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A HYBRID ENERGY PRODUCTION SYSTEM MODEL FOR ELECTRIC VEHICLES IN GIRESUN PROVINCE AND ENERGY PRODUCTION PROJECTION FOR 2030

Renewable energy sources are increasingly gaining interest due to their environmentally friendly features and sustainability. This interest is increasing with the awareness of the environmental damage and depletion possibilities of fossil fuels, which are currently used intensively. However, discontinuity, which is a significant disadvantage of renewable energy sources, is seen as a factor limiting the development of this field. In this study, a study focusing on a hybrid energy system that combines solar and wind energy with biogas sources was conducted. The inability to provide solar energy production at night, the fluctuation of wind energy production due to changing weather conditions, and the variability in energy production of biogas systems depending on the raw material are the factors affecting the design of this hybrid system. In this study, discontinuity in renewable energy production was minimized with the hybrid system. Hybrid systems integrate solar, wind and biogas energy sources, ensuring that the energy obtained from these sources balances each other. In this way, even in cases such as adverse weather conditions or night hours, the fluctuation in energy production is reduced and a continuous and stable energy source is obtained. With the widespread use of electric vehicles, energy demand is expected to increase even more. A sample design proposal has been made in order to meet this increasing energy need from clean and sustainable sources. In addition, in this study, a system has been proposed for the future reference of Turkey's energy need for electric vehicle charging stations, for a time estimate over a location determined in Giresun province and for this need to be met with clean energy. The design of the system was carried out through the HOMER PRO program.

Keywords: Hybrid energy; electric vehicle; solar and wind energy; HOMER PRO

1. Introduction

Nowadays, the growing interest in environmentally friendly energy sources is becoming increasingly important with the environmental impacts and limited reserves of fossil fuels. In this context, renewable energy attracts attention with its potential to meet sustainable and clean energy needs. However, the inherent intermittency of renewable energy sources such as solar and wind makes stability in energy production difficult. To overcome this challenge, this study focuses on a hybrid energy system combining solar, wind and biogas energy sources. The motivation for designing the hybrid energy system is to tackle the factors such as the fluctuations of solar energy at night, wind energy due to variable weather conditions, and the variable energy production of biogas due to feedstock. By integrating different energy sources, this system aims to provide continuous energy production even during adverse weather conditions or certain hours.

The primary objective of this study is to encourage the use of clean energy for the charging stations of electric vehicles, which are becoming increasingly widespread in Turkey, with plans to transition to fully electric vehicles in Europe by 2030. Ensuring that the energy used to meet the charging needs of electric vehicles comes from clean and sustainable sources is an effort to reduce environmental impacts and contribute to the transformation of the energy sector. In addition, a solution will be proposed in terms of using clean energy sources against the increasing energy demand with the widespread use of electric vehicles. In this context, the focus will be on clean energy sources such as solar energy, wind energy and biogas, avoiding petroleum and derivative fuels to prevent harmful emissions to the atmosphere. A simulation was designed to simulate the charging of 56 vehicles per day and 20,440 vehicles per year in Giresun province, which was chosen as a reference for Turkey's electric vehicle charging stations, on the Black Sea coastal road. Consid-

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ering the charging waiting time with DC 50 kW fast charging, a charging station with a suitable value and socket structure for each vehicle was designed.

The innovation in this scientific study is scientifically proven by the design of a renewable energy production system with a three-source hybrid system, which is a different aspect of meeting the green energy used by electric vehicles that have just entered the market. By increasing the number of this type of power plants, it will be possible to make more predictions in determining the need for fossil fuels.

In this study, no direct experimental or analytical study was conducted on the conversion of landfill gas into energy. Instead, calculations and system modeling were performed using coefficients and default parameters taken from scientifically published works provided by the software called HOMER Pro. In this context, energy conversion coefficients, efficiency ratios and other technical variables were evaluated in accordance with the accepted standard values in the database of HOMER Pro and system performance analyses were conducted within this framework. Therefore, the results were obtained based on the parameters provided by the software and do not include an independent field study or additional experimental analysis.

1.1. Turkey's 2030 Projection

Turkey's population is constantly changing and increasing over time. When the population change and population growth rate of Turkey for the years 2008-2022 are analyzed in Fig. 1, it is seen that while there is a continuous increase in the amount of population, there are fluctuations and even decreases in the population growth rate [1].

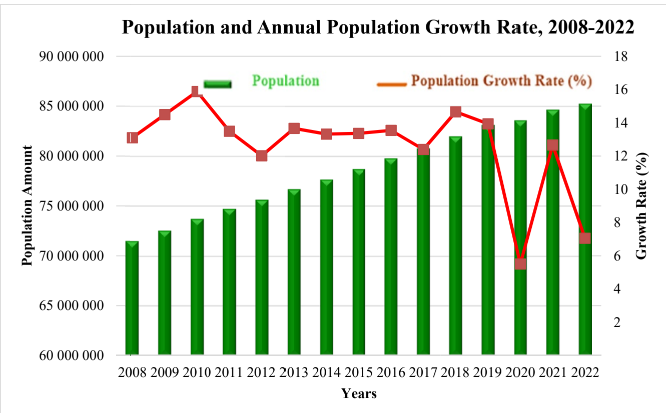


Fig. 1. Turkey's Population Change and Population Growth Rate by Years [1]

Based on the latest population projection study 2018-2080, which is based on the 62-year population projection prepared by the Turkish Statistical Institute (TurkStat), the population is expected to be 93.3 million in 2030.

1.2. Turkey's Energy Targets

Turkey's energy need is an ongoing situation with factors such as the country's economic growth, industrialization, population growth and increasing energy demand. Energy products differ depending on the types of energy used in production, electricity, transportation, industry and other sectors [2,3]. As Turkey's energy needs increase year by year, the government determines energy policies by paying attention to factors such as energy economics, environmental protection and sustainability. These policies can be shown as sections such as promoting supportive energy activities, increasing the amount of energy and diversifying energy sources [4]. Turkey's energy target supports diversifying energy consumption, increasing energy space, ensuring the amount of energy supply and sustaining growth. These targets are set with the aim of sustaining economic growth, minimizing the extraction of energy and moving towards environmentally friendly energy sources [5]. Options for Turkey's energy targets:

Increasing Renewable Energy Sources: Turkey aims to invest more in renewable energy sources and increase their use in electricity generation [4]. Energy Efficiency Improvement: Improving energy efficiency enables more efficient use of energy resources, reduces energy costs, reduces environmental impacts and promotes energy sustainability [4]. Security of Energy Supply: It is important in terms of access to and continuous supply of energy. If energy supply security is not taken care of, it may face problems such as energy shortages, price fluctuations and external dependency. Therefore, it is important to develop and implement long-term strategies to enhance energy supply security. Turkey aims to diversify its energy sources and reduce energy imports in order to ensure energy supply [6]. Infrastructure Development: Turkey aims to strengthen its energy infrastructure and modernize its energy distribution and distribution systems [3]. Nuclear Energy: Turkey aims to add nuclear energy to its portfolio with nuclear energy projects such as the Akkuyu Nuclear Power Plant [7]. Decarbonization and Sustainability: Turkey plans to reduce carbon emissions from the energy sector. This is done in order to combat climate change and promote clean energy [8].

1.3. Climate Change and Energy Demand

Climate change can lead to temperature increases, droughts, reduced water resources, changes in agricultural productivity, forest fires, floods and sea level rise [9].Turkey is considered as an affected country that plays an important role in combating climate change. The Turkish government is implementing various policies and projects to combat climate change. These projects include steps such as renewable energy investments, efforts to increase energy efficiency, forest regeneration projects and the creation of national action plans to combat climate change. In addition, policies and strategies aiming to realize Turkey's climate goals in accordance with the Paris Agreement are also determined [10].

