind turbine, biomass, and the cost of the converter.

2. Materials and Methods

2.1. Area of Study. The selected location for this study is in Bile Savar, Iran. Bile Savar city is one of the cities of Ardabil province. To calculate the biogas potential of animal waste, the amount of waste and waste available in the area should be estimated. For this reason, information about the number of livestock by the livestock type (Table 1) in Bile Savar city was prepared from the statistics of Ardabil Jihad Agricultural Organization and Statistics Centre of Iran. The average monthly production waste of each livestock (Table 2) was also extracted from the sources.

2.2. System Model. HOMER software is one of the simulation models. This software can provide the possibility of rearranging production systems for the loads defined in the system. HOMER software is designed to use renewable energy, save energy, reduce greenhouse gas emissions, and provide intelligent designs and equipment optimization while preserving the environment and reducing networking costs. HOMER software has been used to model the studied system.

2.3. Governing Equations. In the present work, solar cells, wind turbines, biomass generators, and batteries have been used to design the hybrid system. Therefore, the governing equations of the performance of this equipment are given in equations (1)–(4), respectively [26–29].

Table 1: The amount of daily production waste of each type of livestock in the Bile Savar.

Type of livestock	Number (head)	Amount of waste production (tons per year)	tons per year
Purebred cattle and calves	9627	1000	9627000
Traditional cattle breeding	17390	9	147510
Sheep and goats	4183600	1.2	5020320

Table 2: Average monthly production waste per livestock.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Ton	1477.060	1485.020	1488.280	1505.170	1512.360	1504.960	1442.500	1432.500	1412.500	1404.080	1382.150	1352.230

$$P_{pv} = Y_{pv} \times f_{pv} \times \frac{\overline{H_T}}{H_{T,\mathrm{STC}}}, \tag{1}$$

$$P_{\mathrm{WTG}} = \frac{\rho}{\rho_0} \times P_{\mathrm{WTG.\,STP}}, \tag{2}$$

$$\eta_{\mathrm{Biog.gen.}} = \frac{3.6\, P_{\mathrm{Biog.gen.}}}{\dot{m}_{\mathrm{Biog.}}\, \mathrm{LHV}_{\mathrm{Biog.}}}, \tag{3}$$

$$P_{\mathrm{batt.}\,c\max} = \frac{\mathrm{Min}\left(P_{\mathrm{batt.}\,c\max.\mathrm{kbm}}, P_{\mathrm{batt.}\,c\max.\mathrm{mcr}}, P_{\mathrm{batt.}\,c\max.\mathrm{mcc}}\right)}{\eta_{\mathrm{batt.}c}}. \tag{4}$$

In the optimization phase by HOMER software, the planned designs are thoroughly examined to achieve the maximum amount of energy and cost savings [20]. Economic calculations in the software are based on total NPC (equation (5) and COE equation (6)) parameters [30, 31]. The most optimal system has the lowest total NPC [32, 33].

$$\mathrm{NPC} = \frac{C_{\mathrm{ann,total}}}{\left(i\,(1+i)^N\right)/\left((1+i)^N - 1\right)}, \tag{5}$$

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

2.4. The System under Study. Figure 1 simulates the system studied in HOMER software. In microgrids, energy is generated solely by the inflexible sources of wind turbines, photovoltaics and biomass, and energy storage (battery bank) is used to balance production and consumption. Information and technical and economic specifications of the components of the simulation microgrid are in accordance with Table 3.

In the present study, 4 scenarios have been examined that the purpose of this scenario is to achieve the highest amount of electrical energy production by considering the lowest investment cost.

Biomass (Scenario 1)

Wind turbine-biomass-converter (Scenario 2)

Solar-wind turbine-biomass-converter (Scenario 3)

Solar-wind turbine (Scenario 4)

Due to the fact that each region needs a special hybrid system and a certain number of components, depending on the wind, solar, and load conditions and the desired load, it is necessary to conduct feasibility studies for each region separately. In other words, it is necessary to examine different systems in terms of economics and other parameters in their design for the region or regions in question and select the best case. In this study, feasibility studies for different hybrid systems have been performed and the results have been presented.

