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Feasibility Study of Renewable Energy Generation Opportunities for a Dairy Farm

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ABSTRACT

The current study investigated the feasibility of renewable energy harvesting to meet the energy need of a dairy farm in Shahroud, Iran. Therefore, considering the available renewable resources including solar, wind, and biomass in the site and the electrical demand of the farm, the techno-economic and environmental analyses were carried out. By using Homer software, the optimized system was selected. It was shown that although there was wind potential within the farm site, the most economical system would be a system consisting of a 100 kW biomass power plant and a 169 kW PV plant. Furthermore, by using RETScreen software, the economic and environmental analyses for the selected system were carried out. The simple and equity paybacks were 5.8 and 4.2 years for the proposed system, which confirmed the economic feasibility of the proposed system. Moreover, the gross annual GHG emission would be reduced by 91.5 %. The techno-economic and environmental analyses conducted in the current paper confirmed that the proposed system could be easily extended for other dairy farms, which resulted in a significant increase in the energy ratio of the dairy farms.

1. INTRODUCTION

While the energy demand rises rapidly with population growth, environmental concerns such as global warming and the emission of greenhouse gases have attracted much attention toward the use of clean energies [1,2]. To deal with this problem globally, the Paris agreement was signed by 195 UNFCCC members and 170 countries have become a party to it. The goal of the agreement is to hold global warming less than 2 C and to pursue efforts to restrain it below 1.5 C [3].

The selection of different renewable energies for a site is much dependent on the environmental conditions and the availability of the primary resources and the related challenges. For instance, arid regions due to great solar potential and land availability are favorable for mounting large-scale solar installations [4-6]. However, regarding the literature, dust accumulation on PV surfaces and transition losses are among the most significant challenges in developing the PV systems [7-11]. To overcome the dust accumulation, several cleaning methods were introduced in the literature [12-14]. While the Distributed generation (DG) was introduced to solve the transition lost challenges [15], resulting in better economic feasibility for the generation systems [16-20]. Moreover, energy policies play an essential role in the development of renewable energies [21,22]. Considering this fact, Zandi et al. [23] assessed the economic policies with the aim of growing the DG capacity of PV systems in the household sector.

Given the renewable resources available to a site, a hybrid system could be used to provide electricity. Recently, several studies have been done to make renewable energy harvesting more feasible both technically and economically [24-27]. The energy ratio in a farm is defined as the ratio of the equivalent output energy (containing the biomass and the products) to the input energy (providing electricity, fossil fuels, the human resources, feed intake, etc.). In general, the energy ratio of dairy farms in Iran is between 30-38 %. Although this ratio is usually higher than 200 % for the agricultural farms [28], this is because agricultural farms use renewable energy resources. Therefore, by using renewable energy resources, besides reducing the emission of greenhouse gases and the input energy demand, the economic feasibility of a dairy farm and its energy ratio will be improved significantly.

In recent years, many studies have been conducted to help meet the energy demand of a dairy farm using different technics. For instance, Minnaert et al. [29] suggested a wireless optimal energy storage solution using supercapacitors to help to mitigate the high energy consumption of the on-cow components in a dairy farm. In another study, in order to determine the cooling savings and mitigate the energy demand in a dairy farm, Mhundwa et al [30] introduced a low-cost empirical model. Their results indicate an average of a 39.6 % reduction in energy demand for the milk cooling process on a dairy farm. Furthermore, renewable energy harvesting technics on dairy farms were also proposed as a great solution toward overcoming energy demand and offering a sustainable future. In this regard, a 50 kWp PV power plant was experimentally investigated to supply electricity to a dairy farm on Fota Island, Cork, Ireland [31]. Moreover, the feasibility of biogas plants [32] and hybrid renewable energy systems [33] was also studied in South Africa. These studies confirm the importance of renewable energy harvesting strategies. However, it should be noted that in order to achieve the best result, the optimized energy generating system regarding the techno-economic and environmental aspects should be considered at each site.

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In this regard, in the current study, the feasibility study of harvesting renewable energies to provide electricity for a dairy farm in Shahroud, Iran is investigated. The novelty of the current work is that by considering the local availability of solar, wind, and biomass resources, energy generation opportunities and their corresponding financial implications will be assessed for the case study site, and the optimized capacity share will be provided.

