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Modeling of an HPS for the electric power demand of the cattle farm using genetic algorithm

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ABSTRACT

Today, as the demand for energy increases based on the increasing population and improving technology, resorting to new energy sources has become a necessity. Due to the rapid consumption of fossil fuels and the responsibility of humanity for the environment, Renewable Energy Sources (RES) are of a quality that may respond to this necessity. But the RES such as sun and wind vary depending on the weather conditions. Considering such variance, Hybrid Power Systems (HPS) are suggested in order to assure reliability and continuity in energy generation. For the sake of strengthening the HPS that are dependent on weather conditions, it is considered to increase the system's reliability and continuity through the inclusion in the HPS of cattle biomass reserves in the area. In this paper, it was studied on modeling of HPS based on sun, wind and biogas that will meet the electric power demand of the cattle farm located at Afyonkarahisar, Turkey. The two decades' animal population and load value changes were estimated through Genetic Algorithm (GA), and the HPS model was investigated under different scenarios considering sustainable energy and environment objectives, and the analyses were performed considering the changes in economic parameters.

1. Introduction

The energy demand rapidly increases worldwide in parallel with the population increase and industrialization. As basic needs such as water and food are also acquired and transported using energy, having high-quality, uninterrupted energy is essential. Due to the limitedness of the fossil fuels' reserves and the fossil fuels' high cost and environmental damage, demand for new and alternative energies is increasing. The electrification of small rural compounds or villages far from settlements is among the most significant and great steps taken towards a higher quality of life in developing countries [1–4]. As per many studies, the access to electricity in a region, or the quality and sustainability of the electricity reached are possible with renewable HPS. In such systems, the main principle is the minimization of costs while enabling the system's control. In the system to be designed, the cost of each energy source is expressed by COE [5]. Through comparison of such cost values, the combination of sources that will meet the load demand is searched, and the most feasible system is found among these combinations as per the criteria of region, environment, and cost. Such an HPS may contain more than two sources, storage means, a controller, and a power cycle unit. In addition, such a system may be on- or off-grid [6, 7]. In the review of studies in the literature, in Ref. [8], the simulation of PV, wind turbines, Biogas Generator (BG), and battery system

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modeling under eight different scenarios were performed in order to examine the effects of the HPS's potential. The sun and the wind were exploited sufficiently, a 20% savings was obtained from the BG and a cost-effective system was designed. In Ref. [9], a hybrid system comprised of PV, WT, a BG, and VRFB was modeled and experimentally implemented. In order to meet the daily energy demand, the optimization of different RES from a technological and economical standpoint was modeled via a simulation program. The data was verified by comparing the obtained data with the simulation practices. In Ref. [10], the integration of a renewable system with wastewater treatment plants was studied. In the system, the integration of PV panels, a wind turbine, and an internal combustion engine operating with biogas generated through anaerobic digestion suggested techno-economically suitable solutions by designing a system that will meet the electricity demand of the main wastewater plant with an energy cost lower than the real electricity cost. In Ref. [11], it was studied for the optimization of the HPS's integration. In terms of cost, the most efficient scenario was determined to be a micro-hydro, PV, biomass, biogas, diesel, or battery system. In Ref. [12], the selection of the optimal locations was made by taking into account the sizes of cattle farms and their economic transportation distances. Accordingly, it was suggested to establish on-site biogas plants for large-scale farms and central biogas plants for medium- and small-scale farms. In Ref. [13], operations were performed for the generation of heat or electricity from the biogas obtained from livestock manure produced at farms in the Canary Islands. In Ref. [14], is concerned with the technological, fiscal, and environmental viability of a HPS grid-connected biomass/PV/wind energy structure. Using the modeling tool and historical geographic and climatic data from the University campus, the optimal HPS design was realized. According to the simulation results, the best construct is the HPS with the lowest energy cost (COE) and net present cost (NPC). In Ref. [15], it was suggested to make a comparison among the simulations presented by the PV simulation software by using four different meteorological databases. It was revealed that consistent production estimates were provided by the simulation with a percentile difference of less than 5% when compared with the real system. In Ref. [16], technical, economical, feasibility, and sustainability analyses were performed for a hybrid micro-network based on PV and biomass sources. In Ref. [17], the daily manure amount of the animals was determined following the determination of their number, and the biogas amount that may be generated as per such a manure amount was calculated. And the power amount that may be obtained as per such a biogas amount was determined. In Ref. [18], the HPS simulation and optimization model have been studied. Based on the simulation results obtained, solar/hydro/battery HPS reveals the most suitable model for off-grid rural electrification due to grid low NPC and minimal greenhouse gas emissions. In Ref. [19] is relevant to on-grid PV system, and it was designed using simulation software. The study focused on key points such as system production, the Sankey diagram, output power losses, the performance rate (PR) of the system to be positioned, output energy, examination of the output of the PV module, adjustment of field type, and drawing the power distribution curves. In Ref. [20], the feasibility assessments of PV and biomass systems were performed for implementations in the telecom sector, flour plants, and rural communities. In Ref. [21], off-grid combinations of wind turbines, PV panels, and BGs are modeled and optimized. To show the technological and economical application of HPS, modeling tool, optimization, and susceptibility analysis were used. The research has shown that HPS is a dependable and cost-efficient solution for environmental and rural electrification. In Ref. [22], a HPS study regarding electricity supply to rural regions without power through a hybrid mini grid was performed. In the study, three alternative configurations were modeled for electricity generation by different combinations of solar energy, biomass generator, diesel generator, and battery storage sources, and technical and economical assessments with respect to the system were performed. In Ref. [23], electric power generated in ten different fields via an on-grid PV system was investigated. In the system, the control of the energy generated using the constant slope method in the simulation program was ensured. It was focused on total energy at the output of the inverter and on global facts about current energy. In Ref. [24], a hybrid PV-wind production system along with biomass and storage was modeled in order to meet the electric load demand of a small area. In the system, a swarm-based artificial bee colony algorithm was implemented, and in order to verify this method, it was compared with the results obtained from the HOMER model and particle swarm optimization algorithm. It was understood that the results were close. In Ref. [25], the evaluation of an off-grid PV system was presented. The purpose of the simulation operation was to design a reliable PV system and estimate the annual energy generation efficiency. The total electric power that may be provided by the system and the power losses were also determined. In Ref. [26], a study was performed to evaluate the spatial potential of biomass energy. A mathematical model was developed for gathering site-specific geographical information, and biomass. According to Ref. [27], the on-grid hybrid system comprised of the grid, PV, and biomass systems was the best answer when considering the average intensity of solar radiation on a monthly basis, the bioenergy potential of rice husk, and the present equipment costs In Ref. [28], an optimal model for on-grid and off-grid PV-biomass hybrid energy systems for meeting the electric power demand of a village was presented. In addition to the system's simulation programs, a brief comparison of results obtained from the artificial bee colony algorithm and hybrid optimization model was also performed. As a result, it was discovered to be a cost-efficient and dependable solution for rural electrification. In Ref. [29], the applicability of the establishment of an on-grid mono-crystalline silicon solar energy power plant was investigated. By reviewing simulation reports, total energy generation and specific energy generation were determined, respectively. Moreover, the main source of the losses was determined, detailed loss estimation for the whole year was performed, and it was shown with an arrow loss diagram. In Ref. [30], in order to provide power to off-grid base stations (BS), the hybrid supply systems based on solar photovoltaic (PV) and biomass resources were examined, focusing on technical, economical, and environmental aspects. The suggested system revealed that BS had sufficient potential to meet the power demand. In Ref. [31], a hybrid renewable energy system comprised of photovoltaic panels, wind turbines, and BGs was formed for rural electrification. Consequently, the optimal system configuration in terms of the parameters of biomass price and inflation rate was obtained. In Ref. [32], the off-grid PV system consisted of PV panels, accumulators, an inverter, and a charge controller. The performance analysis of the suggested off-grid PV system was performed using simulation software. The results of the simulation included the total power generated by the PV series, the unused power, the power assigned to load, PV transformation efficiency, system losses, and performance rate. In Ref. [33], the techno-economical feasibility of an autonomous hybrid renewable energy system was analyzed. In the system's design, solar energy, wind energy, biogas, synthesis gas, and hydrokinetic energy with a spare battery were used. By presenting the optimal HPS, sensitivity analysis was performed for various parameters. In Ref. [34], optimal HPS was modeled with solar photovoltaic technologies, wind turbine, and bio-generators for rural electrification. In the study, the optimum techno-economical evaluation was performed as a mixture of different load models, such as housing, commercial, corporate, and agricultural demands. Moreover, it was indicated that the system could be the most cost-effective and sustainable power alternative. In Ref. [35], a study was performed to determine the most economical hybrid system under different loads in a rural area. The designed system used an optimization method embedded in HOMER (hybrid optimization of multiple energy resources) and PVsyst application software. The hybrid system selected is based on the lowest levelized cost of energy value. In Ref. [36], an off-grid HPS was modeled. The modeled system includes biomass, solar, wind and fuel cells. In the system, the technical and economic analyses were made and compared using the genetic algorithm (GA) and simulation software. In Ref. [37], a commercial laboratory was established for the PV systems. In the study, the system's performance parameters, energy generation, and operational characteristics were examined using the simulation software. The economic analysis in terms of payback period and the environmental analysis in terms of the reduction of greenhouse gas emissions revealed the practical applicability of the suggested system along with sustainable development. In Ref. [38], the biogas, diesel, hydroelectric, PV, and wind HPS feasibility studies were performed for the supply of rural electrification and potable water. Various energy configurations were simulated for each village. The results indicated that the off-grid system was the most cost-effective option for all the villages selected. In Ref. [39], the techno-economical feasibility study of biomass gasification in off-grid and on-grid micrograms was presented. It was used to simulate single-source and hybrid minigrids based on solar energy, biomass gasification, and diesel production. It was determined that the hybrid PV-biomass or PV-diesel systems provided the highest reliability for off-grid power at the lowest cost. In Ref. [40], in order to analyze the load demands of a hospital, a hybrid model comprised of biogas cofiring, diesel generators, PV solar energy series, and an accumulator was designed. In the referred study, renewable energy was compared with conventional energy, and it was determined that the optimal solution might reduce carbon emissions and diesel consumption. In Ref. [41], concentrated on the design of PV-biomass, gasifier-diesel, and grid-based hybrid systems, and the form of the systems was optimized for varied load profiles. The simulation results showed that the biomass gasification system, rather than the photovoltaic system, was the best alternative under all conditions. In Ref. [42], it was intended to examine the roof implementation potential of PV in the housing industry, considering apartment buildings and villas. Considering various structural and cultural parameters and parameters relevant to services, remote sensing and GIS techniques, focusing on the usability of building roofs, were used. Simulation software was used to model the PV implementation and to determine the effects of shading on building roofs. In Ref. [43], it was revealed that the efficient use of biogas, which is an alternative energy source, might overcome the energy crisis and that the establishment of a biogas plant was beneficial in decreasing respiratory and eye infections as well as being cost-effective. In Ref. [44], the system was compared to a PV module's lab measurements under 15 distinct nonconformity situations, including as partial shadowing and short-circuit failure, using a PV simulation tool. The results showed that the predicted and measured I–V curves were consistently similar and that the faults at the curves' maximum power points were within the accuracy range of the equipment. In Ref. [45], a hybrid power system consisting of wind, biomass, solar photovoltaic, and batteries was proposed. It was also suggested to preserve the optimal energy storage level for meeting the highest load demand along with biomass, wind, and solar photovoltaic in periods of low or no solar radiation or low wind. In Ref. [46], a hybrid power system based on decentralized solar energy, PV, wind, biomass, and fossil fuels was suggested. It was revealed that the suggested system, simulated for four different fuel combinations, reduced pollutant formation by about 50% along with biomass In Ref. [47], investigated the viability of building-scale photovoltaic system reinforcement for the office buildings. Through the modeling software, the simulations of PV systems were evaluated in terms of costs and anticipated energy generation for a few PV systems. By calculating the output capacity of each system, the annual energy outputs and initial project costs of different systems were modeled in a simulation program. In Ref. [48], PVsyst software was used in order to perform the techno-economical analysis of an off-grid solar system, and it was revealed that the energy cost of the off-grid system was better than the mains supply and that it was reducing the carbon emissions. In Ref. [49], a study regarding some performance indicators of PV systems, such as performance rate, system efficiency, filling and capacity usage factors, and regarding electricity generation based on four different methodologies was presented. Within this scope, for the determination of annual production, not only the theoretical approach and simulation programs (PV*SOL and TRNSYS) were used, but experimental studies were also performed for verification. It was considered that the annual values regarding the system's efficiency were somewhat close to each other. In Ref. [50], a renewable energy-based distributed energy generation (DEG) system was considered for an eco-village directed by the integrated biomass and solar town concepts. A mixed integer linear programming (MILP) model was developed for designing a cost-effective integrated biomass and solar town. In Ref. [51], a study was performed for six PV systems, eighteen cities were selected, and the annual electricity demand of five types of dwellings was determined. It was benefited from the net present value, internal rate of return, profitability index, and reduced payback period to establish the system's feasibility while the capabilities and efficiency of PV systems were shown using a modeling tool. Consequently, it was indicated that the systems with low energy generation capacity were economically applicable. In Ref. [52], it was revealed that the gasification of cashew nutshells had high potential for electricity generation, and the techno-economical evaluation of a solar photovoltaic-biomass gasification hybrid system was performed. In addition, the efficiency of the system compared to diesel generators was also compared. In Ref. [53], The green roof's and roof PV solar panels' effect on a common building's energy efficiency was investigated. Three commercially used solar panels, namely Canadian Solar, Trina Solar, and Suntech were studied and examined for this purpose. And their technical and economic analyses were simulated using the Design Builder (DB) and PV*SOL software programs, respectively, and the net present value (NPV) method. In Ref. [54], it was tried to optimize the size of a biomass-based PV power plant for the supply of electric power to agricultural wells. The harmony search (HS) algorithm was used in the system. The system revealed that it may be an effective means of forming a reliable and cost-effective HPS. In Ref. [55], it was focused on the use of various simulation software programs such as PV*SOL, PVGIS, SolarGIS, and SISIFO for the analysis of the performance of an on-grid roof solar photovoltaic system. The study evaluated the energy generation, performance rate, and solar fraction for the performance estimation of the solar energy power plant.