The Paris agreement was adopted in Paris in 2015 at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC). Within the framework of this agreement, the importance of reducing greenhouse gas emissions was emphasized and decisions were taken on this issue [11]. In addition, Turkey has prepared the Green Deal Report by adapting the European Green Deal prepared by the European Commission to its own conditions. There are 9 main headings and 32 targets in this report. This report, the content of which is generally sustainability and economic growth that can achieve high efficiency with limited resources, also addresses the issue of clean economic and secure energy supply [12]. Turkey ratified the Paris Climate Agreement in 2016 and made commitments to combat climate change in accordance with the agreement.Within the scope of Turkey's National Energy Plan prepared by the Ministry of Energy and Natural Resources, a study is being conducted to assess electricity generation for 2030. This study attempts to forecast energy demand by taking into account population projections, economic growth forecasts, sectoral energy allocations, industrial demands, energy efficiency target, growth and sustainability. This report, developed by the Ministry of Energy and Natural Resources, is used to guide the country's energy strategies, resource diversification targets, the aim to support sustainable energy use, and investments, policies and projects in the energy sector.

1.4. Turkey's Energy Needs in 2030

In December 2022, Turkey's National Energy Plan 28 (NEAP) was published by the Ministry of Energy and Natural Resources (MENR). In this study, the target was set as "Zero Emissions by 2053". This plan includes detailed forecasts for the year 2035. By 2035, the installed capacity of renewable energy reaches 64.7% [13].The installed capacity of electricity rises to 149.1 GW in 2030. This power is expected to be provided by 32.9 GW solar, 29.6 GW wind and 7.2 GW newly commissioned nuclear energy. TUEP 2022 Electricity Installed Capacity (GW) data are given in TABLE 1. Electricity installed capacity projections were made for 3 different years. A significant increase is foreseen in the data related to renewable energy sources. When the total installed capacity is analyzed, it is seen as 116.2 GW for 2025, 149.1 GW for 2030 and 189.7 GW for 2035.

TABLE 1

Electricity Installed Capacity (GW) [13]

SOURCES	2025	2030	2035
Coal	21.1	22.8	24.3
Gas	24.2	30.3	35.5
Nuclear	2.4	4.8	7.2
Hydraulics	33	35.1	35.1
Wind	13.1	18.1	29.6
Sun	17.9	32.9	52.9
Other	4.5	5.1	5.1
TOTAL	**116.2**	**149.1**	**189.7**

TABLE 2 shows the projection of electricity generation by source (TWh) for three different years (2025-2030-2035). The increasing share of renewable energy sources in electricity generation is a trend seen across the world and in many countries. This increase is supported by important reasons such as environmentally friendly energy production, energy security and combating climate change [13]. Fossil resources refer to energy derived from fossil fuels such as coal, oil and natural gas. These sources are widely used in energy production, but the transition to renewable energy sources is encouraged due to their environmental impacts, climate change and sustainability concerns [12]. The projections foresee a significant increase in the share of renewable energy sources in electricity generation. This increase can be based on factors such as developments in renewable energy technologies, costs, government policies and societal demands. In addition, technological innovations and sustainability goals in the energy sector may also have an impact [12]. Projections for a smaller increase in fossil resources can be based on factors such as the fact that fossil fuels are finite resources, efforts to reduce carbon emissions, and increased energy efficiency [14]. Such projections and resource allocations provide important information on how energy policies and investments should be shaped.

TABLE 2

Sources of Electricity Generation (TWh) [13]

SOURCES	2025	2030	2035
Thermal	196.4	201.2	173.7
Nuclear	18.6	37.2	55.8
Hydraulics	81.9	87.9	87.9
Wind	38.3	53.7	90.1
Sun	28.3	52.2	84
Other	16.7	20.5	16.2
TOTAL	**380.2**	**452.7**	**507.7**

There are many factors that need to be taken into account for future projections of per capita energy consumption. Some of these factors can be Economic Growth, Population Size and Demography, Technological Progress, Energy Policies and Regulations, Energy Resources, Social Habits and Lifestyle, Global Factors, Environmental and Social Factors. According to the Turkish Statistical Institute data, the population is expected to be 93 328 574 people in 2030 [15]. For 2030, Turkey's generation is projected to be 452.7 TWh [13]. Based on this, to calculate the per capita consumption for 2030, we divide 452 700 TWh by the population, i.e. 93 328 574, and the result is approximately 4843.6 kWh per capita. As a result, the per capita energy consumption in Turkey increases approximately one and a half times in 2030. It is very important to meet a large part of the increasing energy need from renewable energy sources.

With the widespread use of electric vehicles, people's energy demand is expected to increase even more. A design proposal will be made to meet this increasing energy demand from clean and sustainable sources. In this context, the focus will be on completely clean energy sources such as solar energy, wind energy and biogas. This choice has been made to avoid the harmful emissions of petroleum and derivative fuels into the atmosphere, the safety risks associated with nuclear energy, and the negative impacts of hydroelectric power on the environment and ecosystem. This design proposal aims to promote the integration of clean energy sources in order to meet future energy demand and at the same time minimize environmental impacts. In this way, it aims to minimize the negative impacts of energy production processes and contribute to a sustainable energy future. This system was modeled with Homer Pro.

1.5. Electric Vehicles

The history of electric vehicles dates back to the early 19th century. In the 1830s, the concept of the first electrically powered transport vehicles emerged and the era began with the first electric vehicle built by Thomas Davenport in 1835. However, in this early period, electric vehicles often had a limited impact due to their high cost and complexity. While electric vehicles were preferred especially in urban transportation from the early 1900s onwards, they fell into the background with the widespread use of internal combustion engines in the 1920s. With the oil crises and environmental concerns in the 1970s, electric vehicles, which do not require oil, came back on the agenda. Towards the end of the 1990s, interest in hybrid vehicles increased with technological developments. In the 2010s and beyond, fully electric vehicles, led by companies such as Tesla, revitalized the electric vehicle market. Today, various automobile manufacturers are expanding their electric vehicle portfolios and technological advances in this field continue. Electric vehicles will continue to play an important role in the future of sustainable and environmentally friendly transportation [16].

1.6. Transition to Electric Vehicles in Turkey

The Turkish Statistical Institute (TurkStat) shared with the public the number of motorized land vehicles in the country by sharing updated data for the end of November 2023. According to the announcement, the number of cars, vans, motorcycles, trucks and buses among motorized land vehicles was determined. The distribution of motor vehicles by fuel type and the total number of vehicles in Turkey by years 2021-2022 and since November 2023 can be followed in TABLE 3. The spread of electric vehicles and technological advances in this field reflect Turkey's development in the field of sustainable transportation [17].

As of the end of November 2023, a total of 15 million 131,392 vehicles were registered in Turkey. Of these vehicles, 69,914 were registered as fully electric cars, while 213,105 were hybrid cars. Hybrid cars are a technology that combines electricity with diesel or gasoline engines. This data shows the impact of electric vehicles and hybrid cars on traffic in Turkey. Electric vehicles reflect Turkey's increasing shift towards sustainable transportation and environmentally friendly technologies, while hybrid cars aim to improve energy efficiency by combining electric motors with conventional fuel engines. These data show the diversification of vehicle types and developments in sustainable transportation trends in the country [17].