3. Results and Discussion

3.1. Scenario 1: Biomass. Table 4 compares the proposed systems for the target area. As can be seen, the combined biomass system has a higher priority than other systems, with the lowest energy production cost and final net cost. The reason for this is the low initial cost of the system based solely on biomass generators compared to other systems under study.

The energy production by the most cost-effective system in different months of the year is shown in Figure 2. The data show that the highest amount of energy production was from mid-May to mid-September and the maximum amount in this period is in July and August.

In the most cost-effective system, having environmental pollution with the amount of 53.5 kg/yr carbon dioxide emissions, the amount of pollution is more than other systems. Table 5 shows the pollutants produced for the optimal economic system. As it turns out, the major pollutants are related to CO_2, followed by CO and NO_x.

3.2. Scenario 2: Utilization of Biomass with Economic Optimization of Wind Turbine. In this scenario, the surplus electricity production amount of 6,798 is equal to 2.91%. The lowest electricity production occurred in February and the highest production occurred in July. Figure 3 and Table 6 show the results of electricity generation by different energy sources. According to the results, 95.53% of electricity is generated by biomass generators and the rest by wind turbines, and 233798 kWh of electricity are generated annually by the system under study. In this case, carbon dioxide emissions are reduced by 1 kg/yr to 52.5 kg/yr compared to the first scenario. The results of producing different pollutants for this scenario are given in Table 7.

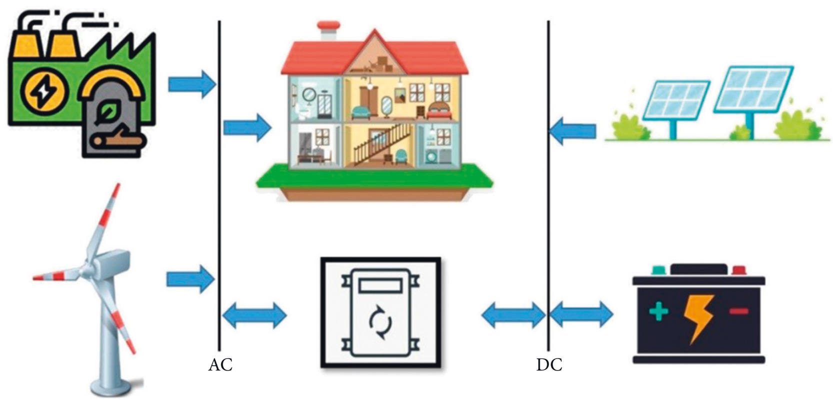

Figure 1: The schematic representation of the system under study.

Table 3: Technical and economic information of the equipment used in the solar-diesel system [28, 29].

Equipment	Cost ($) Capital	Replacement	O & M	Size (kW)	Other information
PV	2000	2000	10	0–600	Lifetime: 20 years, derating factor: 80%
Generic 1 kWh lead acid	1200	1100	50	0–1200	Nominal voltage: 2, nominal capacity: 1.03 kWh, lifetime throughput: 843 kWh
Biomass generator	300	270	0.1	0–100	Lifetime: 15000 hr, minimum load ratio: 25%
Converter	300	300	0	0–100	Lifetime: 15 years, efficiency: 95%
Generic 10 kW	10,000	8,000	1,500	10	Lifetime: 20 years, hub height: 24 m

Table 4: Comparison of proposed systems for the area under study.

Combined system	Solar panel (kW)	Wind turbine	Biomass (kW)	La Asm	Converter (kW)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Total fuel (Tons/yr)
Biomass (scenario 1)	—	-	73	—	—	991,012	74,965	21.900	102
Wind turbine-biomass-converter (scenario 2)	—	1	73	—	—	1.02 M	76,549	31,900	100
Solar-wind turbine-biomass-converter (scenario 3)	10.7	1	73	—	1.55	1.04 M	76,668	53,781	99.3
Solar-wind turbine (scenario 4)	501	28	—	1,192	78.2	4.81 M	160,604	2.74 M	—