Considering all these studies, most of the studies deal with the obtainment of biogas from the wastes of bovine animals, ovine animals, and poultry, as well as other RES such as PV, wind etc., and HPS modeling. It was also observed that economical and technical studies were also performed on the gasification of cattle wastes. The novelty of our present study is the modeling of HPS with bioenergy obtained from bovine animal manure along with PV and wind energy, which are other RES, and making it an on-grid HPS by the joint usage of the PVsyst, PV*SOL, and HOMER software programs. Moreover, based on the growth, development and increase in cattle numbers at the facility, two decades' load was estimated using GA, an HPS was designed under different scenarios, and the results of the analysis were evaluated.

2. Material and methods

2.1. Load profile

The biogas potential is high around the world, but benefits from biogas are not being realized at a sufficient rate. This study was performed at a cattle farm with a daily load requirement of 328 kW h located in an area where the cattle farms are concentrated at the coordinates of 38° 43′ 33.36″N, 30° 38′ 5.60″E at Salar Village of Afyonkarahisar Province in the Aegean Region. The location view of the area is provided in Fig. 1.

The farm's load distribution charts were formed as per its installed capacity and annual electric bill. There were 250 animals at the farm. On the farm, there are 10 units of backscratcher of 0.18 kW, 4 units of manure mixture of 11 kW, 4 units of scraper of 0.25 kW, 2 units of water heater of 150 kW, 2 units of air compressor of 3.7 kW, 2 units of tank transfer motor of 2.2 kW, 2 units of submersible pump of 15 kW, 1 unit of separator of 12 kW, 1 unit of milk cooling tank of 18 kW, and 50 units of lighting fixture of 0.05 kW. The graph of the daily and annual energy consumption of the loads of devices and 250 animals on the farm is given in Figs. 2 and 3.

2.2. Photovoltaic (PV)

The area's average solar radiation value was calculated to be 4.49 kW h/m^2/day. In Fig. 4, the area's solar radiation (GHI) data is provided. In the synthesis, the data is created using specific statistical characteristics reflecting the holistic averages [56].

The roof area's annual average solar radiation value was calculated to be 4.49 kW h/m^2/day. Based on the data, the roof was determined to be suitable for the installation of PV. Eq. (1) is used to compute a PV series' power output [57,58].

$$P_{PV} = Y_{PV} \, . f_{PV} \, . \, \frac{G_T}{G_{T,stc}} \, . \left(1 + \alpha \, . \, \left(T_C - T_{C,stc}\right)\right) \tag{1}$$

Fig. 1. Satellite image of the Salar Village.

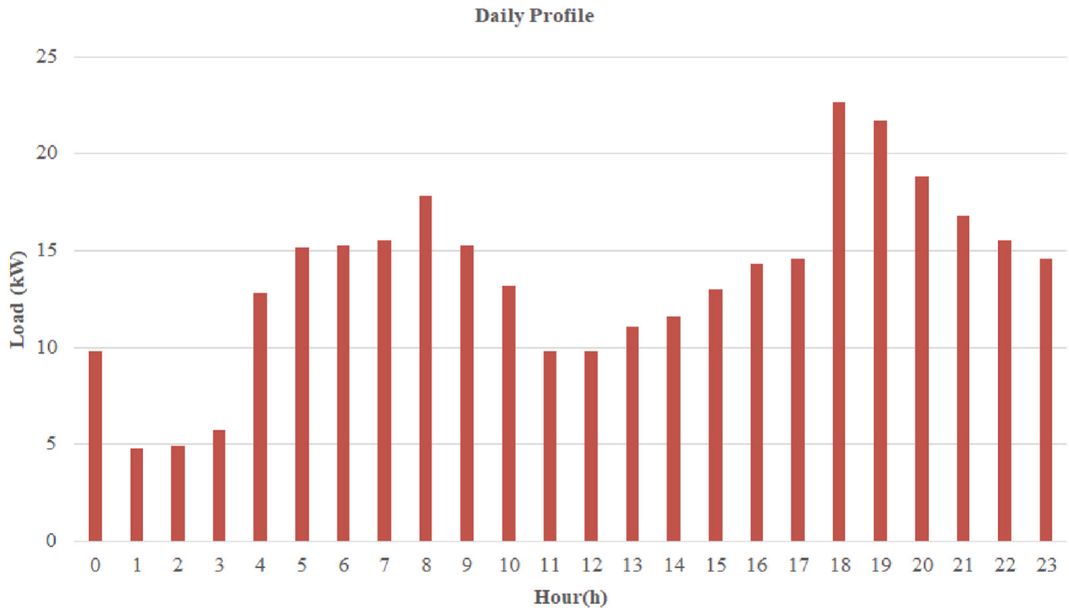

Fig. 2. Daily energy consumption of the farm.

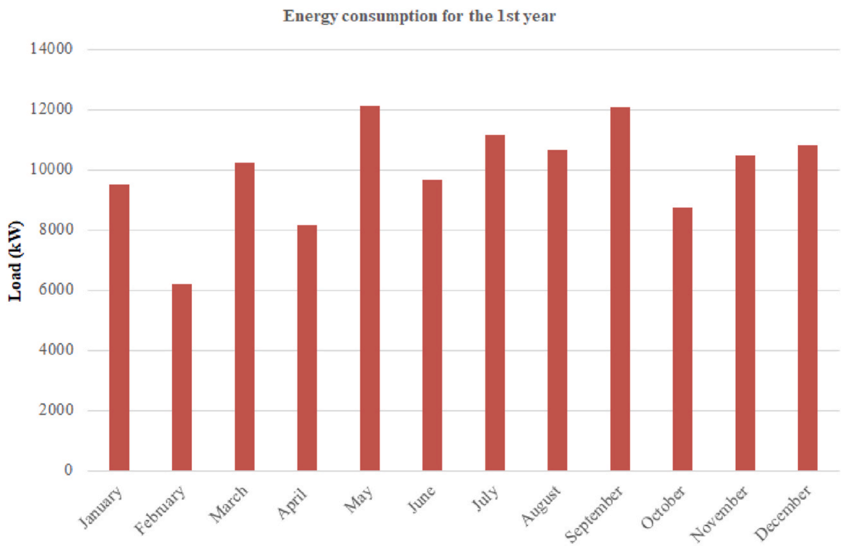

Fig. 3. Annual energy consumption of the farm.