The Mobility Vehicles and Technologies Roadmap, prepared by the Ministry of Industry and Technology with the contribution of relevant public institutions and sector actors, focuses on the development of electric vehicles in Turkey. Within the scope of this roadmap, a projection with three different scenarios (low, medium and high) has been created, as shown in TABLE 4. These scenarios for the diffusion and development of EV technologies provide a strategic framework for determining the future directions and potential development levels of the sector. This framework is an important guide for the policies and practices to be adopted in Turkey's EV sector [18].

TABLE 3

Distribution of Motor Vehicles by Fuel Type [17]

Year	Total	Gasoline	Diesel	LPG	Hybrid(2)	Electricity	Unknown(3)
2021	**13 706 065**	3 495 172	5 158 803	4 923 275	86 682	**6 267**	35 866
2022	**14 269 352**	3 817 104	5 261 876	5 005 563	134 662	**14 552**	35 595
2023(1)	**15 131 392**	4 312 931	5 416 875	5 083 162	213 105	**69 914**	35 405

(1) Data are as of end-November.
(2) Includes hybrid, gasoline-electric and diesel-electric cars.
(3) Unknown fuel type includes automobiles for which the fuel type was left blank or incorrect data was entered by mistake in the registration process.

TABLE 4

Projection of the Number of Electric Vehicles in 2025 and 2030 [18]

Projection Years	Scenarios	Number of Electric Vehicles	Total Number of Electric Vehicles
Year 2025	**High**	180 000	400 000
	Medium	120 000	270 000
	Low	65 000	160 000
Year 2030	**High**	580 000	2 500 000
	Medium	420 000	1 600 000
	Low	200 000	880 000

2. Research findings

2.1. Establishment of the Energy Production Model

Hybrid energy systems are systems that aim to produce energy by combining various renewable energy sources. These systems usually include solar panels, wind turbines, biogas generators and converters. By combining various energy sources, the system aims to increase energy production and ensure continuity. According to the research, while energy consumption per capita was 3360.4 kWh in 2022, this value is expected to increase to approximately 4843.6 kWh in 2030. In addition, there will be an increase in the number of power plants and production power. In this system design, the discontinuity of renewable energy resources will be eliminated with complementary systems. Thanks to this system, 24/7 uninterrupted energy production from renewable energy sources will be possible. Turkey's National Energy Plan, which is taken as a reference for the establishment of the energy production model, 2022 Data and 2030 Estimates of Production by Sources are given in TABLE 5 [13].

TABLE 5

Turkey's National Energy Plan 2022 Data and 2030 Forecasts of Generation by Sources [27]

Sources	2022 Data (TWh)	2030 Forecasts (TWh)	Difference (TWh)
Sun	15.43	52.2	36.77
Wind	35.14	53.7	18.56
Hydraulics	67.19	87.9	20.71
Nuclear	0	37.2	37.2
Fossil Fuel	186.74	201.2	14.46
Other	19.99	20.5	0.51
Total	**324.49**	**452.7**	**128.21**

The amount of energy needed by Turkey for 2030 is determined as 452.7 TWh. Within the scope of this study, a hybrid power generation system is designed to generate electricity by using solar, wind and biogas energy together under Turkish conditions [18]. According to the data of GEPA, Turkey, which is put into service by the Ministry of Energy and Natural Resources, Turkey's sunshine potential is calculated as 7.49 on average per month in line with Turkey's radiation values and Turkey's sunshine duration data [19].

2.2. Modeling the System

2.2.1. Homer (Hybrid Optimization of Multiple Electric Renewables) Program

HOMER Pro is a software used by experts in microgrid design, energy systems optimization and analysis. This software can perform the design of complex energy systems involving different energy sources and components. By integrating various components such as wind turbines, solar panels, diesel generators, hydroelectric systems, batteries and other energy storage solutions, it allows users to determine optimal energy configurations. With scenario analysis and optimization tools, it offers various options for creating cost-effective and efficient energy systems [20]. HOMER Pro also has the capacity to conduct sustainability assessments of energy storage systems, as well as analytical and reporting tools. Users can take advantage of extensive analytical features to monitor and report on the performance of energy projects. These features make it an essential tool for experts in various sectors, especially those carrying out projects in areas such as energy access in remote areas, microgrids, energy planning and sustainability projects. HOMER Pro is a powerful tool for engineers, planners and energy professionals who want to work on complex energy systems [20].

2.2.2. Determination of System Needs

According to the evaluations made, the electric car model that reached the highest sales in the Turkish automobile market in 2023 was the "TOGG T10X", Turkey's domestic production, with a total of 19583 units sold. The second ranked domestic electric car was the "TESLA Model Y" with 12150 deliveries. Turkey's own brand TOGG continues its presence in the electric car market, attracting attention with its contribution to both domestic production and electric vehicle technologies [21].The best-selling electric car models and sales numbers in the Turkish market are given in Fig. 2.

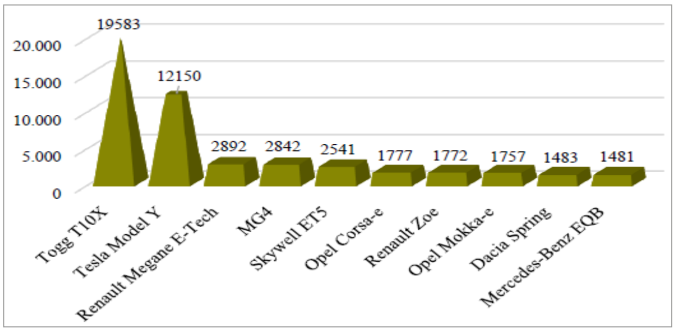


Fig. 2. Brands and Their Numbers in the Turkish Automotive Market [21]

In this study, the leading electric vehicle models in the Turkish market were selected and calculations were made based on the battery capacities of these vehicles as given in TABLE 6.

TABLE 6

Selected Electric Vehicle Models and Battery Capacities [22]

Electric Car Models		Battery Capacities (kWh)
TOGG T10X	V1RWD	52.5 kWh
	V2RWD	88.5 kWh
TESLA	Model S	85 kWh
	Model Y	75 kWh
Total		**301 kWh**

The planned hybrid power system is designed to charge electric vehicles in the selected region. There are 4 electric vehicle models with a total battery capacity of 301 kWh, and the system design is planned to charge 2 of these vehicle models per hour. In this case, it is aimed to charge 8 vehicles per hour, that is, to meet the energy need of 602 kWh in 1 hour. The installed capacity of the system is calculated annually as follows:

$$602 \text{ kW} \times 7 \text{ hour-day} = 4214 \text{ kWh} \tag{1}$$

The monthly energy requirement of the station is given in equation (2):

$$602 \text{ kW} \times 7 \text{ hour-day} \times 30 \text{ day} = 126420 \text{ kWh} \tag{2}$$

The annual energy requirement of the station is given in equation (3):

$$602 \text{ kW} \times 7 \text{ hour-day} \times 365 \text{ day-year} = \\ = 1\ 538110 \text{ kWh/year} \tag{3}$$

In TABLE 7, the information given above, the daily-monthly-yearly energy requirement of the system is tabulated. The system is planned to charge 56 vehicles per day and 20440 vehicles per year with renewable energy systems.

