Gazi Üniversitesi
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GU J Sci, Part C, 11(4): 1244-1260 (2023)

Hydrogen Production using a Hybrid System Built with Renewable Energy Resources in Yenice

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Article Info

Research article
Received: 28/11/2023
Revision: 12/12/2023
Accepted: 17/12/2023

Keywords

HOMER
Zero Emission
Optimization
Hybrid Renewable Energy System
Hydrogen Storage

Makale Bilgisi

Araştırma makalesi
Başvuru: 28/11/2023
Düzeltme: 12/12/2023
Kabul: 17/12/2023

Anahtar Kelimeler

HOMER
Sıfır Emisyon
Optimizasyon
Hibrit Yenilenebilir Enerji Sistemi
Hidrojen Depolama

Graphical/Tabular Abstract (Grafik Özet)

The hybrid system with electrical energy requirements was simulated using HOMER Pro software. A generator, wind turbine, solar panel, hydrogen tank, electric inverter, and battery system are components of the hybrid energy system. /HOMER Pro yazılımı kullanılarak elektrik enerjisi ihtiyacına sahip hibrit sistemi simüle edilmiştir. Jeneratör, rüzgar türbini, güneş paneli, hidrojen tankı, elektrik invertörü ve akü sistemi hibrit enerji sisteminin bileşenleridir.

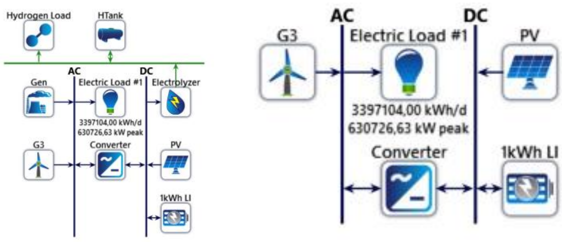

***Figure A**: The system designed in the specified areakarabük province /**Şekil A:** Belirlenen alanda tasarlanan sistem bilgileri*

Highlights (Önemli noktalar)

- *The percentage of renewable energy used was taken into consideration while evaluating energy prices and environmental harm. / Enerji fiyatları ve çevreye verilen zarar değerlendirilirken yenilenebilir enerjinin kullanım yüzdesi dikkate alınmıştır.*
- *August, September, and October seemed to be the months when the 500 kg hydrogen tank was fully loaded. / Ağustos, Eylül ve Ekim ayları 500 kg'lık hidrojen tankının tam dolu olduğu aylar olduğu görülmüştür.*
- *According to the investigation, altering the MNR Ratio boosts the hydrogen tank's filling capacity. / Yapılan araştırmaya göre MNR Oranının değiştirilmesi hidrojen tankının dolum kapasitesini arttırmıştır.*

***Aim (Amaç):** The aim of this study is to investigate the production of hydrogen in electrical loads at different renewable energy rates. / Bu çalışmanın amacı, farklı yenilenebilir enerji oranlarında elektrik yüklerinde hidrojen üretimini araştırmaktır.*

***Originality (Özgünlük):** The originality of this study is to investigate hydrogen production, environmental impacts and cost analysis with hybrid energy system optimization for the determined region. / Bu çalışmanın özgünlüğü, belirlenen bölge için hibrit enerji sistemi optimizasyonu ile hidrojen üretimi, çevresel etkiler ve maliyet analizini araştırmaktır.*

***Results (Bulgular):** When the renewable energy rate was 100%, there was an increase in the unit energy cost while the damage to the environment could not be detected. When the occupancy rate of the hydrogen tank capacity was checked, it was observed that the occupancy rate was high when the hydrogen load was low, and there were fluctuations in the occupancy rate when the hydrogen load was high./ Yenilenebilir enerji oranı %100 olduğunda çevreye verdiği zarar bulunamazken birim enerji maliyetinde artış olmuştur. Hidrojen tankı kapasitesinin doluluk oranı kontrol edildiğinde hidrojen yükü az olduğunda doluluk oranının yüksek olduğu, hidrojen yükü fazla olduğunda ise doluluk oranında dalgalanmalar olduğu gözlemlenmiştir.*

***Conclusion (Sonuç):** In this study, the optimum hybrid system was investigated to meet the energy demand of Yenice district of Karabük province and to investigate hydrogen production. When the results of all system simulations are evaluated, although the use of 95% renewable energy sources causes an increase in the unit energy cost and net current cost, the impact of environmental damage has decreased. / Bu çalışmada Karabük ili Yenice ilçesinin enerji talebini karşılamak ve hidrojen üretimini araştırmak amacıyla optimum hibrit sistem araştırılmıştır. Tüm sistem simülasyonlarının sonuçları değerlendirildiğinde, %95 yenilenebilir enerji kaynaklarının kullanımı birim enerji maliyetinde ve net bugünkü maliyette artışa neden olsa da, çevreye verilen zararın etkisi azalmıştır.*

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DOI: 10.29109/gujsc.1397323

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Abstract

Renewable energy demand such as solar, wind, biomass, and geothermal, which are the least harmful to nature and natural life, has increased due to the depletion of fossil fuels used in energy production and the greenhouse gases they have released to the environment. Thus, with the inclusion of renewable energy sources in the system, a rich structure in terms of energy diversity has emerged. A region simulating a hybrid system with an annual average electrical energy need of 3997104 kWh/day was selected using HOMER Pro software. Solar radiation and wind data belonging to the region were taken from NASA Surface. The hybrid energy system consisted of a generator, wind turbine, solar panel, hydrogen tank, electrifier inverter, and battery system. The energy produced by the resulting system was used by 11.26 kg/day hydrogen load and 3997104 kWh/day electrical load. The economic evaluation criteria of the hybrid energy system were the cost of energy production, the net present value (NPC), and the payback period. The environmental evaluation criteria were determined as the renewable energy rate and emission values. When the renewable energy rate was at the lowest level, the most economical system was the Gen/PV/WT/Bat/300Htank/Hloaded hybrid system when emissions were not considered, while the Gen/PV/WT/Bat hybrid system had the lowest emissions without considering the cost. When the renewable energy rate was higher, the most economical system was the PV/WT/Bat hybrid system when emissions were not considered.