In this Eq.; P_{PV} PV generated power (kW), Y_{PV} PV generated power at STC (kW) f_{PV} loss factor of PV array (%), G_T solar irradiance (kW /m^2), $G_{T,stc}$ solar irradiance at STC (1 kW /m^2), α power temp. coefficient ($-$ 0.485% /∘C), T_CPV cell temp. (∘C) $T_{C,stc}$ PV cell temp. at STC (25 ∘C).

The efficiency of a PV series is calculated as in Eq. (2) [59].

$$\eta_{stc} = \frac{Y_{PV}}{A_{PV}\ .\ G_{T,stc}} \tag{2}$$

In this Eq.; η_{stc} PV panel efficiency (%), Y_{PV} rated capacity of the PV array (at standard test conditions), A_{PV} surface area of PV panel (m^2), $G_{T,stc}$ solar irradiance at STC (1 kW /m^2).

In Fig. 5, the temperature data for the area is provided. The area's annual average temperature was 11.63 °C.

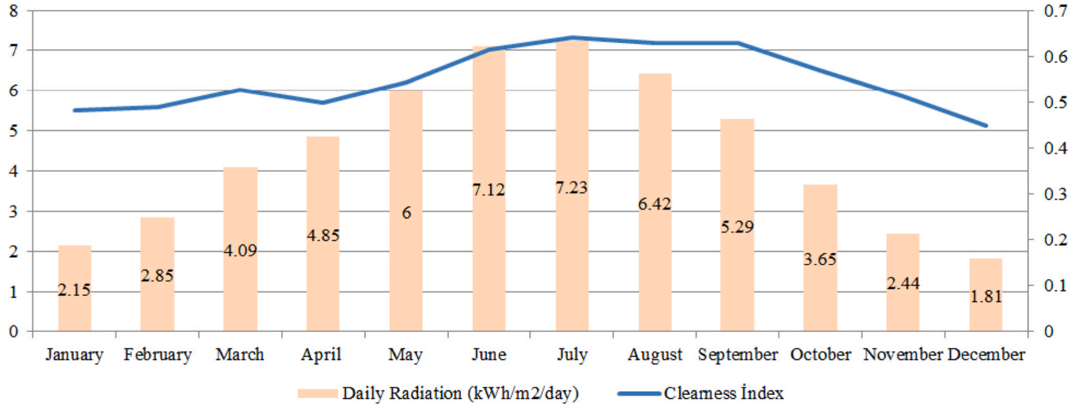

Fig. 4. Average solar radiation (GHI) for Salar Village.

2.3. Wind turbine (WT)

The Weibull k value is a measurement of the wind speeds' distribution over the course of a year. The wind's randomness is measured by the dependency factor (r_1). Higher r_1 values show that the change in wind velocity in an hour is closely related to the previous hour's wind velocity, whereas lower r_1 values show that the change in wind velocity is not directly related to the previous hour's wind velocity.

Fig. 6 depicts the average wind speeds in the area. In this investigation, $k = 2$ and $r_1 = 0.85$ were determined. The daily change factor (δ) measures how the wind velocity varies over the course of a day. It was determined to be 0.25 in this investigation. According to the annual average, the hour of highest wind velocity is the day's windiest hour. In this study, it was deemed to be 15:00. In HOMER simulations, the height of the anemometer was deemed to be 10 m. The area's annual average wind velocity value was calculated to be 5.10 m/h. As a result, the location is excellent for the installation of a modest powerful wind turbine.

Eq. (3) is used to compute a wind turbine's power output, and Eq. (4) is used to compute the wind velocity equations that a wind turbine is affected by Ref. [60].

$$P_{WT} = P_{WT,stc} \cdot \frac{\rho}{\rho_0} \tag{3}$$

In this Eq.; P_{WT} WT generated power (kW), $P_{WT,stc}$ WT generated power at STC (kW), ρ real air density (kg /m^3), ρ_0 air density at standard temperature and pressure (1.225 kg/m^3).

$$\frac{u_{hub}}{u_{anem}} = \left(\frac{z_{hub}}{z_{anem}}\right)^{\lambda} \tag{4}$$

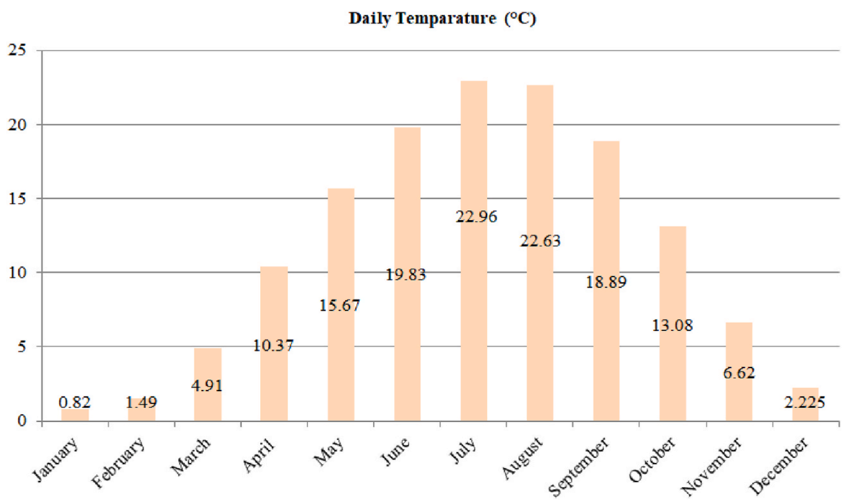

Fig. 5. Average temperature data for Salar Village.

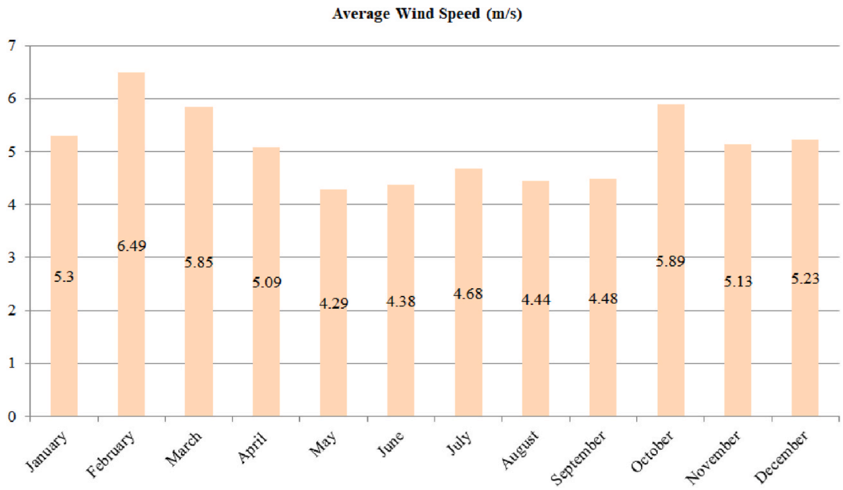

Fig. 6. Average wind velocities at Salar Village.

In this Eq.; u_{hub} wind speed at the height of the WT (m /s), u_{anem} wind speed at anemometer height (m /s), z_{hub} WT hub height (m), z_{anem} anemometer height (m), λ force factor.

2.4. The Area's bioenergy data and BG

Bioenergy basically means the useable gas production from organic wastes. Cattle manure is used in various ways in some countries. The manure of bovine animals is the most extensively used product in biogas production. 1 ton of fresh calf manure can produce approximately 33 m^3 of biogas. 1 m^3 of biogas provides between 4700 and 5700 kCal of heat. This amount of energy is equivalent to 0.66 L of diesel fuel, 0.75 m^3 L of gasoline, and 0.25 m^3 of propane. The methane content of the biogas produced from cattle manure is 53%. The daily average fresh manure production of 1 cattle is about 10 kg [61–63].

Eq. (5) gives the amount of daily collected manure, Eq. (6) gives the biogas amount, Eq. (7) gives the value of calorific biogas, and Eq. (8) gives the biogas electric power value [64].

$$M_{DW} = M_W \ . \ T_S \tag{5}$$

In this Eq.; M_{DW} each animal's manure's daily amount (kg.day/number), M_W raw manure on a daily basis (kg.day/number), T_S duration of animals in shelters (%).

$$B_A = 0,365 \ . \ P_L \ . \ M_{DW} \ . \ C_b \tag{6}$$

In this Eq.; B_A amount of biogas (m^3 /a), P_L animal population amount (number), M_{DW} each animal's manure's daily amount of manure per animal (kg.day /number), daily amount (kg.day/number), C_b biogas efficiency (m^3 /t).

$$B_T = B_A \ . \ C_C \tag{7}$$

In this Eq.; B_T caloric biogas (MJ), B_A amount of biogas (m^3 /a), C_C caloric biogas coefficient (MJ /m^3).

$$B_E = B_A \ . \ C_E \tag{8}$$

In this Eq.; B_E biogas electrical energy value (kWh), $B_A$amount of biogas (m^3 /a), C_E electric energy coefficient (kWh /m^3).

In Fig. 7, the stages of biogas production are provided. The wastes of bovine animals are processed at specific stages, and eventually, biogas is obtained. And the biogas obtained may be used as fuel for energy generation, and the generator produces energy like diesel fuel. In Fig. 8, the graph indicating the amount of manure used as fuel by the biogas facility as of each year is provided. The number of animals and the manure amount are directly proportional. As the number of animals increases, the amount of waste manure also increases at the same rate.

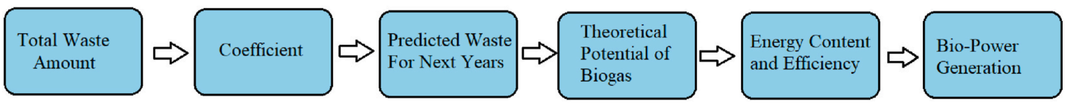

Fig. 7. Bio-power from feedstock to end use.