TABLE 7

Daily, Monthly and Annual Energy Requirement of the System

Daily (7 Hours)	Monthly (30 days) (210 Hours)	Yearly (365 days) (2555 hours)
602 kW	4214 kW	1538110 kW
56 Vehicle	1680 Vehicle	20440 Vehicle

2.2.3. Area Selection for the System

The selected area is the former landfill site in Giresun province, where the Aksu Stream flows into the sea and has a total area of 33 thousand m^2. This area is currently being planned for the nation garden project and has been used as a garbage accumulation site in the past. One of the reasons for choosing this area is that garbage waste, which is suitable for biomass energy production, is easily accessible in this region. In addition, the availability of important renewable energy sources such as solar and wind energy in this location is very advantageous for energy production. It is often difficult to identify a suitable location where these three important renewable energy sources coexist, but the selected region is very advantageous in this respect. At the same time, the location of the site by the highway can facilitate the accessibility of the charging station for users. A highway-side location can increase the accessibility of the charging station for electric vehicle owners to meet their charging needs. This is also an important factor in the choice of the region, as ease of transportation can increase the use and access of charging stations, promoting sustainable energy use. Fig. 3 shows the location of the selected region from the Homer application.

2.2.4. System design

It aims to achieve this goal by utilizing important renewable energy sources such as solar, biogas and wind. The biogas generator produces AC type voltage in nature, while the wind turbine and PV panels are DC type. This configuration allows to charge the batteries by converting alternating current type loads to DC through bidirectional converters and convert the load on the batteries back to AC current. The model of the off-grid system designed with Homer Pro is given in Fig. 4.

In the off-grid system, photovoltaic panels, wind turbine and biogas generator, deep batteries for energy storage were installed to diversify energy production. This system aims to provide a continuous and reliable energy supply to the user by storing electrical energy obtained from different energy sources. In particular, the use of deep batteries aims to optimize the system performance by increasing the energy storage capacity. The part indicated as the electrical load in the figure represents the daily demand of the station, which is taken as 4214 kW and the peak value as 782.4 kW. In TABLES 8-11, technical information about the solar panel, wind turbine and biogas generator proposed in the system and selected based on the calculations are presented.

Fig. 3. View of the Region Selected for the Project in Homer Program

TABLE 8

Technical Specifications of the Panel Used in the System (Flat Pv 450 W, Standard Flat Plate) [23]

Output Power (W)	**Max. power point voltage Vmp (V)**	**Max. power point current I_{mp} (A)**	**Open circuit voltage V_{oc} (V)**	**Short circuit current I_{sc} (A)**	**Module Dimensions (Mm)**	**Module Weight (kg)**
450 W	42.83	10.62	49.66	11.2	2109*1052*42	25

TABLE 9

Technical Specifications of the Wind Turbine (1 kW) Used in the System [24]

Type	**Half Diameter**	**Start of Production Wind Speed**	**Optimum Output Power**	**Output Voltage**
Type 3 Blade, variable speed rotor	140 cm	3.0 m/s	3.0 m/s	12VDC and 24VDC (36VDC and 48VDC optional)

TABLE 10

Technical Specifications of the Gas Generator Used in the System [25]

Model Rated Speed 1500 rpm	**Rated power**	**Nominal Voltage**	**Proportional frequency**	**Power factor**	**Weight**	**Size**
500GF-N	500 kW	400 V	50 Hz	0,8	1849 kg	1748×1243×1500 mm

TABLE 11

Technical Specifications of the Battery Used in the System [26]

Weight	**Nominal Voltage**	**Nominal Current**	**Size**
30.5 kg	12 V	100 Ah	330×175×216 mm

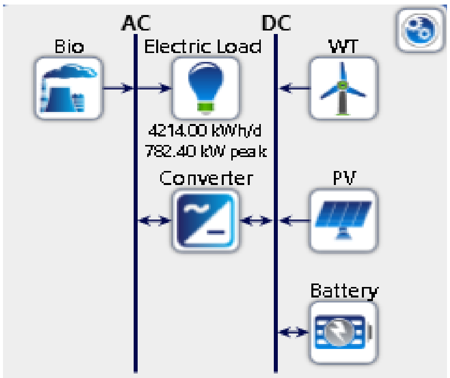


Fig. 4. Modeling the System with Homer

Deep cycle batteries are suitable for storing energy from renewable energy sources and for use in charging stations for electric vehicles. This type of battery can be used to store energy from renewable energy sources such as solar panels or wind turbines. In charging stations for electric vehicles, these batteries can be used for functions such as regulating energy demand, storing energy and providing power against demand peaks [27]. The variety of capacities allows to choose according to different energy needs. Deep cycle batteries are generally maintenance free or minimal maintenance, especially closed type VRLA (Valve Regulated Lead Acid) batteries offer users a practical and easy to use energy storage solution. Different types include flooded (bulk acid), AGM (Absorbent Glass Mat) and gel type deep cycle batteries and this diversity allows users to make choices to suit their specific needs [27]. The source values and formulas used in the system are given below. Fig. 5 shows the solar radiation values, Fig. 6 shows the wind speed values and Fig. 7 shows the projected amount of landfill waste. Using NASA data from

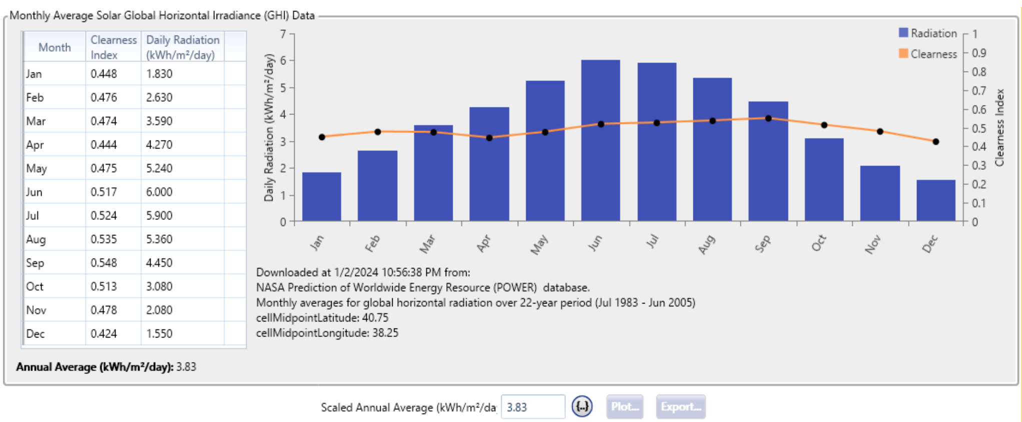


Fig. 5. NASA Data in Homer Program – Solar Radiation Data for the Selected Region

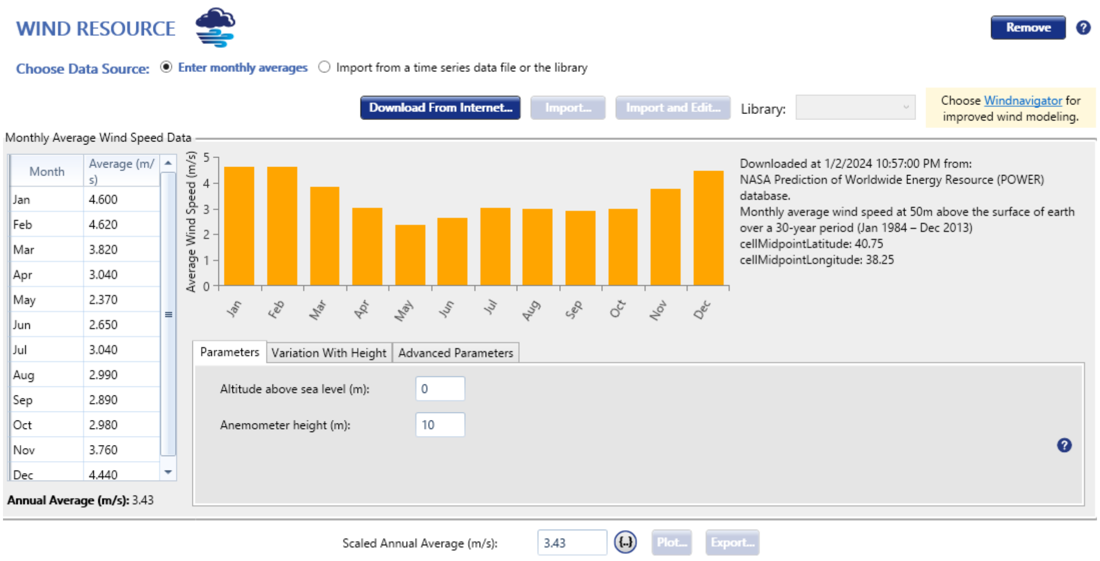


Fig. 6. NASA Data of the Selected Region in Homer Program – Wind Speed Data

2007, the HOMER Pro program determines the average annual solar radiation for a given region as 3.83 kWh/m²/day.