Yenice'de Yenilenebilir Enerji Kaynakları ile Kurulan Hibrit Sistemle Hidrojen Üretimi

Makale Bilgisi

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Öz

Enerji üretiminde kullanılan fosil yakıtların tükenmesi ve çevreye saldıkları sera gazları nedeniyle doğaya ve doğal hayata en az zarar veren güneş, rüzgar, biyokütle, jeotermal gibi yenilenebilir enerjilere olan talep artmıştır. Böylece yenilenebilir enerji kaynaklarının sisteme dahil edilmesiyle enerji çeşitliliği açısından zengin bir yapı ortaya çıkmıştır. HOMER Pro yazılımı kullanılarak yıllık ortalama 3997104 kWh/gün elektrik enerjisi ihtiyacına sahip hibrit sistemi simüle eden bir bölge seçilmiştir. Bölgeye ait güneş radyasyonu ve rüzgar verileri NASA Surface'tan alınmıştır. Hibrit enerji sistemi; jeneratör, rüzgar türbini, güneş paneli, hidrojen tankı, elektrikli invertör ve akü sisteminden oluşmaktadır. Ortaya çıkan sistemin ürettiği enerji, 11,26 kg/gün hidrojen yükü ve 3997104 kWh/gün elektrik yükü ile kullanılmıştır. Hibrit enerji sisteminin ekonomik değerlendirme kriterleri, enerji üretiminin maliyeti, net bugünkü değer (NPC) ve geri ödeme süresiydi. Çevresel değerlendirme kriterleri yenilenebilir enerji oranı ve emisyon değerleri olarak belirlenmiştir. Yenilenebilir enerji oranının en düşük seviyede olduğu dönemde emisyonlar dikkate alınmadığında en ekonomik sistem Gen/PV/WT/Bat/300Htank/ Hyükü hibrit sistem olurken, en düşük değere sahip sistem ise Gen/PV/WT/Bat hibrit sistemi olmuştur. Yenilenebilir enerji oranının yüksek olduğu oranda emisyonlar dikkate alınmadığında en ekonomik sistem PV/WT/Bat hibrit sistemi olmuştur.

1. INTRODUCTION (GİRİŞ)

Key and keyseat Due to the conditions of the Covid-19 pandemic, the increasing population has tended to rural areas. Thus, as a result of the increasing population and energy demand in rural areas, the need for renewable energy sources has increased. According to these needs, it is important to deploy the systems closest to the location when it comes to energy production, energy access, cost, and efficiency in certain regions and rural areas [1]. In this regard, the efficient use of hybrid renewable energy systems is in question in line with the uninterrupted energy need for using

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DOI: 10.29109/gujsc.1397323

environmentally friendly energy systems [2, 3, 4]. Hybrid systems provide the highest production efficiency [5]. It can provide the maximum energy from wind and solar energy [6, 7]. Dursun [8] examined renewable energy sources in terms of energy demand, optimization, economic evaluation, design criteria, and greenhouse gas emissions in rural areas as off- grid system. This research was carried out using the National Renewable Energy Laboratory's HOMER (Hybrid Optimization Model for Electric Renewable) software [9, 10]. While solar, wind, and diesel generators were included in the system; energy production, cost, emission, and optimum design were evaluated by adding a storage system.

Sustainable energy systems are crucial in light of the recent trend toward rural areas [11]. The use of renewable energy sources (RES) in the energy sector promotes sustainable and environmentally friendly energy production [12]. To be an uninterrupted power supply in hybrid systems, a battery system that provides sufficient conditions is added to the solar and wind energy systems [13]. It is predicted that the energy demand in developing countries such as Turkey will increase day by day [14]. Turkey is moving towards increasing its renewable energy resources in order not to pose any difficulties in terms of energy continuity [15-17]. Even if there are discontinuous and high-cost systems, they become popular because of their availability, technology, and features [18-19]. For such reasons, optimal sizing and developed software are used because they are low-cost, easy to access, and problem-solving systems [20- 22]. In a comparison of wind turbine and diesel water pumping systems in the north-central Anatolia region of Turkey, Sinop was determined as the most cost-effective electricity generation as various wind energy conversion systems reduce costs [23].

HOMER Pro software performs an economic analysis of a system while estimating its technical feasibility. Then, it sorts the systems according to NPC and optimizes them to minimize COE and better NPC [24]. In addition, when software systems meet, HOMER Pro has optimum system design and high usage capacity [25]. Although off-grid or on-grid systems were examined in the studies, the aim of them was to achieve cost-effective energy production with simulation and optimization methods. [26-28]. When the grid is 44 km away from the reserve and an off-grid system analysis is evaluated, it is known that the off-grid system is cheaper and will provide maximum benefit with 2-stage emission trading [29, 30].