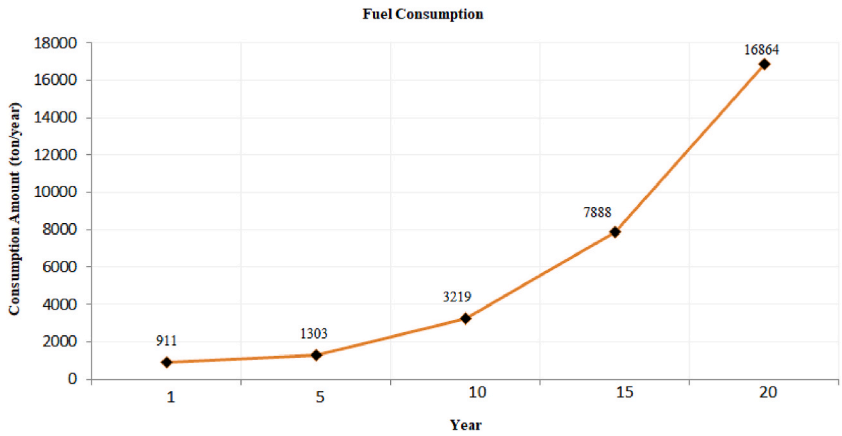

Fig. 8. Annual manure data.

2.5. Converter

In renewable energy systems, the transformers are used to charge the batteries by transforming the AC power to the DC power used by operating in converter mode or to transform the DC power integrated to the AC load bar into AC power by operating in inverter mode [65,66].

2.6. Animal estimation by genetic algorithm (GA)

In this section, the number of animals at the cattle farm was estimated via GA, from among the estimation methods. Through accurate estimation of the increase rate and number of animals, the operating costs and losses will decrease, and thus, technological and economic improvements will be in question for the producer. The change in the number of animals as per year on the farm is given by the GA Flow Scheme in Fig. 9.

The data required for the GA was formed considering the number of animals at the farm in the initial year, the pregnancy rate of the animals, the survival rate of the born calves, the gender of the calves, and the number of animals to be removed from the herd. They are provided as functions in Eq. s (9) and (10). Furthermore, Eqs. (11) and (12) explain the constraints of the goal function benefited in the genetic algorithm.

$$y = \sum_{i=3}^{t} 0,75.f(i-1) + f(i-2).\ G_o\ .B_o.B_{yo}\ .H_{co} \tag{9}$$

$$f(x) = \{3 \leq t \leq 20\} \tag{10}$$

$$g(1) = \{0.779 < Byo < 0.751\} \tag{11}$$

$$g(2) = \{0.489 < Hco < 0.511\} \tag{12}$$

In this Eq.; y result, f activation function, i year, G_o pregnancy rate, B_{yo} survival rate of the new born calves, B_o calving rate of the animal, H_{co} gender rates and coefficients of the animals born.

In this study, the roulette technique was used in the estimation of the increase in the number of animals. In Fig. 10, the estimation curve of values obtained for the number of animals in two decades by the end of the GA training is provided. The results obtained indicate that the estimation model developed may be used reliably.

2.7. PVsyst

This program is extensively used in the solar energy modeling of the buildings. In this program, analysis of sun angles, inputs of the photovoltaic system, losses, shade, series modeling, and performance analysis are able to be performed. As the database, the information of institutions having large meteorological databases such as Meteonorm, NASA, and PVGIS is used. This program is extensively preferred due to advantages such as its extensive selection range, hosting in its infrastructure the elements of a PV system, detailed observation of the losses in the installed system, conformity of default selection terms with the literature, ability to determine the shading losses with its 3D drawing feature, ability to perform economic analysis, and having a slight difference between the real results and the results of the simulation.

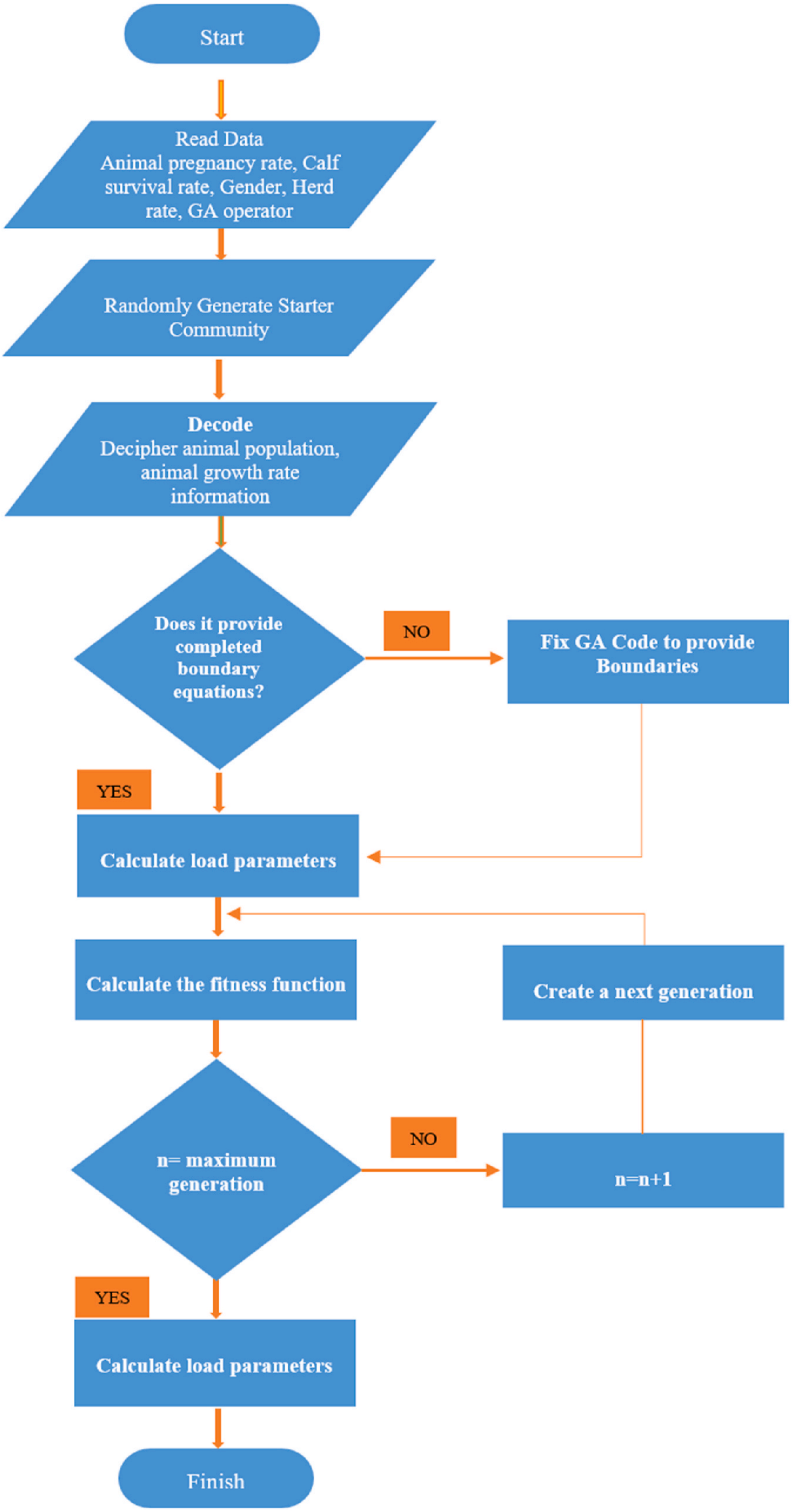

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Fig. 9. Genetic algorithm flow scheme.

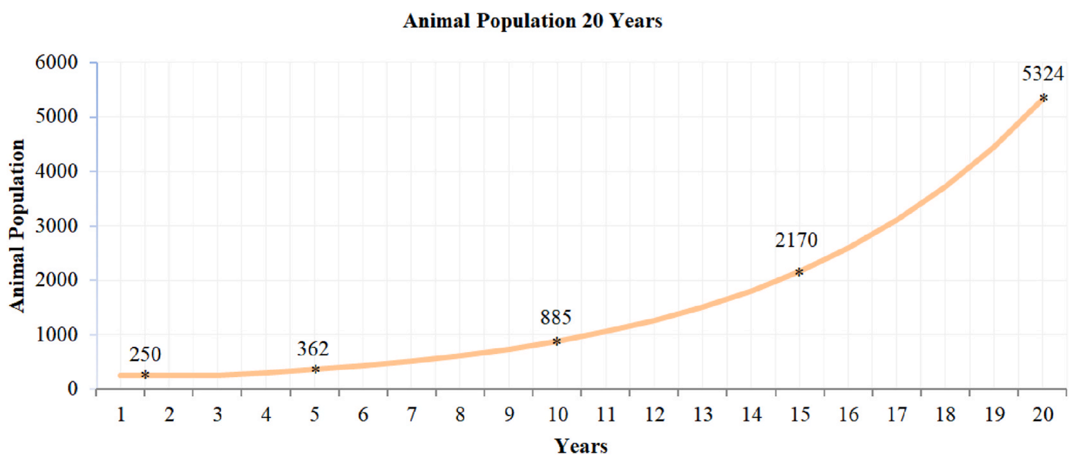


Fig. 10. Number of animals in two decades.

2.7.1. Economic analysis

Net present value is the term used for the difference between the net present value of cash inflows and the net present value of cash outflows in a specific period. The net present value is calculated using the following Eq. (13).

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t} \tag{13}$$

In this Eq.; R_t (t) net balance (income minus expense) for the year, i discount rate that may be gained from alternative investments, $E_t$annual electricity generation, n lifetime of the installed system.

2.8. PV*SOL

It is the solar power plant analysis program that performs the realistic design and simulation of land-type and roof-type solar power plants. It is a versatile program used to perform the installation of on-grid or off-grid systems. By virtue of this program, one can examine in the clearly and accurately provided report the effect on the system of components creating shading around a photovoltaic system and calculate more accurately the efficiency of the system.

2.8.1. Economic analysis

By the PV*SOL program, the economic efficiency is calculated using Eq. s (14) and (15).

$$CV = Z.b(T, q, r) \tag{14}$$

In this Eq.; CV cash value, Z payment series, T system's lifetime, b net worth factor.