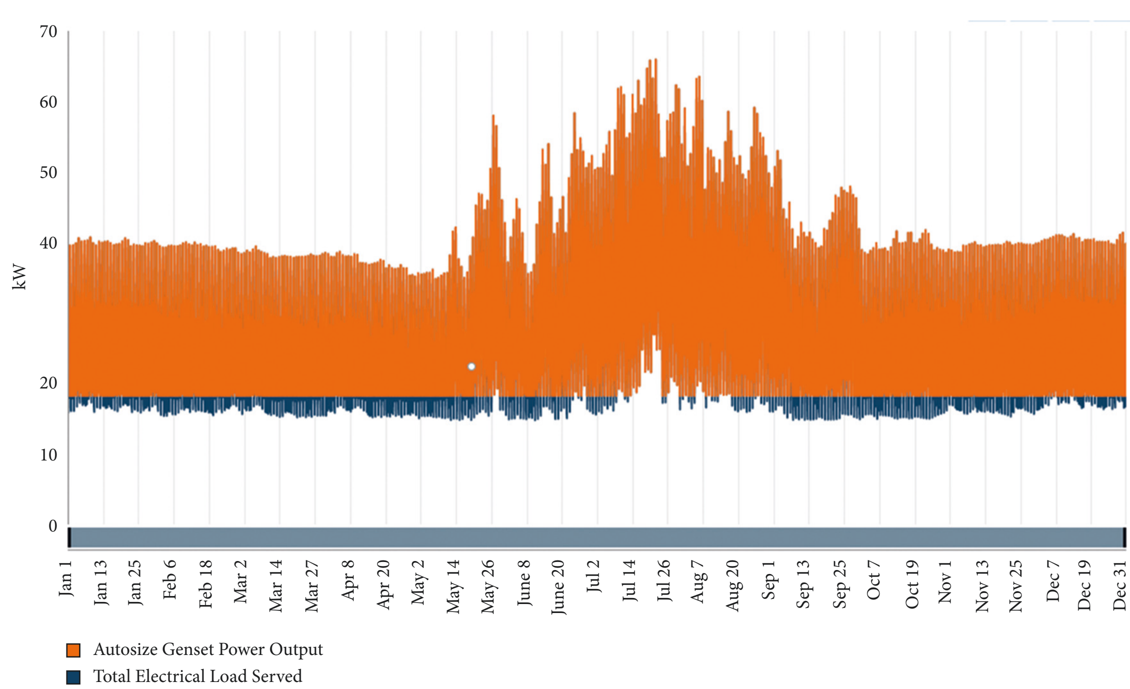

Figure 2: Energy production in different months of the year (Scenario 1).

Table 5: Properties data of the system under study for Scenario 1.

Quantity	Value	units
Carbon dioxide	53.5	kg/yr.
Carbon monoxide	1.69	kg/yr.
Unburned hydrocarbon	0.0736	kg/yr.
Particulate matter	0.0102	kg/yr.
Sulphur dioxide	0	kg/yr.
Nitrogen oxides	1.58	kg/yr.

Table 7: Properties data of the system under study for Scenario 2.

Quantity	Value	units
Carbon dioxide	52.5	kg/yr.
Carbon monoxide	1.65	kg/yr.
Unburned hydrocarbon	0.0722	kg/yr.
Particulate matter	0.01	kg/yr.
Sulphur dioxide	0	kg/yr.
Nitrogen oxides	1.55	kg/yr.

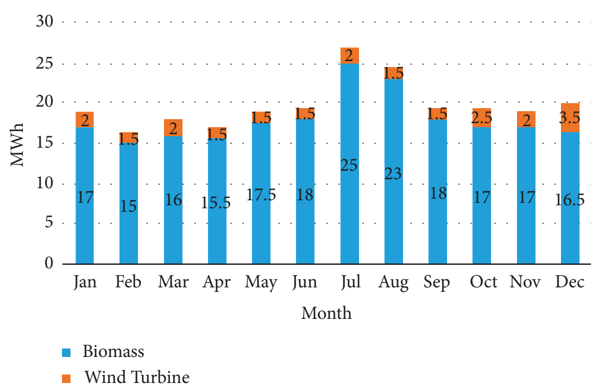

Figure 3: Monthly electric production in different months of the year (Scenario 2).

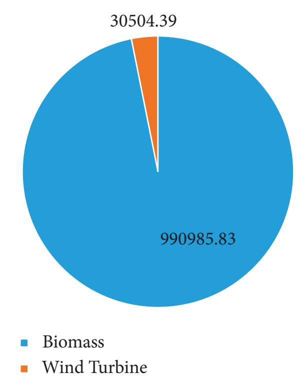

Figure 4: The cost summary of the scenario 2.