The equation given in (4) is used to calculate the energy produced by the PV array.

$$P_{PV} = f_{PV} \times Y_{PV} \times (I_T / I_S) \tag{4}$$

Equation: P_{PV} = power generated, f_{PV} = reduction rate, Y_{PV} = total capacity, I_T = solar radiation, I_S = 1 kW/m^2. The HOMER program calculates the annual average wind speed as 3.43 m/s for this region, which was determined based on 2007 NASA data, using anemometer data at a height of 10 meters. According to Betz, the theoretical maximum power that can be obtained from wind is given by the formula in (5) [18]:

$$P = 1/2 \times \rho \times V^3 \times \pi \times r^2 \times C_{P,\,Betz} \tag{5}$$

In this equation: P = Wind power [W], ρ = Density of air = 1,225 [kg/m^3], V = wind speed [m/s], r = rotor radius [m]. If this formula is adapted for wind turbines, the power of a wind turbine is given by the following formula. Cp is in practice smaller than $C_{P,\,Betz}$. Cp is also called the power coefficient.

There is Çavuşlu Solid Waste Disposal Facility in Çavuşlu Town of Görele District of Giresun Province. The facility has a daily capacity of 98 tons [28]. Considering the projected increase in the amount of waste from other settlements along the coastal belt of Giresun, 98 tons of landfill waste per day is added to this amount in 2030. In Equation (6), the mathematical formula of the process of obtaining biogas from landfill gas is presented. This formula contains the basic mathematical expressions of the landfill gas to biogas conversion process.

Landfill Gas Account: AQG = Calculated IPS Installed Capacity (kWe), EDP = Energy conversion potential of unit municipal waste (kcal/ton), BTK_{GAS} = Amount of Municipal Waste to be Disposed for Landfill Gas Production (Ton/Year), $\eta_{EÜV}$ = Electricity generation efficiency (35%).

$$AQG = (1/8760) \times (1/860) \times \eta_{EÜV} \times BTK_{GAS} \times EDP \tag{6}$$

The connection between the 1/860 coefficient and the landfill gas calculation is based on the process of generating electricity from heat energy. Landfill gas is a type of biogas formed as a result of the anaerobic decomposition of organic waste and can generate energy through combustion due to the methane (CH_4) it contains. However, the direct conversion of this energy into electricity production depends on a specific heat-electricity conversion process. Accordingly, the Relation,

- Landfill gas releases heat energy by burning.
- This heat energy (in kcal) must be converted into electrical energy.
- Approximately 860 kcal of heat energy is required to generate 1 kWh of electricity.
- The 1/860 coefficient is used to convert the heat energy calculated in kcal into electrical energy in kWh.

The 1/860 coefficient in the formula is used to calculate how many kWh of electrical energy the heat energy obtained from the landfill gas corresponds to.

In this formula (6), the function of 1/860 is to convert the total heat energy calculated with EDP (energy conversion potential of municipal waste – kcal/ton) into electrical energy.

The unit kcal is converted to kWh with 1/860.

- Since 860 kcal is required to produce 1 kWh of electricity, the total energy is converted to electrical energy.
- Here, the coefficient 1/860 is the factor that converts the total heat energy into electrical energy.

The installed power on an hourly basis is calculated with 1/8760.

- The coefficient 1/8760 is used to convert annual energy production to hourly average power and shows the average installed power (kWe) that the system should have in case of continuous operation.

The Homer program in Fig. 7 consists of average data stored and changed in its content. When no external data is entered into the program, programming is carried out based on these fixed data.

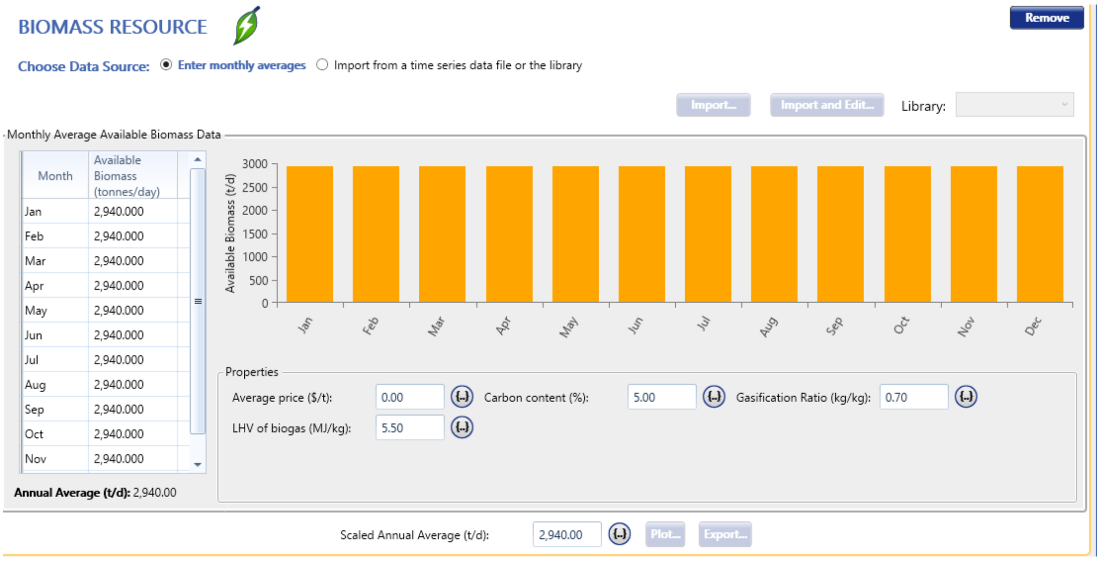


Fig. 7. Amount of Waste Entered in Homer Program

2.3. System output

According to the calculation report for the designed system (Fig. 8), a total of 5280 different solutions were simulated in the HOMER Pro program. While 2,889 of these solutions are feasible, the remaining 2391 solutions are not feasible due to lack of capacity. The most feasible model suggested by the system was used. The most feasible model suggested by the system was selected and the results were analyzed.

According to the most feasible system model of the scheme, 70.5% of the 1538110 kWh of electricity targeted to be generated annually will be provided by landfill gas, 29.5% by solar panels and 0.0466% by wind turbines. This plan aims to diversify energy production and utilize sustainable sources. Fig. 9 shows the output report of the system.

The output report of the system for the solar panel is given in Fig. 10 and the annual operating range of the panel is given in Fig. 11. Solar panel output data are as follows: it operates for 4384 hours per year, it produces a total of 512 927 kWh of energy per year, the capacity of the panel is set at 400 kW.