The net worth factor is determined using the following Eq. (15).

$$b(T, q, r) = \begin{cases} \dfrac{1 - \left(\dfrac{r}{q}\right)^T}{(q-r)}, r \neq q \\ \dfrac{T}{q}, r = q \end{cases} \tag{15}$$

In this Eq.; q simple interest factor, r price change factor.

2.9. HOMER

This program models the physical properties, system lifetimes, and total installation and operating costs of hybrid power systems as well as the design of renewable energy systems. This program enables the design of different power systems using technical and economic data. Moreover, it also assists in the understanding of changes and uncertainties in the data used during the modeling of the system. It enables the simulation of different system configurations or components. HOMER will also be able to compare the simulation results and configurations and evaluate their economic and technical advantages.

2.9.1. Economic analysis

The NPC comprises installation and operation costs incurred over the system's lifetime. The system's economic outputs are computed to establish the net present cost. Eq. (16) is used to compute the net present cost.

$$NPC = \frac{C_{ann,total}}{CRF(i,N)} \tag{16}$$

In this Eq.; NPC net present cost (\$), $C_{ann,total}$ total annualized cost (\$ /year), $CRF(i,N)$ capital recovery factor (1 /year).

The capital recovery factor (CRF) is used to compute the annual revenue's and expense flow's present value using Eq. (17).

$$CRF(i,N) = \frac{i\ .\ (i+1)^N}{(i+1)^N - 1} \tag{17}$$

In this Eq.; $F(i,N)$ capital recovery factor (1 /year), i real interest rate (%), N project lifetime (year).

The unit energy cost is defined by HOMER as the average cost per kWh of useable electric power generated by the construct and is explained using the formula in Eq. (18).

$$COE = \frac{C_{ann,total}}{E_{AC} + E_{DC} + E_{grid}} \tag{18}$$

In this Eq.; COE levelized cost of energy (\$ /kWh), $C_{ann,total}$ total annualized cost (\$ /year), E_{AC} primary AC load served (kWh /year), E_{DC} primary DC load served (kWh /year), E_{grid} total grid sales (kWh /year).

The total annual cost (CT) is the sum of the annual costs of each element of the system and of other annual costs. The total cost of the system is equal to the sum of the costs of the components used in the system, as provided in Eq. (19). Individual costs for each component are calculated using the formula in Eq. (20) [67,68].

$$C_T = C_{PV} + C_{WT} + C_{BAT} + C_{BG} + C_{inv} \tag{19}$$

In this Eq.; C_T unit investment of transformer (\$ /kVA), C_{PV} PV panel cost (\$), C_{WT} wind turbine cost (\$), C_{BAT} battery cost (\$), C_{BG} BG cost (\$), C_{inv} inverter cost (\$),

$$C_i = N_i\ .\ \left(C_{cap,i} + C_{rep}\ .\ K_i + C_{O\&M}\right) \tag{20}$$

In this Eq.; C_i component cost (\$), N_i number of components (number), $C_{cap,i}$ capital cost of grid extension (\$/km), C_{rep} cost of replacing components (\$), K_i number of renewals (number), $C_{O\&M}$ cost of grid extension (\$ /yr /km).

In recent research, self-consumption rate, self-sufficiency rate, and peak power reduction have been general performance measures. SCR is defined as the ratio of energy produced by the BG directly delivered to the load in Eq. (21) to total annual BG output. SSR is defined as the ratio of total BG output directly transmitted to the load to total annual load demand. As seen in Eq. (22), when the share of BG in load demand increases, so does the value of SSR [67,68].

$$SCR = \frac{\sum E_{BG}^{cons}}{\sum E_{BG}^{gen}}\ (\%) \tag{21}$$

$$SR = \frac{\sum E_{BG}^{cons}}{\sum E_{Load}}\ (\%) \tag{22}$$

In this Eq.; SCR self consumption rate, SSR self sufficiency rate, E_{BG}^{cons} produced by the BG and energy directly delivered to the load, E_{BG}^{gen} BG's total energy production on an annual basis , E_{Load} annual total load demand.

3. Simulation and results

First, the PV installations of the system were performed over the software programs of PVsyst, PV*SOL, and HOMER, and their technical analyses were performed. And then, by the forward-looking GA, the number of animals on the farm, the biogas, and the energy consumption of the farm in years 1, 5, 10, 15 and 20 were estimated. In light of such data, the optimal HPS was designed, and its technical and economic analyses were performed.

3.1. PV*SOL models

The placement of panels on the roof to be used for design was performed by the PV*SOL simulation program. The PV was not placed on the northern façade of the roof, where the maintenance facilities and shading were high. The modules, with a 20% or higher radiation decrease due to shading, were excluded due to both their capacity of significantly decreasing the output of the series and economic issues. As observed in Fig. 11, 400 units of panels were placed on an area of 2160 m^2. Moreover, the properties of panels and inverters used in the system's modeling are given in Table 1.

In Table 2, the results of the PV system formed by PV*SOL are given. The system generates 226.417 MW of electric power each year.

It was observed that the energy demand of the farm increases over the years. Moreover, it was observed that the amount of electric power received by the farm from the PV system and grid increases depending on the number of animals.

3.2. PVsyst models

In the direction of the data obtained from PV*SOL, the optimum panel angle was determined annually in constant-angle systems via PVsyst. The correct determination of the panel's angle is important for the system's efficiency. The panel angle was determined as 37° for the Afyonkarahisar area. The sun's elevation is given in Fig. 12.

If the panels will be assembled on an inclined roof, it is required to consider the inclination of the roof. The azimuth angle is used to determine the direction of the sun. The panels are assembled facing south as per the azimuth and tilt angles shown in Fig. 13. The simulation results of the modeled system are given in Table 3.

As observed in Table 3, while the energy drawn from the grid increases over the years, the energy provided to the grid by the system decreases. Thus, a system installed only with PV will not meet the energy demand of the farm in the following years.

3.3. HPS models

In Fig. 14, the single-line diagram of the designed hybrid system is shown. The designed HPS consists of a BG, PV panels, and wind turbines. Here, the PV system was connected to a DC busbar, and wind turbines, farm loads, and BGs were connected to an AC busbar. The converter was indicated as being connected to both busbars in order to actualize the two-way transformation between the AC and DC busbars. The grid connection was also present in the system.

During the system design, it is required to determine the required costs of both components. Under today's circumstances, significant variances are observed among the costs. Therefore, the most proper costs were determined, and their values were entered in the relevant parts. In Table 4, the information on the costs is given.

3.4. Results of simulation (HPS)

The system's monthly electricity generation values over the years are given in Figs. 15–20. In Fig. 16, the graphs indicating the values of the first year of the installed system are given. When these graphs are examined, it is observed that the majority of the farm's energy demand was met by the grid. And the system's annual energy demand met by the wind turbines was 13.52 kW, met by the PV system was 324.99 kW, and met by the biogas was 407.08 kW.

In Fig. 16, the graphs indicating the values of the 5th year of the installed system are given. When these graphs are examined, it is observed that the majority of the farm's energy demand was met by the grid as in year 1. In year 5, while the amount of energy met by the wind turbines and PV system didn't change, the amount of energy met by the biogas increased by 178.66 kW and reached 585.74 kW compared to year 1.

In Fig. 17, the graphs indicating the values of the 10th year of the installed system are given. When these graphs are examined, it is observed that the majority of the farm's energy demand was met by the grid as in years 1 and 5. While the amount of energy met by the wind turbines and PV system didn't change, the amount of energy met by the biogas increased by 794.05 kW and reached 1329.79 kW compared to year 5.

In Fig. 18, the graphs indicating the values of the 15th year of the installed system are given. When these graphs are examined, it is observed that the farm's energy demand was met by the grid and the biogas. The amount of energy met by biogas exceeded the amount of energy met by the surplus grid.

In Fig. 19, the graphs indicating the values of the 20th year of the installed system are given. In year 20, it is observed that the majority of the farm's energy demand was met by the BG and that no electricity was procured from the grid.

In Table 5, the general results of the simulation are given. In year 1, 6.22% of the farm's energy demand was met by the PV panels, 7.81% of it by the BG, 0.29% of it by the wind turbines, and 85.7% of it by the grid. In years 5, 10, and 15, while the rate of meeting the energy demand by the PV panels, wind turbines and grid decreased, the rate of meeting it by the BG gradually increased. And in year

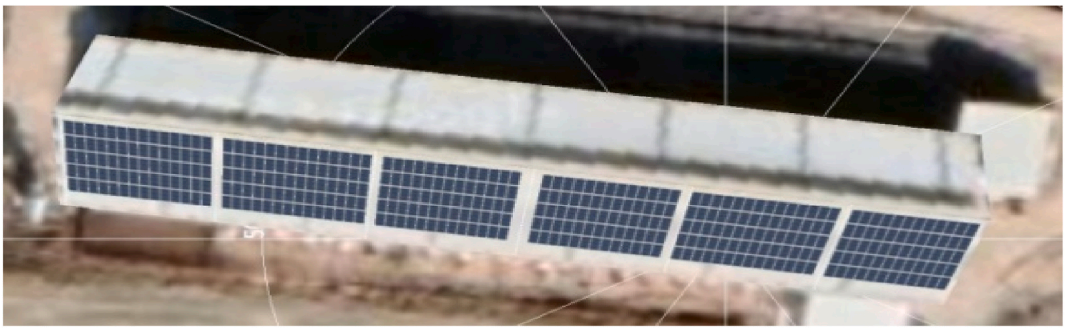


Fig. 11. Determination of PV electricity generation.

Table 1
Properties of the panel and inverter.

Photovoltaic Panel	Panel power	400 W
	Open-circuit voltage	49.8 V
	Max. power voltage	41.40 V
	Efficiency	20.06%
	Short-circuit current	10.38 A
	Max. input current (for each MPPT)	26 A
	Panel's power tolerance	+5 W
Inverter	Max. power current	9.75 A
	Total harmonic distortion	<3%
	Efficiency	98.6%
	Operating voltage	200–1000 V
	MPPT Number	10
	Nominal grid frequency	50/60 Hz

Table 2
Comparison of the results by years in PV*SOL.