Table 6: The amount of energy fraction extracted in different ways.

Biomass (kWh)	223,356 (95.5%)
Wind turbine (kWh)	10,443 (4.5%)
Total	233,798 (100%)

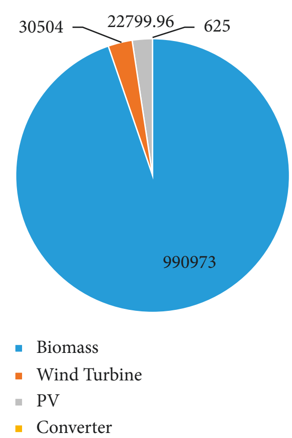

Figure 5: The cost summary of the Scenario 3.

Figure 4 summarizes the financial costs for the system under consideration. The results show that the biomass generator with $ 990,985.8 is the bulk of the cost and the wind turbine with a cost of $ 30,504.4. The important point that can be seen from Figure 4 is that the cost of salvage is -3326 $. This is because at the end of the project life, the equipment is still usable and can be sold second-hand. Another important point is the very high maintenance cost of the biomass generator, which is about 81% of the total system cost, and it is recommended to reduce the system costs in this regard.

3.3. Scenario 3: Concomitant Use of Wind, Solar, and Biomass to Reduce Environmental Pollution.

Figure 5 shows the cost of installation, replacement, repair, and maintenance of the system, the cost of fuel, and the cost of selling the equipment for scenario 3. The total cost of the system equipment is 53,780$, the replacement is 145,737$, and the operating and maintenance cost of the system is 847,464$.

According to the results of Figure 5, the highest price is related to biomass generators, wind turbines cost the second highest price; solar cells and electric converters are the next in rank. Figure 6 shows the monthly electricity generation for the third scenario. Based on the results of Figure 6 and Table 8, which show the details of electricity generated for one year, biomass generators generate d 90.5%, solar cells

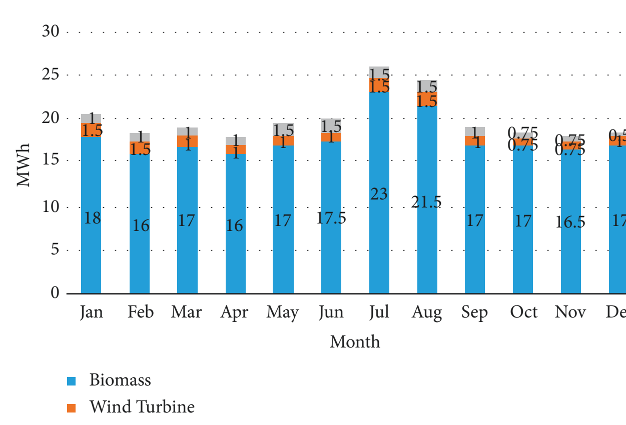

Figure 6: Monthly electric production in different months of the year (Scenario 3).

Table 8: The amount of energy fraction extracted in different ways.

Solar (kWh)	12,752 (5.24%)
Biomass (kWh)	220,147 (90.5%)
Wind turbine (kWh)	10,443 (4.29%)
Total	243,341 (100%)

Table 9: Properties data of the system under study for Scenario 3.

Quantity	Value	Units
Carbon dioxide	52.2	kg/yr.
Carbon monoxide	1.64	kg/yr.
Unburned hydrocarbon	0.0717	kg/yr.
Particulate matter	0.00996	kg/yr.
Sulphur dioxide	0	kg/yr.
Nitrogen oxides	1.54	kg/yr.

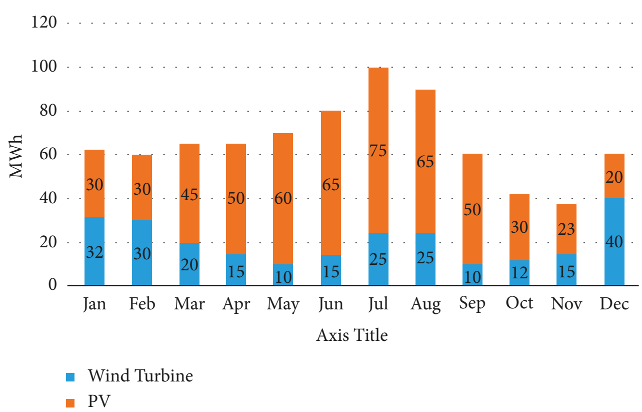

Figure 7: Monthly electric production in different months of the year (Scenario 4).