2. METHODOLOGY

To investigate the feasibility of the proposed system and optimizing the capacity share of each energy generation system, both RETScreen software and Homer software were used. The HOMER model (Hybrid Optimization of Multiple Energy Resources) greatly simplifies the task of designing hybrid renewable microgrids, especially in the case of variable renewable resources or loads. In order to design a system using HOMER, the following steps should be implemented in order.

1. Defining the power system
2. Defining the site load
3. Defining the renewable energy resources
4. Defining the fossil fuel costs
5. Defining economic factors
6. Defining system equipment and components
7. Calculating the results

The RETScreen software allows for the comprehensive identification, assessment, and optimization of the technical and financial viability of potential renewable energy, energy efficiency, and cogeneration projects and for the identification of energy savings/production opportunities. In order to design a system using RETScreen, the following steps should be implemented in order:

1. Defining the site location and facilities
2. Defining system equipment and components
3. Defining the renewable energy resources
4. Defining economic factors
5. Defining the emission indicators
6. Defining the financial risks
7. Calculating the results

In the HOMER software, by considering all the technically possible combinations of the energy system (for instance, different renewable energy resources, connection to the grid, different capacities of each resource, etc.), the best system regarding the economic aspects in the lifetime of the system should be introduced. Therefore, in the HOMER software, the economic parameters were used to define the optimized system, and the proposed system should be the best candidate regarding the economic parameters.

The RETScreen software was not used for optimization and was just used to investigate the financial viability and environmental analysis of the proposed system by the HOMER software and calculate the key financial and environmental indicators in this regard.

In the following part, first, the site climatology is described. Then, the detailed information regarding the available renewable energy resources and the electrical demand of the farm will be provided. Finally, the proposed generation system will be simulated and optimized.

2.1. Site climatology

The farm is located in Shahroud, Semnan Province, Iran. The city is situated about an altitude of 1345m at 36°25'N latitude and 55°01'E longitude. Shahroud has a cold desert climate (Köppen climate classification BSk) with hot summers and cold winters [35]. Figure 1 shows the monthly average temperature of the selected site.

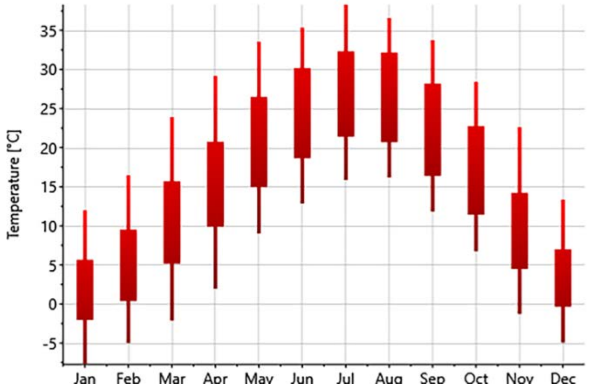

Figure 1. The monthly average of ambient temperature in the site [34].

2.2. Available renewable energy resources

As previously mentioned, solar, wind, and biomass resources are favorable resources on the site. Therefore, Figure 2 and Figure 3, respectively, illustrate the solar radiation and the average wind speed throughout the year. Figure 2 and Figure 3 show potentials for mounting rooftop photovoltaic panels and wind turbines on the site. Although further analysis is needed to determine whether it will be economically feasible to install PV panels and wind turbines on this site. Besides solar and wind, since the selected location is a dairy farm with a herd size of seven hundred, biomass will be a significant renewable energy resource. Table 1 presents the potential energy output based upon the annual waste of one animal [36].

Therefore, for the case study, an operation consisting of 700 dairy cows, the potential electricity generation from the herd's manure would be around 858900 kWh per year. Considering these renewable energy resources and the electrical demand within the farm, the optimized share capacity of primary resources could be calculated. Therefore, in the next part, the electrical need of the farm will be presented in detail.