Years	Year 1	Year 5	Year 10	Year 15	Year 20
PV Generated Energy (MW/year)	226.417	226.417	226.417	226.417	226.417
Required Energy (MW)	120.06	120.226	121.010	122.938	127.669
Energy Drawn by the Farm from the PV (MW)	31.44	31.47	31.59	31.90	32.63
Energy Drawn by the Farm from the Grid (MW)	88.62	88.76	89.42	91.04	95.043
Energy Sold to the Grid (MW)	194.95	194.92	194.8	194.496	193.77
Rate of Solar Energy Used (%)	26.2	26.2	26.1	26	25.6
Rate of Energy Drawn from the Grid (%)	73.8	73.8	73.9	74	74.4

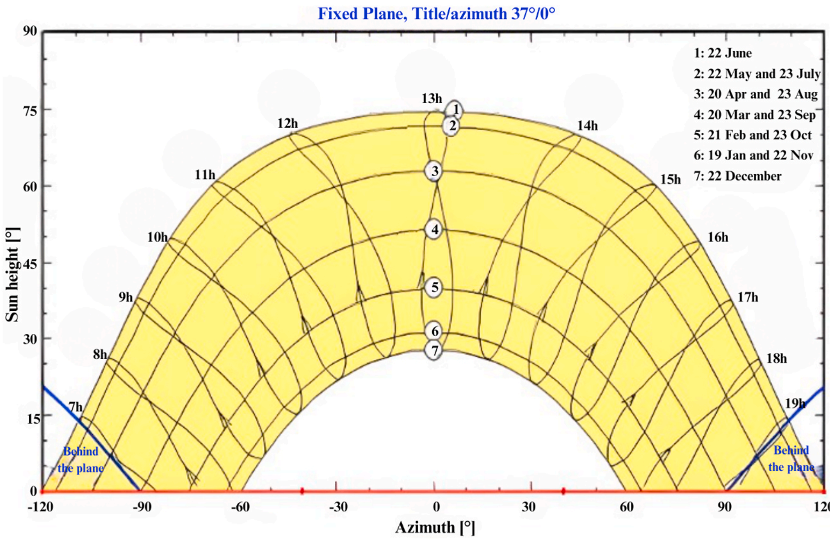


Fig. 12. Sun path.

20, the farm's energy demand was met by the PV panels at a rate of 4.1%, by the wind turbines at a rate of 0.19%, and by the BG at a rate of 95.8%, and no electricity was procured from the grid.

In Table 6, the amount of electricity sold to the grid is indicated in detail. In year one, 5.93% of the electricity produced was resold to the grid; by year twenty, the figure had risen to 38.9%. The system derived profit from such sales of electricity.

In Fig. 20, the emissions were compared on the basis of years for the designed HPS. It was observed that the carbon dioxide (CO_2) in Fig. 20a, sulfur dioxide (SO_2) in Fig. 20b, and nitrogen monoxide (NO) in Fig. 20c values decreased over the years. Fig. 20d an increase in the amount of carbon monoxide (CO) occurs as the result of obtaining energy by burning the biogas. This increase was within acceptable limits.

In Table 7, the comparison data as per years of the electric power generated by the PV system installed for the farm in the HOMER, PVsyst, and PV*SOL programs is given. In years 1, 5, 10, 15, and 20, the electric power generated by the PV system installed in HOMER was 237.43 MW, in PV*SOL it was 226.417 MW, and in PVsyst it was 195.6 MW. Namely, the energies generated in the programs are different from each other.

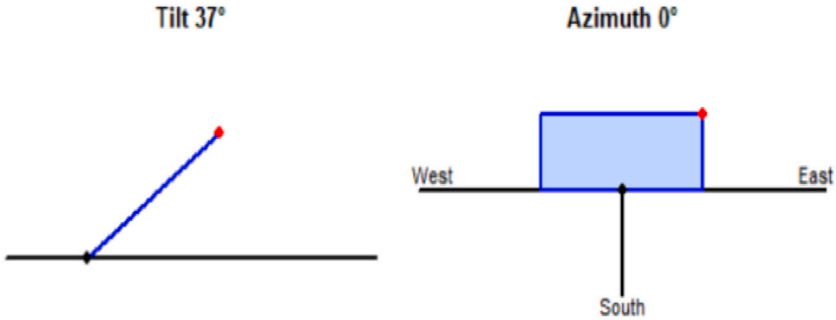


Fig. 13. Tilt angle and azimuth angle.

Table 3
Comparison of the results by years in PVsyst.

Years	Year 1	Year 5	Year 10	Year 15	Year 20
PV Generated Energy (MW/year)	195.6	195.6	195.6	195.6	189
Required Energy (MW)	120.06	120.226	121.010	122.938	127.669
Energy Drawn by the Farm from the PV (MW)	49,57	50.28	53.57	61.41	78.43
Energy Drawn by the Farm from the Grid (MW)	70.49	71.79	77.92	93.21	128.58
Energy Sold to the Grid (MW)	145.99	145.27	141.99	134.2	117.13
Rate of Solar Energy Used (%)	41.29	41.19	40.74	39.72	37.89
Rate of Energy Drawn from the Grid (%)	58.71	58.81	59.26	60.28	62.11

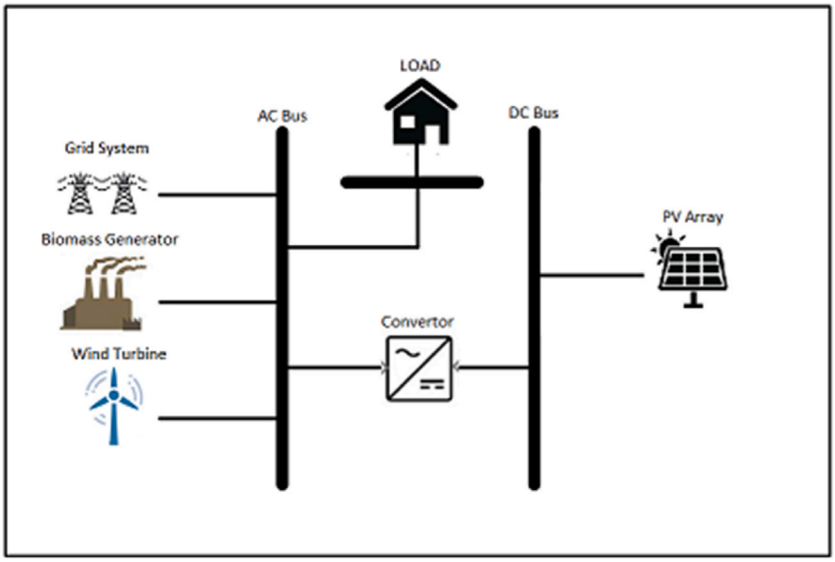


Fig. 14. On-grid HPS modeling.

Table 4
Unit costs.

Components	Capital [$ /kW]	Replacement [$ /kW]	O&M	Lifetime (year)
Wind Turbine	306.9	2600	20 $/year/kW	20
BG	1690	1300	0.0054 $/hour/kW	20
PV	1000	900	20 $/year/kW	20
Converter	400	400	0.01 $/year/kW	20

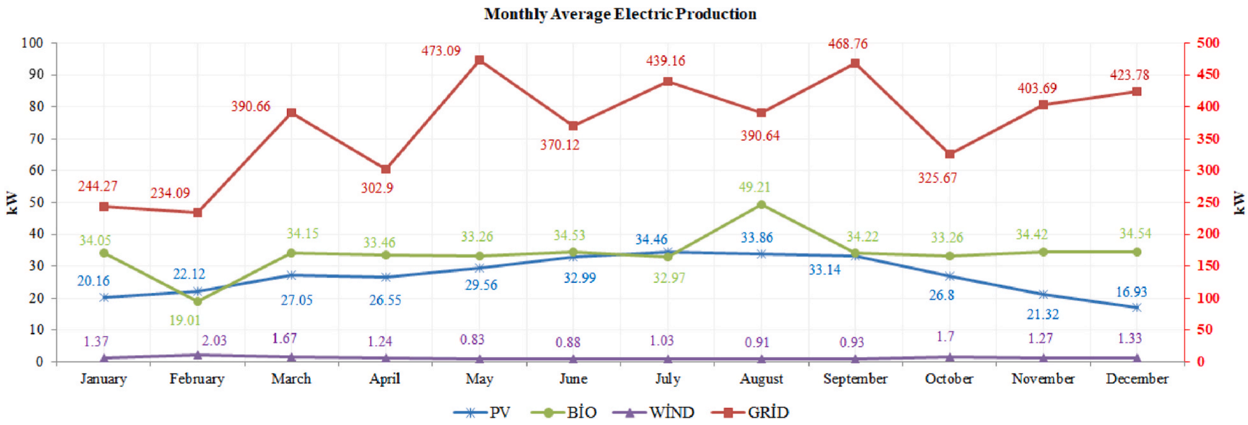


Fig. 15. Electricity generation values in year 1.

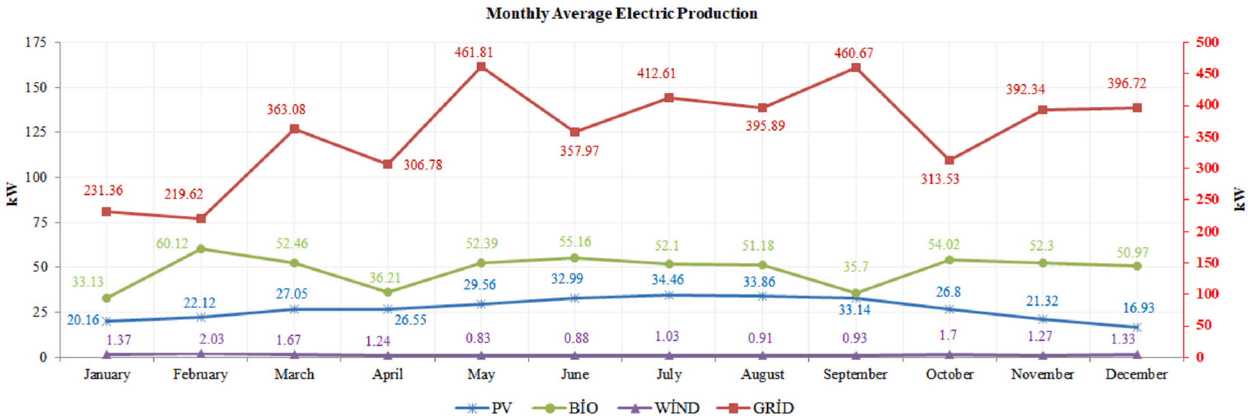


Fig. 16. Electricity generation values in year 5.