For a village located in a rural area, a PV-Wind-Generator-Battery system was installed, and the NPC cost for 176 kWh/day electric loads was obtained as 168,378 $ and the COE cost was 0.173 $/kWh [31]. It showed that a system with a 99% renewable energy rate used in a PV-Wind combination in a rural area in Kenya reduced the energy cost from 0.594 $/kWh to 0.585 $/kWh [32]. In Iran, the COE cost was found to be $0.107/kWh in the optimum off-grid PV-Wind-BG-DG-Battery system according to different geographical and climatic conditions [33]. In a study conducted in Bangladesh, in the PV-BG-DG-Battery system, NPC was 1.28 million $, COE was 0.2 $ / kWh for 1108.5 kWh/day energy demand, while NPC was 357284 $ and COE was 0.370 $ / kWh in the PV-DG-Battery system [34, 35]. NPC and COE cost was $2,087 and $0.362 respectively when installing a PV-WT hybrid system for 770 homes in India [36, 37]. In Taleghan-Iran, the energy cost of the energy system with 0.8 kW using the PV-Wind-Battery system was $1,655/kWh, the initial investment cost was $22998, and the net current cost (NPC) was $24623 [38]. In addition to being the most economical energy source in a study for the Hydro /Battery system, it had the lowest net current cost (NPC) of $162.987 and an energy cost (COE) of 0.111 kWh among all other system configurations [39]. The Homer Pro software finds the most suitable results with the optimization and simulation technique of the energy production of the on-grid and off-grid renewable energy systems [40,41]. In addition to the low efficiency of the electricity-hydrogen-electricity conversion, and the high cost of electrolysis and fuel cells, it has been concluded that hydrogen energy is not sufficient in terms of the economy [24-26]. Moreover, in new studies, the comprehensive feasibility of renewable energy systems is performed using site selection, Geographic Information Systems (GIS), and Multi-Criteria Decision Making (MCDM) in Turkey [42-43]. The hybrid system in the Eskipazar district in Karabük, where fuel consumption has decreased by 28-43% with the in change renewable energy rates, has emerged as a result of the study [44].

According to all research, using hybrid renewable energy systems (HRES) has become widespread especially in developing countries due to optimum sizing. Especially in rural areas, the simulation has been made in the form of off-grid systems. The use of solar panels is generally found in every study. HRESs are widely used in rural, remote, and private areas independent of the grid. The most uncertain parameters in the HOMER Pro system are wind speed, solar radiation, fuel price, component cost, and primary load, and this variation is thought to vary by country, climate, and geography.

Arslan et al. [45] advised a 150-megawatt coal-fired power plant that recovers waste heat for electricity generation, hot water, and hydrogen production. To achieve hydrogen generation, a high-temperature electrolyzer was incorporated into the current system. As current density increases, the study's findings indicate that less hydrogen is produced.

In this study, different from this study [44] and the literature, different hydrogen load and hydrogen production was investigated in the Yenice district in Karabük.

2. MATERIALS AND METHODS (MATERYAL VE METOD)

In this study, renewable energy systems were evaluated in terms of design, sizing, and emission values in the Yenice district of Karabük province. The average consumption values of Karabük province were taken from the Turkish Statistical Institute (TUIK) [46], and a renewable energy system designed to provide off-grid energy demand was simulated in HOMER. One of the biggest advantages of hybrid systems in energy production is the use of battery technology together with renewable energy systems to meet energy demands according to changing climatic conditions and to provide uninterrupted power. There is commercial software that analyzes energy demands with renewable energy systems according to location information. Components, resources, sizing, technical-environmental analysis, emissions data, and system controls are a few of them. When the parameters are examined in detail, HOMER Pro was chosen as the most effective and efficient. The HOMER Pro program, which performs analysis for both grid-connected systems and off-grid systems, was developed by NREL (National Renewable Energy Laboratory) to optimize the project design model and evaluate the sensitivity, as well as select the most applicable hybrid system model based on emission values and cost.

In the designed system, solar panels, a hydrogen tank, a hydrogen load, an electrical load, a wind turbine, a converter, a generator, and battery systems were installed in different ways. They were designed as complementary to each other to be uninterrupted. The power sources in the HOMER Pro program are PV, wind turbine, generator, power grid, hydropower, biomass, and fuel cell. In this study, a hydrogen tank, an electrolyzer, solar panels, a wind turbine, and a generator were used as the power source. While there are a flywheel, a battery, and hydrogen systems in the storage systems in HOMER Pro, batteries were preferred in the design. While seasonally variable daily profiles and thermal loads were present in HOMER Pro, daily profile load was preferred.

In the specified system, Carbon Dioxide (CO_2), Carbon monoxide (CO), Unburned hydrocarbons (UHC), Particulate matter (PM), Sulfur Dioxide (SO_2), Nitrous Oxide (NO_x) are determined as polluting factors, and limits are set according to these factors and penalties are set. The causes of these pollutants are determined by the use of generators in energy production, boilers in thermal energy production, and grid electricity

Karabük province, which has an area of 4145 km^2 and is located in the Western Black Sea Region of Turkey, is located between 40° 57' and 41°34' north latitudes and 32° 04' and 33° 06' east longitudes. The analyzed district of Yenice is located at 41°15.7' north latitude and 32°16.8' east longitude. Yenice, which is 33 km away from the city center of Karabük and has a surface area of 1150 km^2, has the characteristic features of the Western Black Sea Region in terms of land structure, has fertile forests of 85% of its surface area and does not contain flat and plain areas. The fact that it contains a significant diversity in terms of nature and natural life reminds the importance of protecting this life.