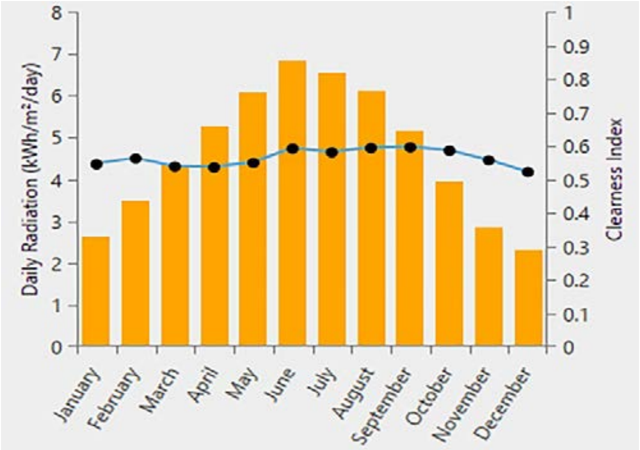

Figure 2. The monthly average of daily radiation and clearness index [34].

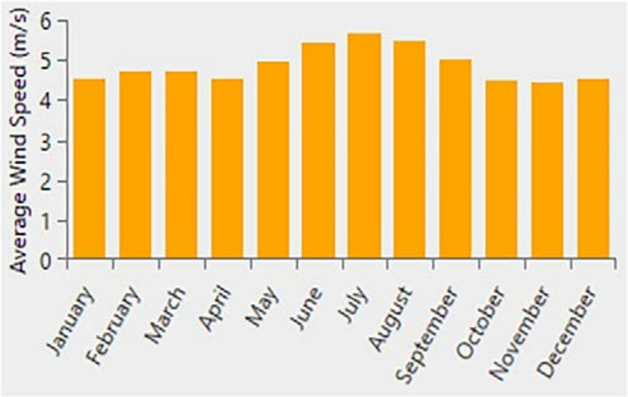

Figure 3. The monthly average of wind speed on the site [34].

Table 1. Manure energy potential per animal of different livestock [36].

Livestock type	Manure excreted (kg/day)	Biogas production (m^3/day)	Electricity potential (kWh/year)
Beef	24	1.1	663
Dairy	62	2.01	1227
Piglet	3.5	0.16	98
Poultry (100 layers)	8.8	0.85	516

2.3. The electrical demand

In-situ measurements and historical billing records covering one year (dated between January 2018 and January 2019) were obtained to determine the electrical demand of the farm. For the in-situ measurements, by using several power meters, the daily electrical energy consumption of the dairy farm was measured. These measurements and the billing records were used to calculate the daily load profile and the monthly average consumption (Figures 4 and 5). Furthermore, as presented in Figure 6, the hourly load profile of the dairy farm was measured. Figure 4 details the average monthly electricity consumption over the billing history analysis per year. Figure 4 indicates that, on average, during March with 12,333 kWh electricity consumption, the farm reached its maximum electrical demands, while, during February, with 7627 kWh electricity consumption, it reached its minimum electrical demand. Figures 5 and 6 show the average daily load profile for each month and the hourly load profile of the dairy farm during the test year, respectively. As can be seen in these figures, due to the change in weather condition within a day and different activities in the dairy farm such as milking, cooling, heating, and cleaning, some variation could be seen in the hourly and daily load profile. However, since there was no unexpected accident during the test year, sharp deviations from the average could not be seen.

Furthermore, the histogram load profile of the dairy farm based on the historical billing analysis and the measurements throughout the studied year are illustrated in Figure 7. This histogram load profile shows the distribution of the electrical demand throughout the year. The figure indicates that although the electrical power demand of the farm reaches more than 30 kW in some rare cases, the power demand most of the time is between 10 and 20 kW. According to the on-site measurements and historical billing records, the total electricity consumed in the analysis year was found to be 122,918 kWh.

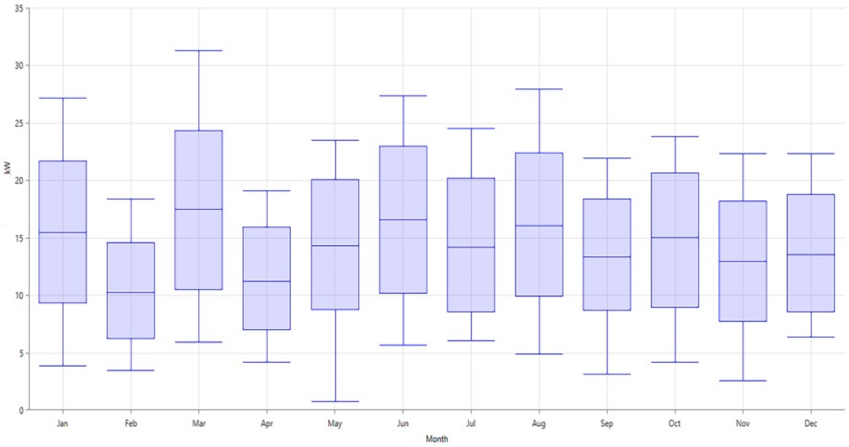

Figure 4. Average monthly electrical load based on historical billing analysis and measurements.