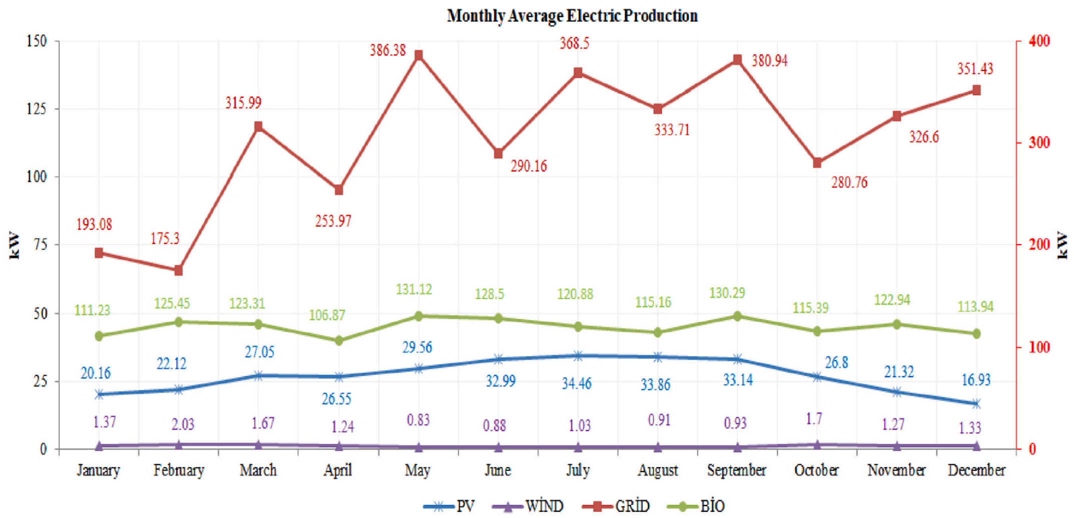


Fig. 17. Electricity generation values in year 10.

In Table 8, the results of the PV system formed in the HOMER program are given. The electric power generated by the PV panels in all the years was the same, and it was 237.42 MW. While the electric power drawn from the PV system by the farm was 31.17 MW in year 1, it became 26.89 MW in year 20. In other words, the rate of meeting the farm's electric power demand from the installed PV system gradually decreases. While the sale of electricity to the grid from the installed system was 206,25 MW in year 1, it increased to

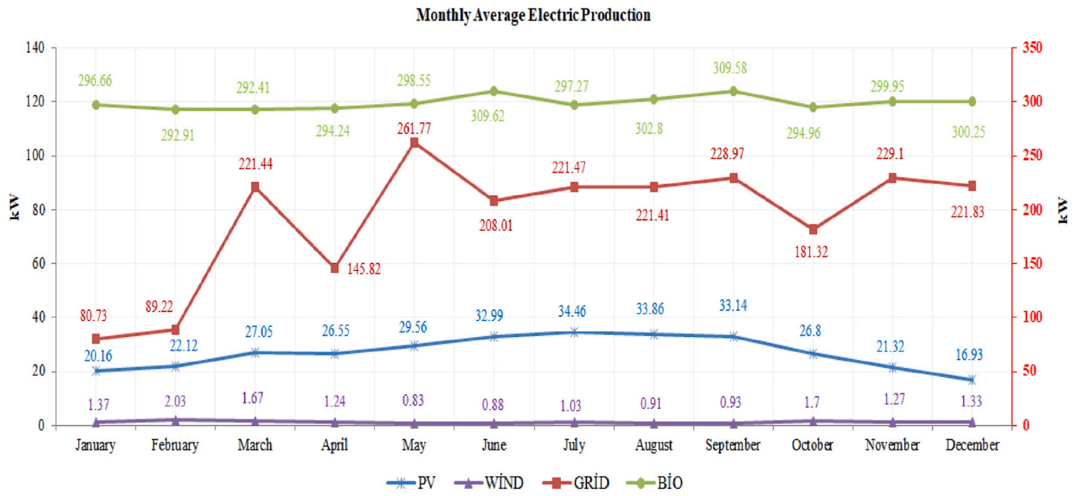


Fig. 18. Electricity generation values in year 15.

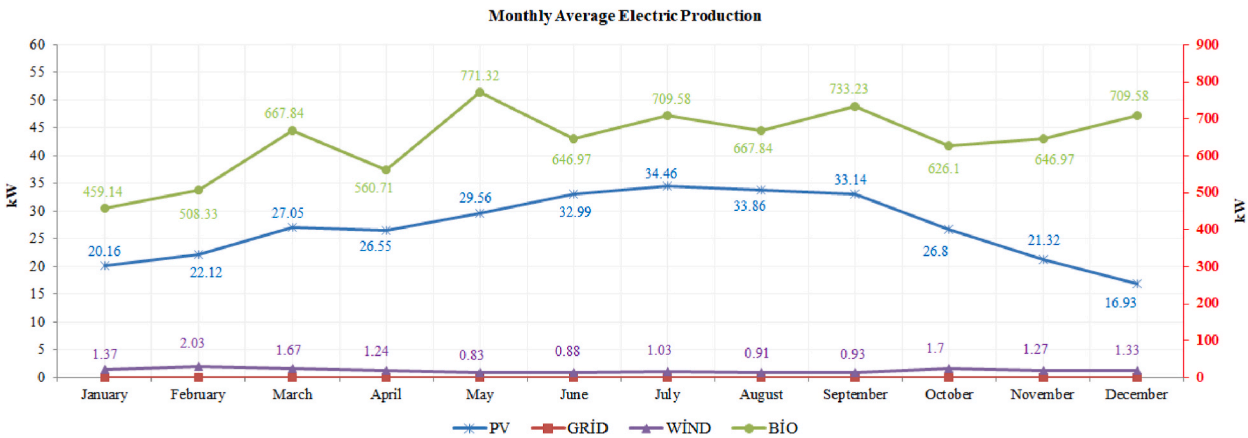
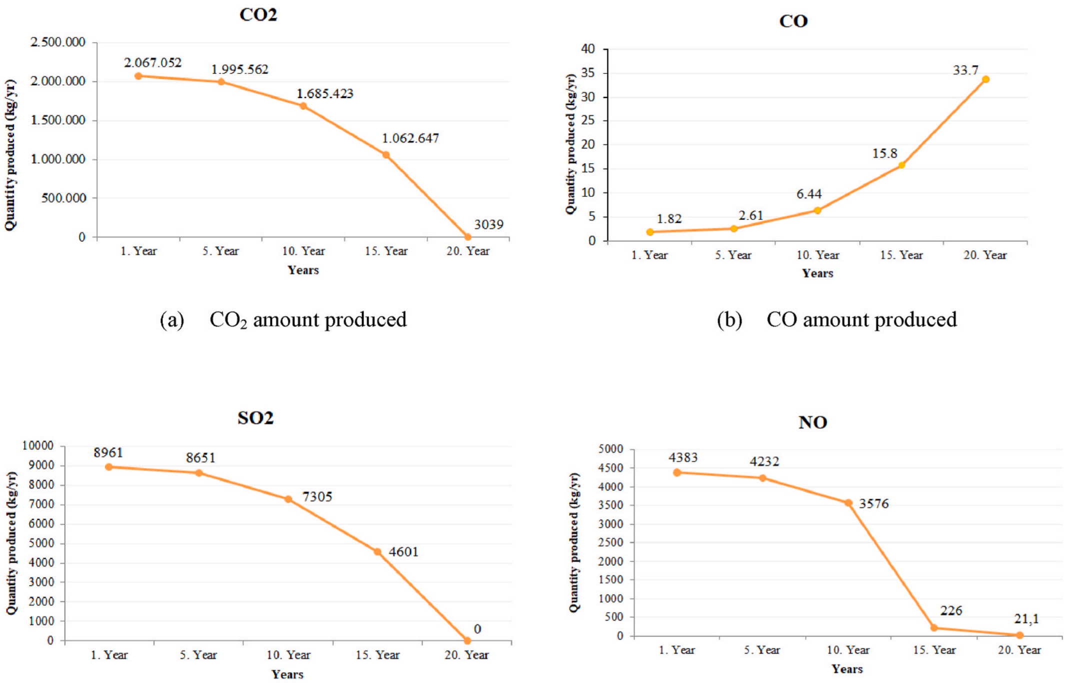


Fig. 19. Electricity generation values in year 20.

210,527 MW in year 20.

In Fig. 21, the comparison years of the results of the PV system installed in HOMER, PVsyst, and PV*SOL programs are shown. In the graphs, the distribution of the generated energy (GE), the farm's energy need (EN), the energy drawn by the farm from the PV system (ERS), the energy drawn by the farm from the grid (ERG), and the energy sold to the grid (ESG) as per years is given.

In Fig. 21(a), the graphs indicating the distribution of the GE, EN, ERS, ERG, and ESG relevant to year 1 in the PVsyst, PV*SOL, and HOMER programs are given. The amount of energy generated was different in all three programs. The farm's energy need was indicated as 120.06 MW. The energy drawn by the farm from the panels was the highest in the PVsyst program at 49.57 MW. While the generated energy sold to the grid was 206.25 MW in the HOMER program, it was lower in the PVsyst and PV*SOL programs. In Fig. 21 (b), the GE, EN, ERS, ERG, and ESG relevant to year 5 are given. The amount of energy generated was different in all the three programs as in year 1. The farm's energy demand increased and reached to 120.226 MW. The farm's PV panel energy consumption was 29.96 MW in HOMER, 50.28 MW in PVsyst, and 31.47 MW in PV*SOL. In Fig. 21(c), the GE, EN, ERS, ERG, and ESG relevant to year 10 are given. The amount of energy generated was different in all the three programs as in years 1 and 5. In Fig. 21(d), the GE, EN, ERS, ERG, and ESG relevant to year 15 are given. The amount of energy generated was different in all three programs as in years 1, 5, and 10. The farm's energy demand increased to 122.938 MW. The energy drawn by the energy and PV system drawn by the farm from the grid indicated increases in each program compared to previous years. And while the energy sold to the grid increased in the HOMER program, it decreased in other programs. In Fig. 21(e), the GE, EN, ERS, ERG, and ESG relevant to year 20 are given. The amount of energy generated was different in all three programs as in years 1, 5, 10, and 15. The farm's energy demand increased to 127.669 MW. In Fig. 22, the graph indicating the economic analysis of HPS as per years is given. While the unit cost of the electric power sold (LCOE) was 24.15 TRY in year 1, it decreased over the years, and it began to derive profit by decreasing to negative value in year 5. In 20 years, the unit price of electric power increased by 6.55 TRY.