The geographical location of the Yenice district of Karabük province is shown in Figure 1. There are areas where renewable energy systems can be installed in the Yenice region. At the same time, due to the high wind potential, it is a suitable region for the placement of wind turbines. In addition to renewable energy systems, it is a suitable region for the addition of a hydrogen energy system. The data providing all energy consumption has been taken from the Turkish Statistical Institute. According to these data, total energy consumption in 2020 was 1,750,346 MWh/year.

2.1. Renewable Energy Potential of the Analysis Area (Analiz Alanının Yenilenebilir Enerji Potansiyeli)

When it comes to hybrid renewable energy systems, the first thing that comes to mind is solar energy and wind energy. In this study, the data on the official website of the Ministry of Energy and Natural Resources of the Republic of Turkey was used for the solar and wind data for the district determined. Since Yenice district of Karabük province is in the North of Turkey, the annual average wind speed is between 1.46 m/s and 6.27 m/s at 100 meters altitude, and the annual average wind power density is between 6.533 (W/m^2) and 347.868 (W) at 100 meters. The capacity factor calculated with the technical values of a 3 MW wind turbine at 100 meters varies between 31.7% and 0.59%. Images of all these data are shown in Figure 2.

Considering the solar energy data, it is seen that the annual solar radiation is between 1400-1500 kWh/m^2. At the same time, the Global radiation value varies between 1.24-6.08 kWh/m^2 -day and the sunshine duration varies between 3.02-10.58 hours. Figure 3 depicts the visuals of all of these data for Karabük province, as well as the solar energy atlas.

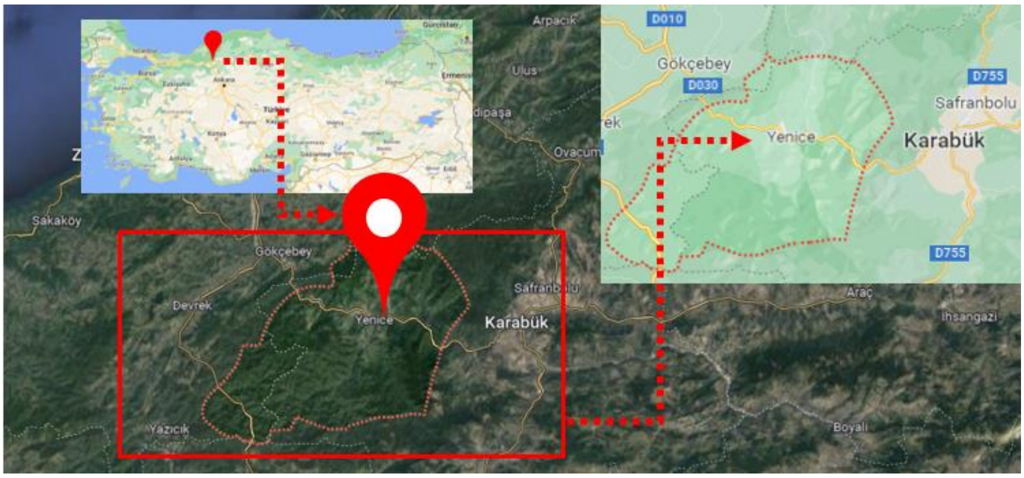
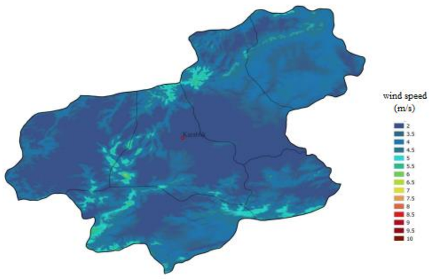
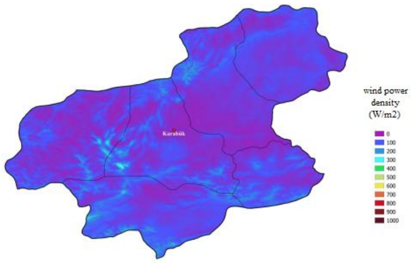


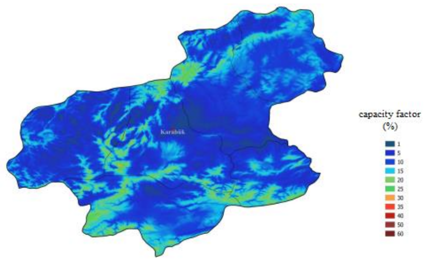
Figure 1. Geographical information of yenice district of Karabük province (Karabük ili yenice ilçesi coğrafi bilgileri)



a) Annual average wind speed distribution in Karabük – 100 meters



b) Karabük province annual average wind power density distribution – 100 meters

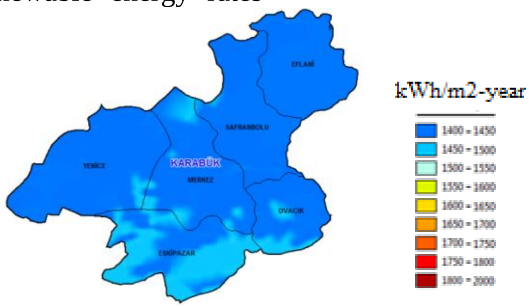


c) Karabük province capacity factor distribution – 100 meters

Figure 2. Karabük province wind energy atlas [47] (Karabük ili rüzgar enerjisi atlası)