5.24%, and wind turbines 4.29% of the total 243341 kWh of electricity generated annually. Also, according to the results of Figure 6, the role of solar cells is more in the warm seasons of the year, but wind turbines have produced almost the same constant electricity throughout the year.

In this scenario, the surplus electricity production amount is 16,171 kWh, equivalent to 6.65%. According to Figure 6, the lowest electricity production occurred in February and the highest production occurred in July. In this case, carbon dioxide emissions are reduced to 52.2 kg/yr. The details of the pollutants produced for the third scenario are shown in Table 9.

3.4. Scenario 4: Hybrid Wind Turbine with PV. In this scenario, the surplus amount of 639,508 is equal to 71.9%. According to Figure 7, the lowest electricity generation occurred in November س and the highest production occurred in July. From the results of Figure 7 and also Table 10, it can be seen that most of the generated electricity, i.e., 67.1%, is generated by solar cells and the remaining 32.9% by wind turbines. In January, February, and November, wind power generation is almost equal to solar power, and in December, wind power generation is higher than solar power. Figure 8 shows the cost summary of Scenario 4.

Table 10: The amount of energy fraction extracted in different ways (Scenario 4).

Solar (kWh)	59,844 (67. 1%)
Solar (kWh)	10,443 (32. 9%)
Solar (kWh)	243,341 (100%)

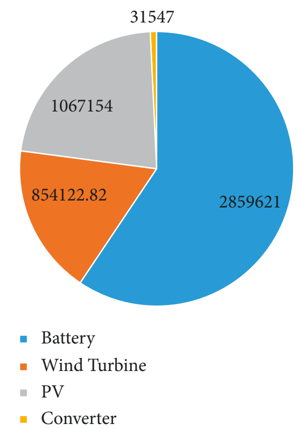

Figure 8: Monthly electric production in different months of the year (Scenario 4).

According to Figure 8, the total cost of system equipment is $2,736,230, replacement cost is $1,047,251, and the system operating and maintenance cost is $1,378,226. In this scenario, the highest cost is related to energy storage batteries, so that it accounts for about 60% of the total system cost. Solar cells, with a total cost of $1067,154, are in the second place, and wind turbines with $854,122 are in the third place, with the highest system costs.

4. Conclusions

In this paper, a study has been carried out to achieve an economically and ecologically optimal hybrid system using animal waste in the Bile Savar area with HOMER software. To supply the energy, four different scenarios have been considered, of which the first scenario is using biomass for the required load, the second scenario is using biomass with economic optimization of a wind turbine, and the third scenario is the combined use of wind, solar biomass to reduce environmental pollution, and scenario 4 is the combined use of wind and solar energy. The analysis of these scenarios showed that in all the designed systems, the highest amount of energy production was in July and related to the hottest season of the year. Among systems under study, the biomass system has a higher priority than other systems with the lowest energy production cost and total net present cost. It was also observed that among the compounds and exhaust gases from the designed systems, carbon dioxide gas is the most common cause of pollution. The amount of exhaust gas from the biomass system reached 53.5 kg/yr and the biomass-wind and biomass-wind-solar systems reached 52.5 kg/yr and 52.2 kg/yr, respectively. The surplus generated electricity also increased from 2.91% to 6.65% from the biomass-wind system to the biomass-with-solar system.

Abbreviations

P: Power
P: Density
Y: Area
f: Shadow factor
H: Radiation intensity
LHV: Lower heating value
C: Cost
NPC: Net present cost
COE: Cost of energy
i: Interest
N: Year
E: Energy

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Additional Points

The amount of electrical energy produced from animal waste was investigated. Different scenarios were evaluated to maximize the production of electrical energy from renewable energies. The optimal size of equipment needed to generate electrical energy was examined with economic, environmental, and energy approaches.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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