(a) CO_2 amount produced

(b) CO amount produced

(c) SO_2 amount produced

(d) NO amount produced

Fig. 20. Emission values.

Table 5
General results over the years in HOMER.

	Year 1		Year 5		Year 10		Year 15		Year 20	
Production	kW/yr	%	kW/yr	%	kW/yr	%	kW/yr	%	kW/yr	%
PV	237.42	6.22	237.42	6.2	237.42	5.96	237.42	5.2	237.42	4.1
Biogas	298,225	7.81	427,139	11.1	1054.37	26.5	2620.16	57.4	5620.86	95.8
Wind Turbine	11,052	0.29	11,052	0.29	11,052	0.28	11,052	0.24	11,052,052	0.19
Grid Purchases	3269.36	85.7	3156.19	82.4	2678.02	67.3	1693.58	37.1	0	0
Total	3816.06	100	3831.80	100	3980.87	100	4562.21	100	5869.34	100

Table 6
Electricity sales to the grid in HPS over the years.

Grid Sales	**Year 1**		**Year 5**		**Year 10**		**Year 15**		**Year 20**	
	kW/yr	%	**kW/yr**	%	**kW/yr**	%	**kW/yr**	%	**kW/yr**	%
	224,885	5.93	240,458	6.31	384,553	9.22	965,308	21.3	2,272,14	38.9

Table 7
Comparison of data of electricity generation from solar energy in HOMER, PVsyst, and PV*SOL.

Years	Year 1	Year 5	Year 10	Year 15	Year 20
PV*SOL (MW/year)	226.417	226.417	226.417	226.417	226.417
PVsyst (MW/year)	195.6	195.6	195.6	195.6	195.6
HOMER Pro (MW/year)	237.42	237.42	237.42	237.42	237.42

Table 8
Comparison as per years of the results of the PV system in HOMER.

Years	Year 1	Year 5	Year 10	Year 15	Year 20
PV Generated Energy (MW/year)	237.42	237.42	237.42	237.42	237.42
Required Energy (MW)	120.06	120.226	121.010	122.938	127.669
Energy Drawn by the Farm from the PV (MW)	31.17	29.96	29.195	28.68	26.89
Energy Drawn by the Farm from the Grid (MW)	88.89	90.27	91.815	94.26	100.78
Energy Sold to the Grid (MW)	206.25	207.46	208.23	208.74	210.527

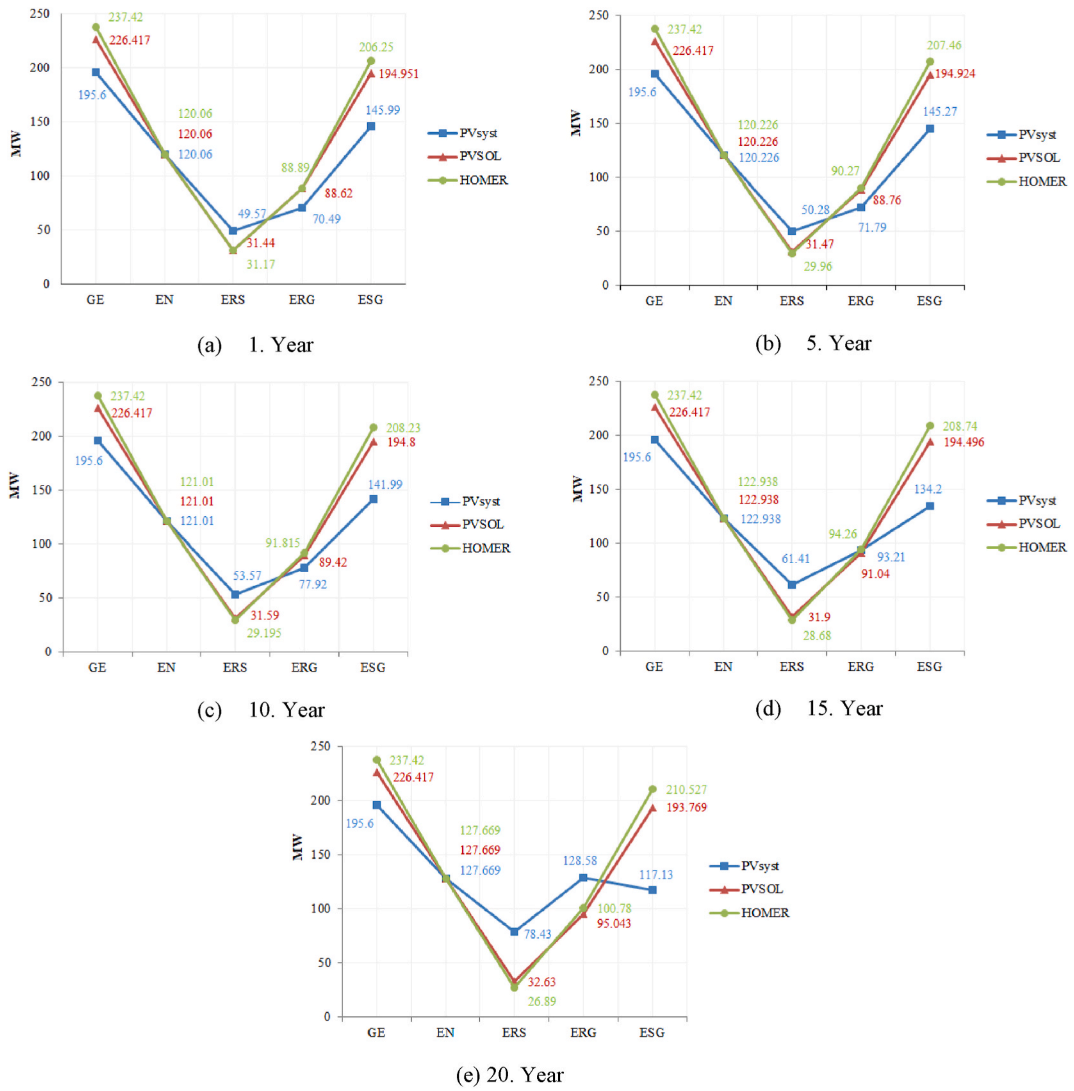


Fig. 21. Comparison as per years of the results of PV systems installed in the programs.

The graph in Fig. 22 is the one indicating the financial status analysis (FS). In the financial status analysis, while there was a loss of 89,828.82 TRY in year 1, it was moved into profit by the 6th month of the 12th year of system's installation, and a profit of 52,712.70 TRY was derived in year 20.

4. Conclusions

The RES has the potential to decrease the energy deficit, especially in rural areas in developing countries. While the biogas meets the local energy demand, it also decreases the environmental effects of bovine animal waste. As a result of the analyses performed, it was observed that only the system installed with PV would not be able to meet the load demand of the farm in the following years. And

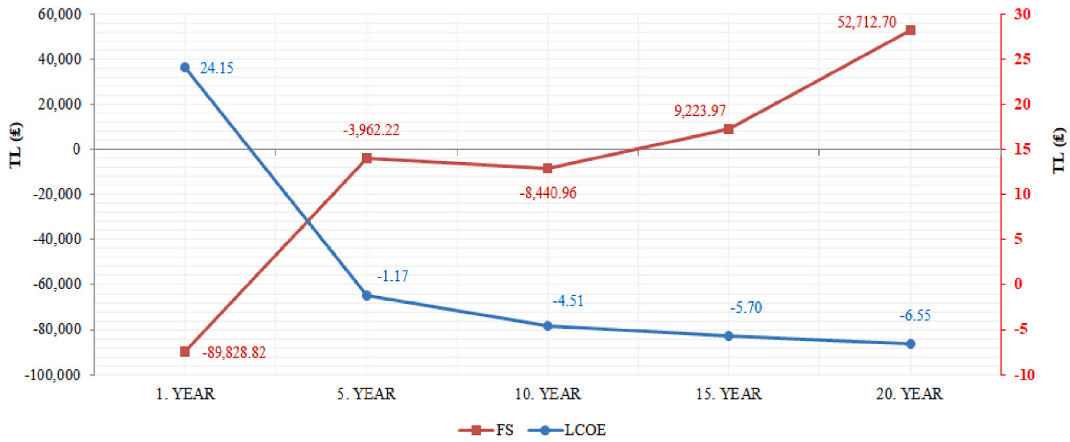


Fig. 22. Economic analysis of HPS as per years.

then an on-grid system was installed with the HPS comprised of a wind turbine, PV panels, and BG. While the farm was drawing electricity from the grid at a rate of 85.7% in the initial years, the rate of procuring electricity from the grid decreased to 0% in the following years. While the farm's energy demand was 120.06 MW in year 1, it didn't increase much in 20 years and reached to 127.669 MW. In HPS, while the rate of energy generation from BGs was 7.81% in year 1, the referred rate increased over the years and reached to 95.8% in year 20. It has monitored that the HPS could supply the farm's energy demand over the years and that it even performed electricity sales to the grid at a rate of 38.9%. Moreover, it is anticipated that meeting the local energy demand at consumption points, considering the dynamics of regional RES, will minimize energy costs and losses and significantly contribute to sustainable energy and environmental objectives.

Author contribution statement

Osman Oz: Performed the experiments; Wrote the paper. Mustafa Sahin: Conceived and designed the experiments. Onur Akar: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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