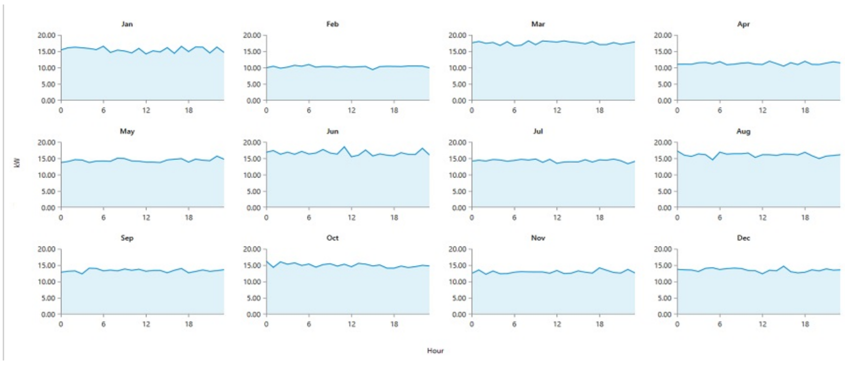

Figure 5. Average daily load profile for each month based on historical billing analysis and measurements.

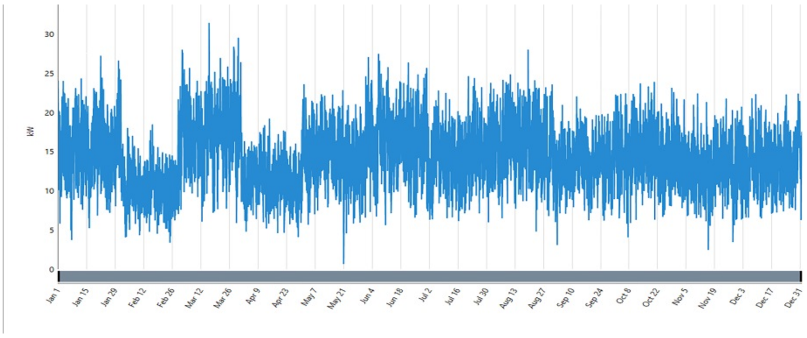

Figure 6. Hourly load profile of the dairy farm based on historical billing analysis and measurements.

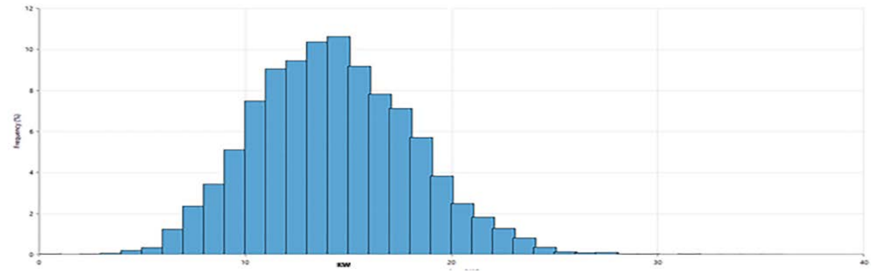

Figure 7. Histogram load profile of the dairy farm based on historical billing analysis and measurements.

The energy intensity on a dairy farm could be benchmarked as the factor of energy consumption regarding the herd size. In this case study, the energy intensity was calculated to be 175.6 kWh/head, given the total use of 122,918 kWh and the herd size of seven hundred (700). This data is critical for benchmark comparisons within the industry to facilitate future growth and information sharing.