The output report of the system for the wind turbine is shown in Fig. 12 and the annual operating range of the turbine is shown in Fig. 13. The wind turbine data are as follows; worked for 5,173 hours per year, the total capacity is determined as 2 kW, produced a total of 810 kWh of energy per year.

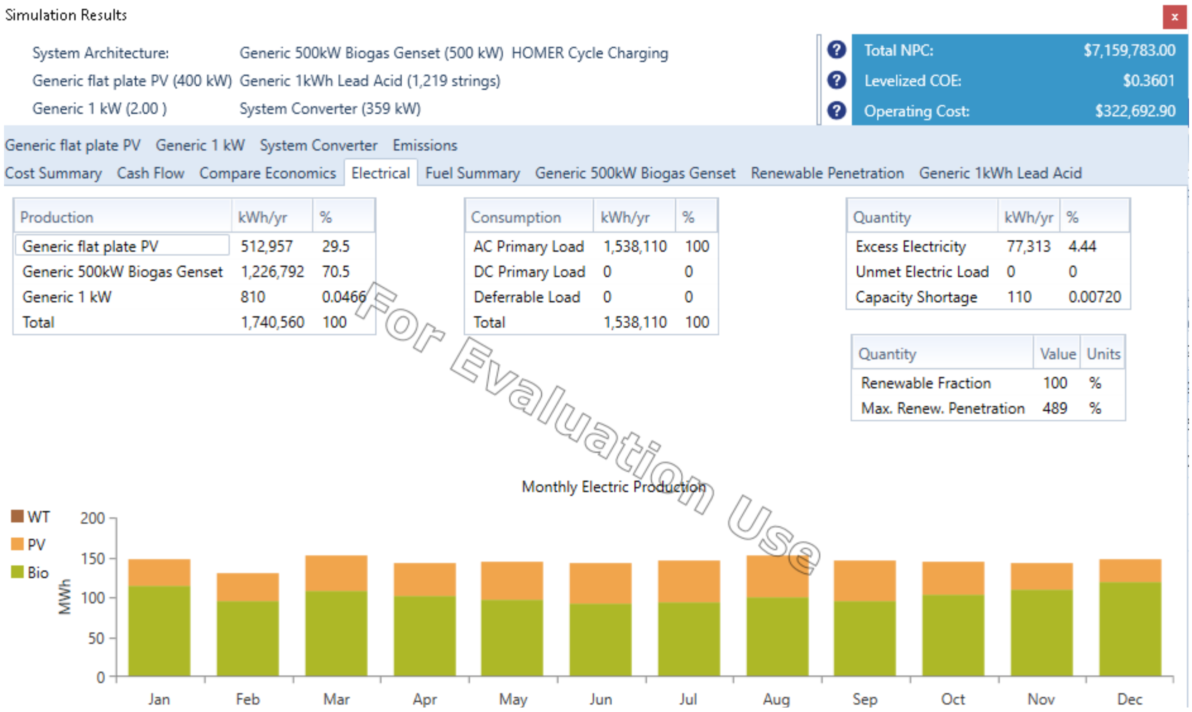


Fig. 8. Electricity Report Output of the System

Production	kWh/yr	%
Generic flat plate PV	512,957	29.5
Generic 500kW Biogas Genset	1,226,792	70.5
Generic 1 kW	810	0.0466
Total	1,740,560	100

Consumption	kWh/yr	%
AC Primary Load	1,538,110	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	1,538,110	100

Quantity	kWh/yr	%
Excess Electricity	77,313	4.44
Unmet Electric Load	0	0
Capacity Shortage	110	0.00720

Quantity	Value	Units
Renewable Fraction	100	%
Max. Renew. Penetration	489	%

Fig. 9. Production-Consumption Output of the System

Quantity	Value	Units
Rated Capacity	400	kW
Mean Output	58.6	kW
Mean Output	1,405	kWh/d
Capacity Factor	14.6	%
Total Production	512,957	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	419	kW
PV Penetration	33.3	%
Hours of Operation	4,384	hrs/yr
Levelized Cost	0.159	$/kWh
Clipped production	0	kWh

Fig. 10. Solar Panel Output of the System

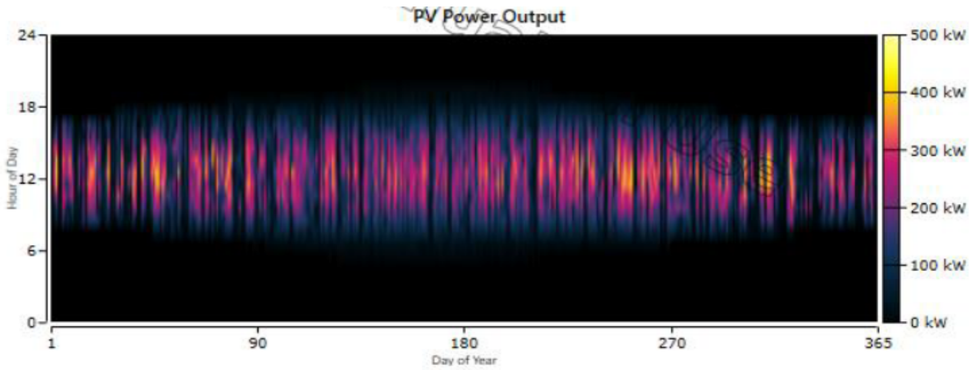


Fig. 11. Photovoltaic (PV) Power Output Values of the System Annual and Hourly Production Data

Quantity	Value	Units
Total Rated Capacity	2.00	kW
Mean Output	0.0925	kW
Capacity Factor	4.63	%
Total Production	810	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	1.96	kW
Wind Penetration	0.0527	%
Hours of Operation	5,173	hrs/yr
Levelized Cost	1.70	$/kWh

Fig. 12. Wind Turbine Output of the System

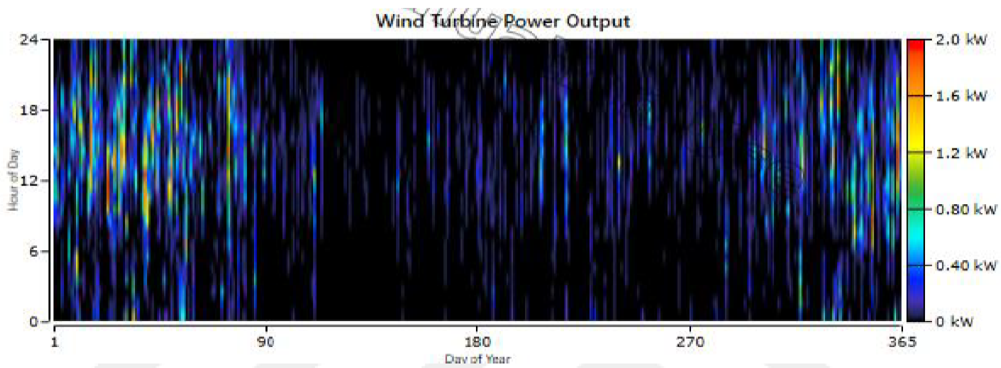


Fig. 13. Annual and Hourly Production Data of Wind Turbine Power Output Values of the System

The output report provided by the system for the biogas generator is given in Fig. 14 and the annual operating range of the generator is given in Fig. 15. Biogas generator data are as follows; actively worked for 3501 hours per year, covered a significant part of the system, generating a total of 1 226 792 kWh of electricity per year.