2.2. Parameters in system design (Sistem Tasarımındaki Parametreler)

In this study, different system components such as solar panels, electrolyzers, wind turbines, diesel generators, electric and hydrogen loads, batteries, hydrogen tanks, and converters were used as shown in Figure 4. It was independently analyzed without restrictions to meet the annual load of 3,397,104 kWh/day modeled with HOMER Pro. The system that provides the energy demand was analyzed using different renewable energy rates for the most cost-effective and environmentally friendly system design. It was aimed for the designed systems to have a high rate of renewable energy sources and have low emissions. Many different renewable energy systems have been designed for the region determined in this study. As shown in Figure 4, systems are designed using certain components such as generators, wind turbines, solar panels, converters, batteries, electrolyzers, and hydrogen tanks. The modeled electrical load of the different designed systems was determined as 1000kWh/day and 3.997.104.00 kWh/day, and a peak load of 630726.63 kW was determined. To obtain a hybrid system design that provides this determined load, scenarios with different renewable energy rates (MiNimum Renewable fraction-MNR) have been produced and examined economically, environmentally, and technically. Information about the electric load and hydrogen load added to the system is shown in Figure 5 and Figure 6.



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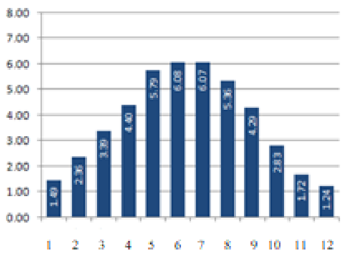
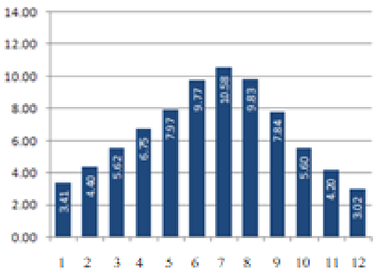




b) Karabük province global radiation values (kwh/m ^{2} -day)

c) Karabük sunbathing times (hours)

Figure 3. Karabük province solar energy atlas [48] (Karabük ili güneş enerjisi atlası)

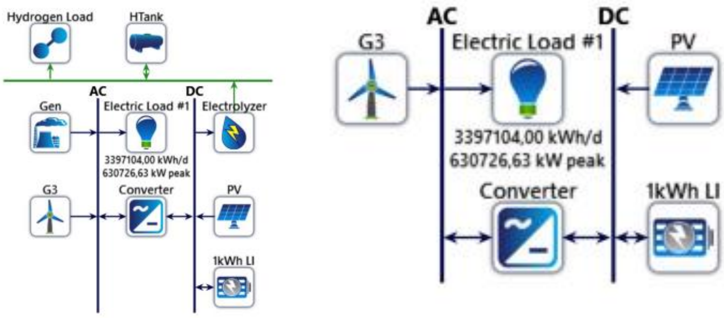


Figure 4. The system designed in the specified area Karabük province (Belirlenen Alanda Tasarlanan Sistem Bilgileri)

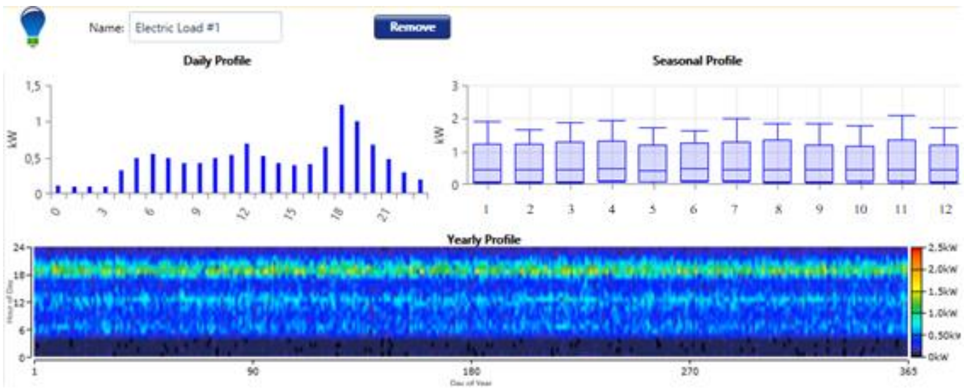


Figure 5. Electricity Load Information of Yenice District (Yenice ilçesi elektrik yük bilgileri)