2.4. Simulation and optimization of The proposed system

In this section, the optimization of the share-capacity of each available renewable energy source for the proposed system and the required technical specifications will be provided. For optimization, all the available resources and the electrical load were simulated. Figure 8 shows the schematic of the simulation system, which was optimized by Homer software. As can be seen in Figure 8, the proposed system was considered to be an on-grid system. This was done to reduce the uncertainty of the system and sell back the extra electricity to the grid. After finding the optimized combination of each resource share capacity, the economic and environmental analyses of the system were done using RETScreen software. In the next section, the simulation results will be presented and analyzed in detail.

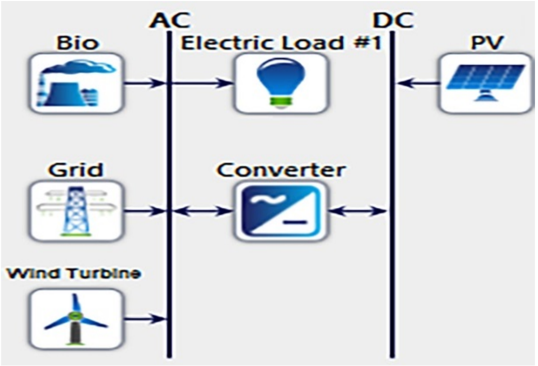

Figure 8. The schematic of the simulation system to be optimized using Homer software.

2.5. Economic key indicators

In order to investigate the economic viability of the proposed system, several key indicators of financial viability were calculated. Three of the best known are the Simple Payback, the Net Present Value (NPV), and the Internal Rate of Return (IRR). The NPV is the golden measure of discounted cash flow mechanics. It is the sum of all costs and benefits, adjusted according to when they occur in the project. If the NPV is positive, then the project is financially attractive at the discount rate specified by the user. The NPV can be calculated as follows:

$$NPV = I_0 + \sum_{t=1}^{n} \left(\frac{C_t}{(1+t)^t}\right) \tag{1}$$

where I_0 is the initial capital investment, C_t is the net cash flow in each subsequent period, i is the interest rate (discount rate), and n is the number of analysis periods. Note that I_0 will be a negative number since it represents a net cash outflow. If NPV is negative, then money will be more profitably invested elsewhere.

The Internal Rate of Return (IRR) is the discount rate that makes the net present value (NPV) of a project zero. The IRR denotes the maximum interest rate in which the project can still be carried out to create an NPV of 0. The IRR can be calculated as follows:

$$NPV = I_0 + \sum_{t=1}^{n} \left(\frac{C_t}{(1+t)^t}\right) = 0 \rightarrow i = IRR \tag{2}$$

Simple Payback (SPB) is the time needed to recover the initial investment through positive project cash flows. Prior to that point in time, the project has not yet recovered all of the initial investment. The exact (decimal) value of SPB (where the sum exactly matches the initial investment) can be calculated by linear interpolation using the following formula:

$$SPB = t - \left[\frac{\sum_t (C_i - C_0)_t}{\sum_t (C_i - C_0)_{t+1} - \sum_t (C_i - C_0)_t}\right] \tag{3}$$

With $\sum_{t}(C_i - C_0)_t < C_{o_o}$ and $\sum_{t+1}(C_i - C_0)_{t+1} > C_{0_0}$

where C_{it} is cash inflows in period t and C_{ot} is the cash outflows in period t. Equity Payback (EPB) accounts for the time value of money by discounting the net cash flows of each period before summing them up and comparing them with the initial investment.

3. RESULTS AND DISCUSSION

Using Homer software and simulating all the available renewable resources on the site and the electrical demand of the farm, the optimized system was obtained. The optimization was done so as to achieve the most economic system with 100 % renewable fraction. The renewable fraction is defined as the renewable originated share of the energy with respect to the whole energy delivered to the load. Considering these conditions, the optimized system among the 10934 feasible solutions consists of a 100 kW biomass power plant fed on the biomass produced by the dairy farm and a 169 kW PV plant. It should be noted that although the wind potentials on the site were considerable, considering the economic aspects, the most optimized system did not consist of any wind power plant. Therefore, a rooftop PV plant alongside an anaerobic digester was supposed to provide the entire electrical load of the farm and sell the excess electricity production to the grid. Based on the simulation results, the required area for the installation of such a PV system is 1675 m^2.