The batteries in the system consist of lead acid type batteries with a voltage of 12 V. A total of 1219 batteries of this type were used. These batteries are designed to store electrical energy in the energy storage system and use it when needed. Lead acid batteries are a durable and cost-effective energy storage solution with a wide range of applications. The output report of the system for the batteries is given in Fig. 16.

The output report of the system for the converters and the annual operating interval are given in Fig. 17. The capacities of the converters used are; Rectifier Capacity is 359 kW and operating time: 3021 hours/year, Inverter Capacity is 359 kW and operating time: 5559 hours/year. The rectifier is used to rectify and store the energy received by the DC (direct current) of the devices used in the system. The converter converts the stored energy back into AC (alternating current) form and makes it usable. Both converters operate at the specified capacities and realize the energy conversion in the system [28-30].

The data presented by the system showing the distribution of the use of energy generated by the combination of off-grid biogas, wind and solar energy sources is given in Fig. 18. It can be seen that the biogas generator is predominantly used and the contribution of wind turbines is very small.

In Fig. 19, according to the emission values output report of the system; annual carbon dioxide (CO_2) emission is calculated as 677 kg/year. In addition, the annual carbon monoxide (CO) emission was determined as 7.51 kg/year. These low emission values show that the system represents an environmentally friendly and low carbon energy generation system.

These values, which are important indicators to evaluate the environmental impact and carbon footprint of the system, emphasize that the system is a sustainable and environmentally friendly energy generation system. The electric vehicle charging station, which is connected to the grid-independent hybrid power system, is designed to charge 8 vehicles with the battery

Quantity	Value	Units
Hours of Operation	3,501	hrs/yr
Number of Starts	1,009	starts/yr
Operational Life	5.71	yr
Capacity Factor	28.0	%
Fixed Generation Cost	61.3	$/hr
Marginal Generation Cost	0	$/kWh

Quantity	Value	Units
Electrical Production	1,226,792	kWh/yr
Mean Electrical Output	350	kW
Minimum Electrical Output	250	kW
Maximum Electrical Output	500	kW

Quantity	Value	Units
Fuel Consumption	3,755	tons/yr
Specific Fuel Consumption	2.14	kg/kWh
Fuel Energy Input	4,015,970	kWh/yr
Mean Electrical Efficiency	30.5	%

Fig. 14. Biogas Generator Output of the System

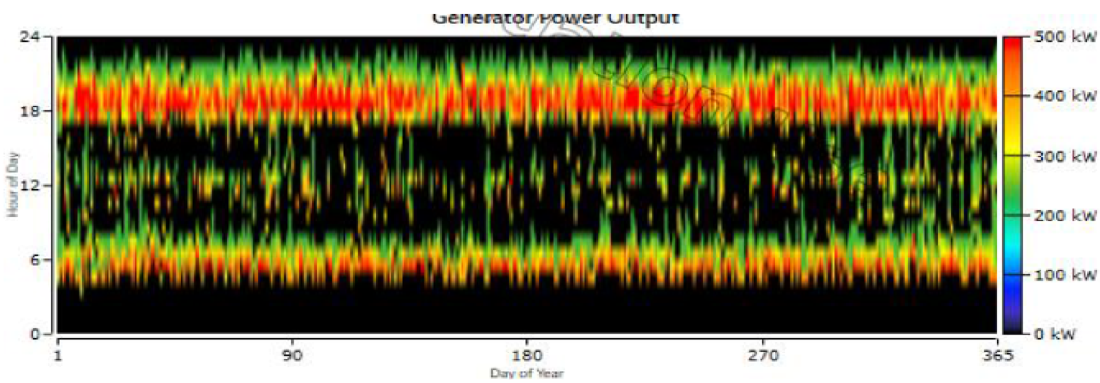


Fig. 15. Biogas Generator Power Output Values of the System Annual and Hourly Production Data

Quantity	Value	Units
Batteries	1,219	qty.
String Size	1.00	batteries
Strings in Parallel	1,219	strings
Bus Voltage	12.0	V

Quantity	Value	Units
Autonomy	4.17	hr
Storage Wear Cost	0.419	$/kWh
Nominal Capacity	1,220	kWh
Usable Nominal Capacity	732	kWh
Lifetime Throughput	975,200	kWh
Expected Life	2.86	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	380,482	kWh/yr
Energy Out	304,476	kWh/yr
Storage Depletion	101	kWh/yr
Losses	76,107	kWh/yr
Annual Throughput	340,415	kWh/yr