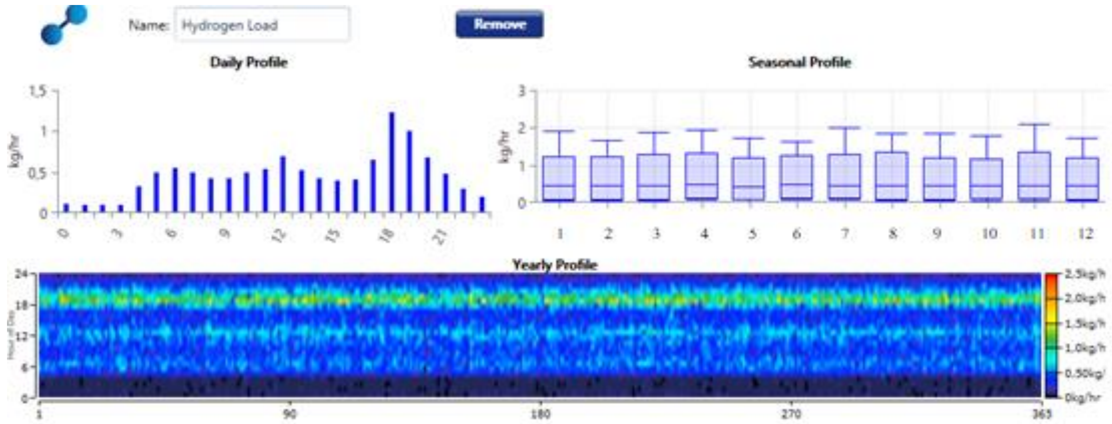


Figure 6. Yenice district hydrogen load information (Yenice ilçesi hidrojen yükü bilgisi)

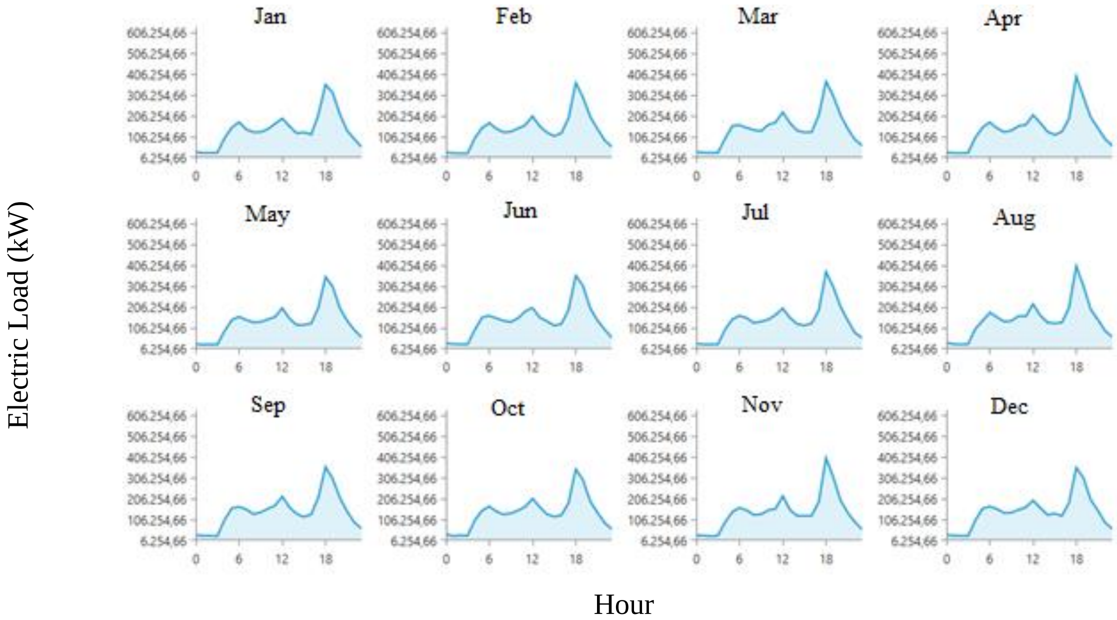


Figure 7. Daily electric load profile (Günlük elektrik yük profili)

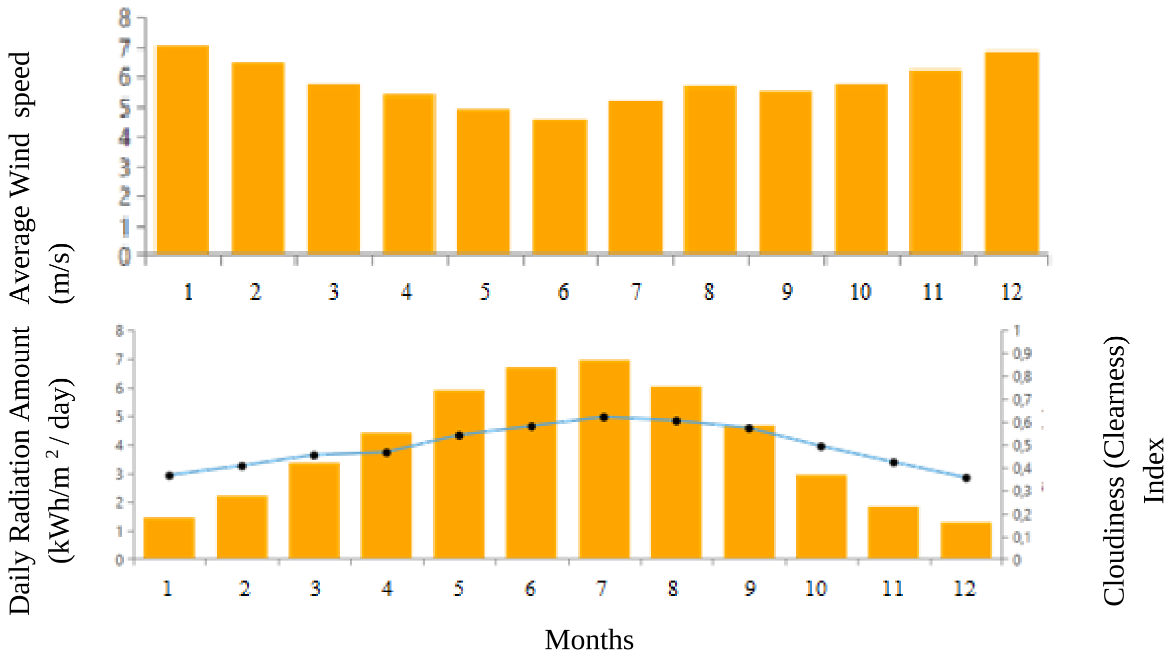


Figure 8. Monthly average wind speed, daily radiation amount, and temperature values (Aylık ortalama rüzgar hızı, günlük radyasyon miktarı ve sıcaklık değerleri)