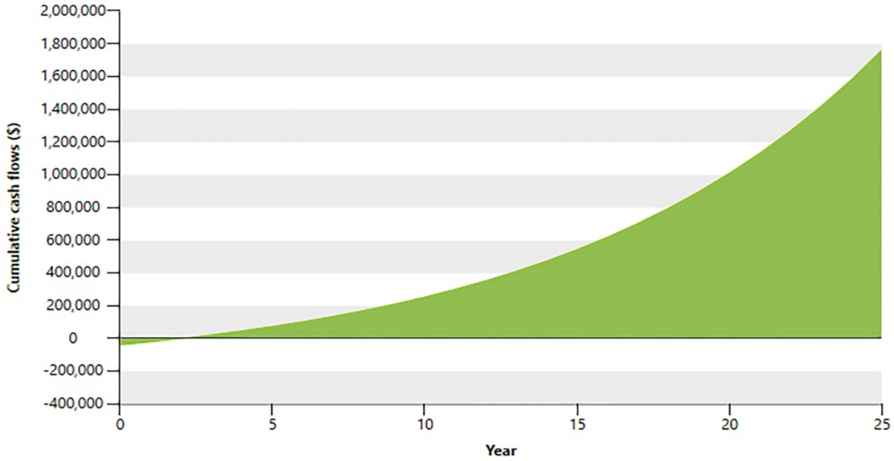

Figure 9. The cumulative cash flows of the biomass section of the optimized system using RETScreen software.

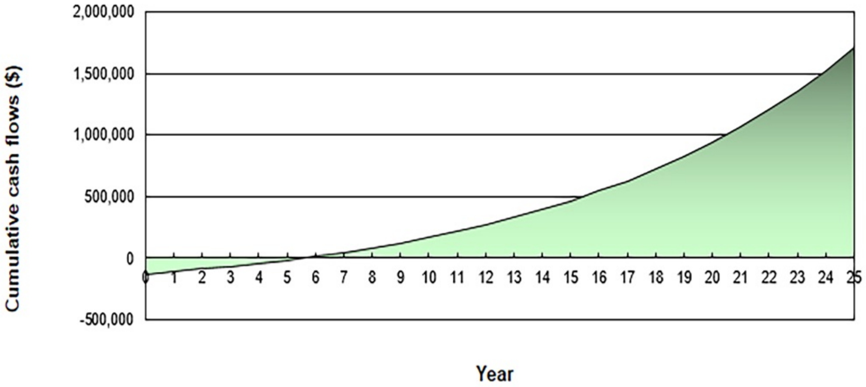

Figure 10. The cumulative cash flows of the PV section in the optimized system using RETScreen software.

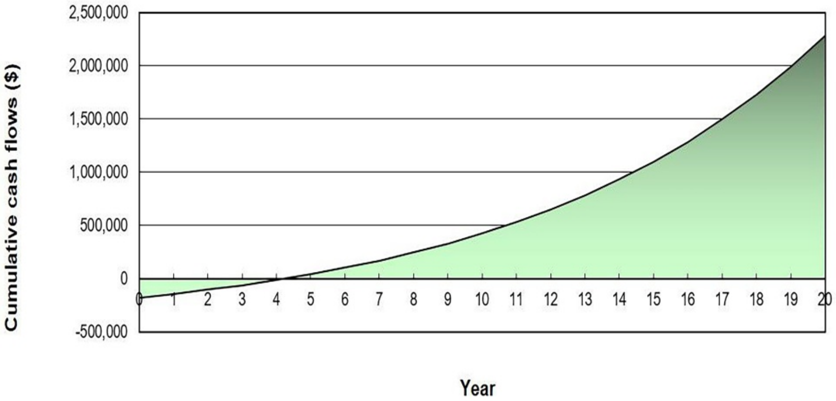

Figure 11. The cumulative cash flows of the optimized system using RETScreen software.

Table 2. The economic simulation results for the biomass section of the proposed system using RETScreen software.

Initial cost	50000 $
O&M cost (Annually)	12483 $
Energy production	876000 kWh
Energy use	122918 kWh
Energy sold	751060 kWh
Electricity export rate	0.035
Electricity export rate (Annually)	29127
Exchange rate	1 $=100000 RIALs
IRR	46.6 %
Simple payback	3 Years
Equity payback	2.5 Years

Table 3. The economic simulation results for the PV section of the proposed system using RETScreen software.