Fig. 16. Battery Values Output of the System

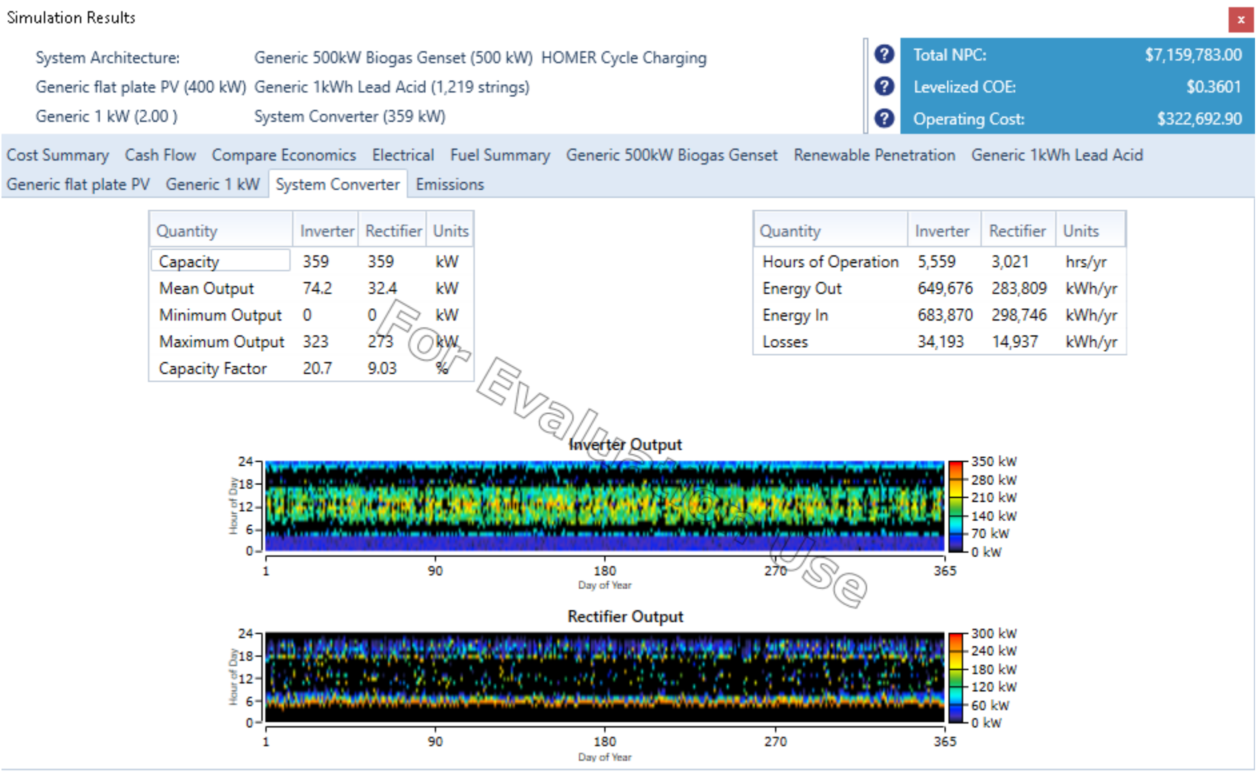


Fig. 17. Converter Values Output of the System

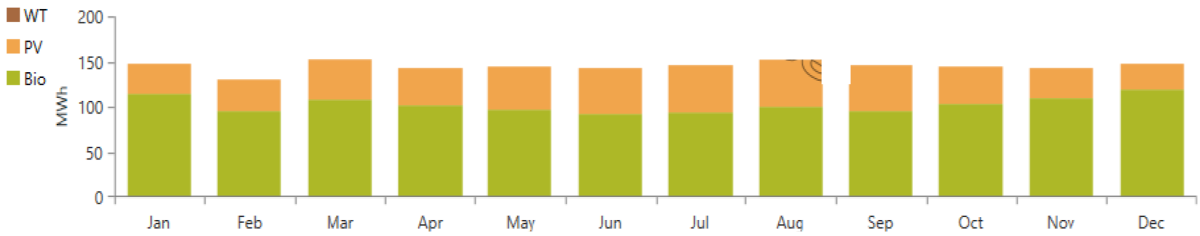
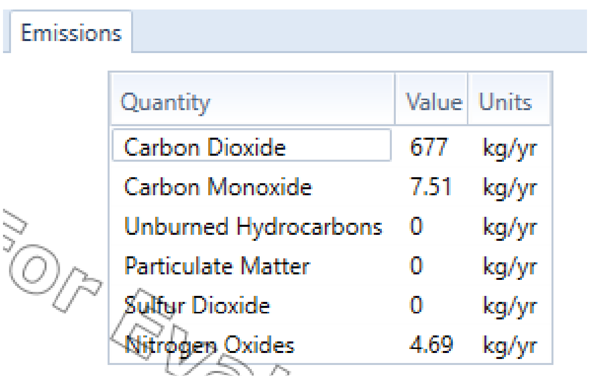


Fig. 18. Monthly Electricity Generation of the Designed System


Emissions

Quantity	Value	Units
Carbon Dioxide	677	kg/yr
Carbon Monoxide	7.51	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	4.69	kg/yr

Fig. 19. Emission Values Output of the System

capacities of the selected models by providing a total of 602 kW of energy per hour. Assuming that the system operates for 7 hours a day, it is planned to have the capacity to charge 56 vehicles per day. The charging station has DC 50 kW charging sockets and is planned to serve all kinds of electric vehicles by using sockets suitable for different models and brands.

3. Discussion and conclusion

In this study, firstly, Turkey's population and energy projections for the year 2030 are analyzed and the energy needed per capita in 2030 is calculated based on these two data. According to the projections taken as a basis, the energy consumed per capita in 2030 is expected to be approximately 4843.6 kWh. At the end of 2022, the total amount of energy produced was 324 517 682.2 MWh, of which 137 770 257.22 MWh is produced from renewable energy sources. Since per capita consumption was 3360,434 kWh in 2022, the energy needed by approximately 35 million people is produced from renewable energy sources, while the remaining 50 million people use fossil-based energy. In 2030, 452.7 TWh of the energy to be produced is expected to come from renewable energy sources, with approximately 47% of this energy coming from renewable sources, 8.2% from nuclear energy, which does not emit carbon emissions, and the remaining 44% from fossil sources.

With the developing technology and growing economy, electric cars have been produced and the consumption of petroleum and its derivatives is aimed to decrease and the use of renewable energy-based electric vehicles is aimed to increase. Although electric vehicles offer a cleaner alternative to conventional fuel vehicles, it is important that the energy source is environmentally friendly. In this study, solar, wind and biogas based power plants are proposed to encourage the use of clean energy for electric vehicles. In parallel with this proposal, charging stations for these vehicles should be built and operated based on renewable energy sources. This step aims to promote a transition towards a sustainable transportation model that will both reduce environmental impacts and lower energy dependency.

Considering that a portion of Turkey's increasing energy need in 2030 will come from electric vehicles, it is recommended that this energy be provided from renewable energy sources such as solar, wind and biogas. This recommendation, which is supported by the findings of other studies, reflects the view that obtaining the energy used with electric vehicles from clean sources can help build a more sustainable and environmentally friendly future in the energy sector in general.

Furthermore, the study addresses Turkey's accession to the Paris Agreement and highlights that the proposed clean energy approach can make a positive contribution to the zero emission targets under this agreement. The adoption of such clean energy fuels, along with the use of electric vehicles, could be an important step that could strengthen Turkey's role in combating climate change.

OECD countries, consisting of 37 countries including Turkey, are taking important steps in the field of renewable energy. The United States is the leader among these countries, playing a pioneering role in terms of investment in renewable energy and technology development. Turkey's renewable energy potential is high, but the utilization rate is currently low. Over the years, thanks to changes in energy policies, incentives and infrastructure investments, Turkey is making significant progress in the renewable energy sector. Towards 2030, Turkey's renewable energy penetration rate is projected to increase as proposed hybrid energy systems become more widespread.

Turkey's geographical location is suitable for the use of renewable resources. While the Southeastern Anatolia region is most preferred for solar energy, the western coasts attract attention for wind energy. For example, of the 47 power plants operating in Giresun, 45 are hydraulic power plants, 1 is a landfill gas power plant (biogas) and 1 is a solar power plant. Giresun has a 2 MW solar power plant under construction and a 30 MW wind power plant with a preliminary license. Giresun, which produces completely clean energy, uses fossil fuels as petroleum and its derivatives in vehicles and natural gas in residences.

In this context, a hybrid energy system consisting of off-grid renewable energy sources such as wind, solar and biogas is proposed to meet Turkey's electricity consumption in 2030 with clean energy. The developed hybrid system consists of elements such as solar panels, wind turbines and generators. This integrated system aims to increase energy efficiency and provide an uninterrupted energy supply by combining various energy sources.

The advantages such as continuous and sustainable energy from renewable energy sources, reduced environmental impacts and increased energy independence are the prominent features of the hybrid energy system designed. This system aims to provide a continuous flow of energy by combining the energy obtained from sunlight during the day with solar panels, wind energy with wind turbines and energy produced from organic waste with biogas.

Within the scope of this study, an off-grid hybrid energy system including solar, wind and biogas energy sources was designed with the HOMER PRO program on the Black Sea coastal road of Giresun province. The purpose of the system is to meet the energy needs of the charging stations that will be formed with the introduction of electric vehicles in the market from clean energy. The two most preferred models in the Turkish electric vehicle market are taken as reference and the energy requirement is calculated. The system designed in this context will provide charging for an average of 56 vehicles for a total of 7 hours a day. In the model shown as the most applicable in the design program, 70.5% of the system's 1 538 110 kWh/year energy requirement is met from biogas produced from landfill gas, 29.52% from solar panels, and 0.0466% from wind turbines.

According to the data obtained from the final reports, the wind energy potential in the region is quite low. The analysis concluded that the investment to generate wind energy is not economically and efficiently effective. Therefore, the proposed solution focuses on obtaining the energy needs in the region only from solar and biogas energy. The contribution of wind energy can be increased by increasing the number of wind turbines. Also, the symbolic use of wind turbines in the system can be preferred to emphasize renewable energy, albeit in small amounts.

In terms of adaptability of the model to other geographies, new designs can be created using scenarios with different amounts of garbage and higher power photovoltaic (PV) panels. This could be an important strategy to diversify the energy system and adapt to different climatic conditions. In this way, various scenarios can be designed with effective and sustainable energy solutions that can be applied in different geographical regions.

This hybrid energy system, proposed to meet Turkey's future energy needs, aims to contribute to sustainable development goals. It also stands out as an important step towards environmental sustainability by diversifying energy sources and increasing the use of domestic and clean energy.

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