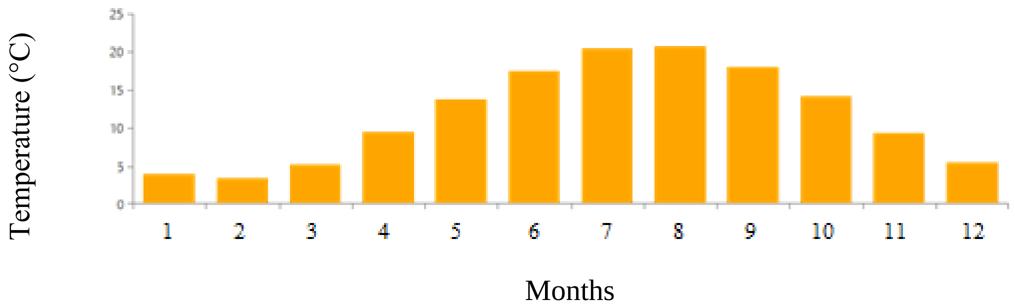


Figure 8. Continued (Devamı)

The graphs of the hourly data of the electrical load classified according to the months are shown in Figure 7. When these graphs were analyzed based on all months, it was observed that the period in which the electrical load was consumed the most was between 5:00 and 8:00 p.m., and the period in which the electricity load was consumed the least was between 11:00 p.m. and 04:00 a.m.

While the average wind speed in the Yenice district of Karabük was 5.77 m/s, the month with the lowest wind speed was June, while the month with the highest wind speed was January. When the solar energy potential was examined as seen in Figure 8, the average daily amount of radiation was 3.99 kWh/m2/day, with 6.97 kWh/m^2/day being the highest in July, while with 1,280 kWh/m^2/day being the last December. While the cloudiness was mostly seen in July, it was less in December. As the cloudiness index decreases, electricity production from solar energy decreases.

When the temperature values were checked, the average value was 11.79 °C, while August was the hottest month and January was the lowest month. All this information was taken from Homer Pro NASA Surface Meteorology and Solar Energy Database. This information is averaged using the values between the years 1983 and 2005.

3. RESULTS (BULGULAR)

While NPC can be reduced to minimum levels by solving optimization problems in all system designs, the lowest cost, zero-emission generation, and energy production costs can vary. For this reason, while solving an optimization problem, the constraints and decision variables that affect the solution may differ. When it comes to accuracy in the solution, it is complicated due to the nonlinearity of the equipment that makes up the system. However, in such systems, the most appropriate decision of a system to be established is reached by correctly determining the decision variables and the effect of constraints on the cost. Energy analysis of the hybrid system consisting of a generator, a wind turbine, a solar panel, a battery, a hydrogen tank, an electricity load and hydrogen load for the Yenice district of Karabük province was modeled using HOMER PRO software. The analysis was made by increasing the percentage of renewable energy use for the selected location. Renewable energy rates of 0 %, 10%, 25%, 50%, 60%, 75%, 90%, 95%, and 100% were used. The results of the analysis with various hybrid system components and graphs of the net present cost and the unit energy cost were shown in Figure 9 and Figure 10.

For the simulated location, 7 different hybrid systems were designed and 63 case studies with 9 different renewable energy rates were conducted. HOMER Pro gave the greenhouse gases (such as carbon monoxide, carbon dioxide, nitrogen oxides, sulfur dioxide, unburned hydrocarbons, particulate matter and consumed fuel values) released as a result of the simulation in the final report. The damage caused by these reports to the environment was shown in Figure 11, Figure 12 and Figure 13.

The use of fossil fuels in energy production causes serious damage in terms of greenhouse gas emissions released to the environment. The amount of fuel used to meet the energy demand according to the different renewable energy ratios of the systems modeled in this study was given in Figure 11. In the Gen-PV-WT-Bat-Elec-300Htank-H-loaded system designed in Yenice district, 232.742.487 litres of fuel were used in the case of 0% renewable energy sources, while there was a fuel consumption of 152.223.144 litres when the renewable energy rate was 50%. Despite these fuel consumptions, when it had a 95% renewable energy rate, there was a fuel consumption of 17.025.145 litres.

In the case of 100% renewable energy rate, any damage to the environment did not appear to be shown in Figure 12 and Figure 13. The system that caused the most damage to the environment raised when it came to the use of renewable energy sources without any rates. When the renewable energy rate of the system called Gen-PV-WT-Bat-Elec-

300Htank-Hload was 95%, it was observed that the amount of carbon dioxide decreased from 622,318.27 tons/year to 44,565.27 tons/year, according to the simulations made for Yenice district. For the same location, the amount of carbon monoxide for the Gen-PV-Bat system was 3962.09 tons/year, while the amount of carbon monoxide was 280,92 tons/year when 95% renewable energy rate was used.