Initial cost	130000 $
O&M cost (Annually)	2000 $
Energy production	311000 kWh
Electricity export rate	0.06
Exchange rate	1 $=100000 RIALs
IRR	23.6 %
Simple payback	7.6 Years
Equity payback	5.5 Years

Anaerobic digestion is influenced by various critical parameters. To ensure an efficient digestion process, it is crucial to provide appropriate conditions for the anaerobic micro-organisms in the digester. Constant temperatures are crucial for anaerobic digestion. Fluctuations stress the micro-organisms and, thus, reduce biogas yield. The mesophilic process was chosen for the proposed system in which the temperature should be fixed between 35-38 °C. Moreover, the pH-value must always be between 6.5 and 8. Furthermore, the hydraulic retention time was set to be between 25-35 days. The hydraulic retention time specifies the average time the substrate remains in the digester. The hydraulic retention time must be long enough to enable the micro-organisms to reproduce themselves at a rate that is faster than the removal of micro-organisms with the effluent.

By using RETScreen software, the economic and environmental analyses of the optimized system were done. Figures 9 and 10 show the cumulative cash flows graph for the biomass and PV sections of the system during the 25 years of lifetime. As can be seen in these figures, the proposed method is highly feasible according to the economic aspects. The financial specifications of the project and the simulation results are presented in Tables 2 and 3. As shown in the tables, the simple paybacks and the equity paybacks are 3 and 2.5 years for the biomass and 7.6 and 5.5 years for the PV section, respectively. Furthermore, the system has an IRR of 46.6 % and 23.6 % for biomass and PV sections. The overall simple and equity paybacks of the proposed system are 5.8 and 4.2 years with an IRR of 30.4 %, respectively (Figure 11). These results indicated that the proposed system was profitable and economically feasible.

Besides the economic aspects, the application of renewable energy harvesting techniques instead of fossil fuels results in cleaner energy and reduces the emission of greenhouse gases. The environmental analysis for the proposed system was done using RETScreen Simulation. The results indicated that, compared to the base case, which is the dairy farm in its current condition (without renewable energy harvesting), the gross annual GHG emission will be reduced by 91.5 %. That is equal to the yearly reduction of about 624 t CO_2. In other words, the application of the proposed system in the current paper not only results in meeting the energy demand of the farm but also reduces the emission of greenhouse gases. In other words, by harvesting renewable energy resources instead of fossil fuels, the proposed system will prevent the emission of GHGs. This amount of reduction in GHG emission (624 t CO_2/year) is equal to the carbon absorption of 58.6 hectares of forest.

4. CONCLUSIONS

In the current study, the feasibility study of renewable energy generation opportunities for a dairy farm in Shahroud, Iran, was conducted. Regarding the available renewable resources including solar, wind, and biomass on the site and the electrical demand of the farm, the techno-economic analysis was carried out. In-situ measurements and historical billing records covering one year (dated between January 2018 and January 2019) were obtained to determine the electrical demand of the farm.

To analyze, first, by using Homer software, the optimized system was selected. It was shown that although there was good wind potential within the farm site, the most economical system would be a 100 kW biomass power plant and a 169 kW photovoltaic plant. The optimization results indicated that by using a 100 kW anaerobic digester and 169 kW PV plant, besides providing the entire electrical load of the dairy farm (123 MWh), 1062 MWh electricity could be sold to the grid.

Furthermore, by using RETScreen software, economic and environmental analyses were carried out. The results of the simulation indicated that the simple and equity paybacks of the proposed system were 5.8 and 4.2 years, respectively. In addition to that, the project has an IRR of 30.4 %, confirming the economic feasibility of the proposed system. Moreover, by harvesting renewable energy resources instead of fossil fuels, the gross annual GHG emission would be reduced by 91.5 %, which is equal to a yearly reduction of 624 t CO_2.

The techno-economic and environmental analyses conducted in the current paper confirmed that one of the best solutions toward a more sustainable future would be harvesting renewable energy resources. Therefore, the proposed pattern for selecting the optimum capacity share of renewable energy resources could be applied to other dairy farms in the country. However, regarding the climatology of each site and the available resources, the capacity share of each resource may vary. Therefore, further studies in this regard would be necessary.

5. ACKNOWLEDGEMENT

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