System designs were examined in the case where the renewable energy ratio of the hydrogen load changing for two different electrical loads is 60 % and 95%. According to the results made in this context, it has been observed that the unit energy cost increases in case of a high electrical load, and at the same time, the unit energy cost of 60% renewable energy is lower in case of the same hydrogen load. The cost analysis of the change according to the MNR Ratio corresponding to the variable hydrogen load for the 3997104 kWh/day electrically loaded system is shown in Figure 14, and the cost variation of the 1000 kWh/day electrically loaded system is shown in Figure 15.

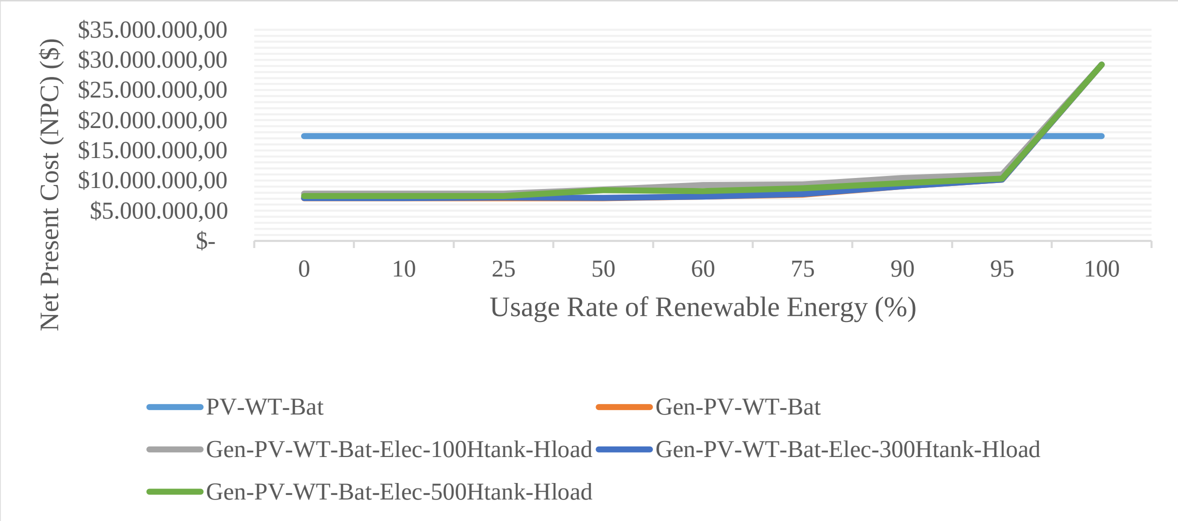


Figure 9. Net present costs scaled by renewable energy ratio (1/1000) (Yenilenebilir enerji oranına göre ölçeklendirilmiş net bugünkü maliyetler)

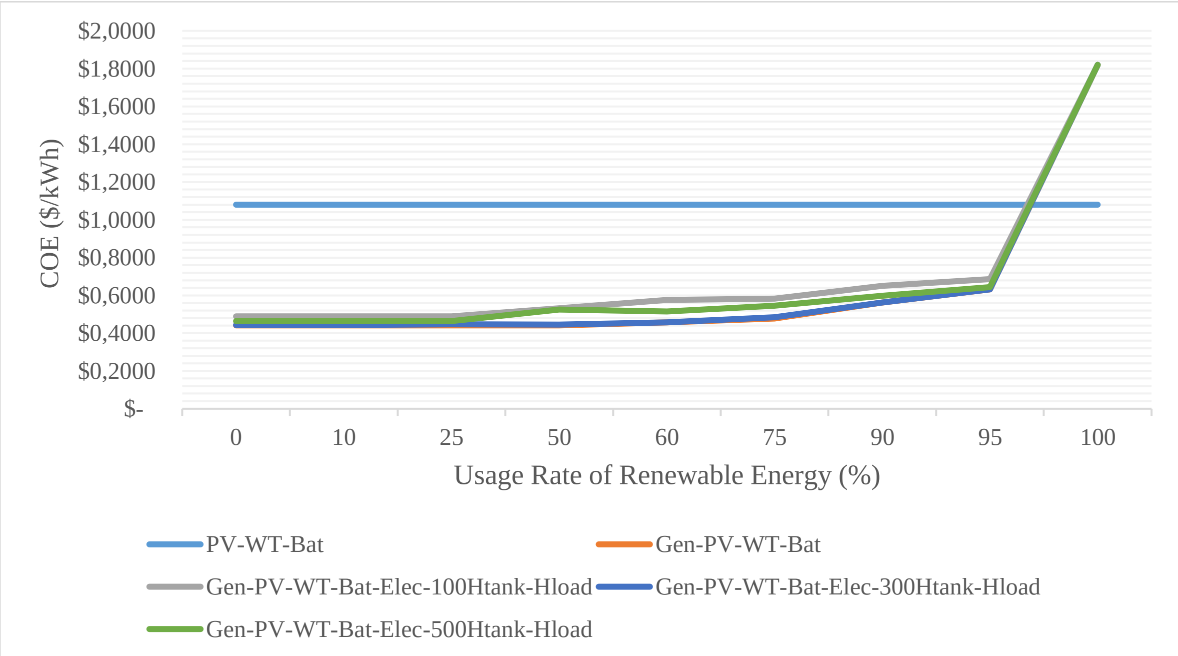


Figure 10. Unit cost of renewable energy by energy ratio ($/kwh) (Yenilenebilir enerjinin enerji oranina göre birim maliyeti)

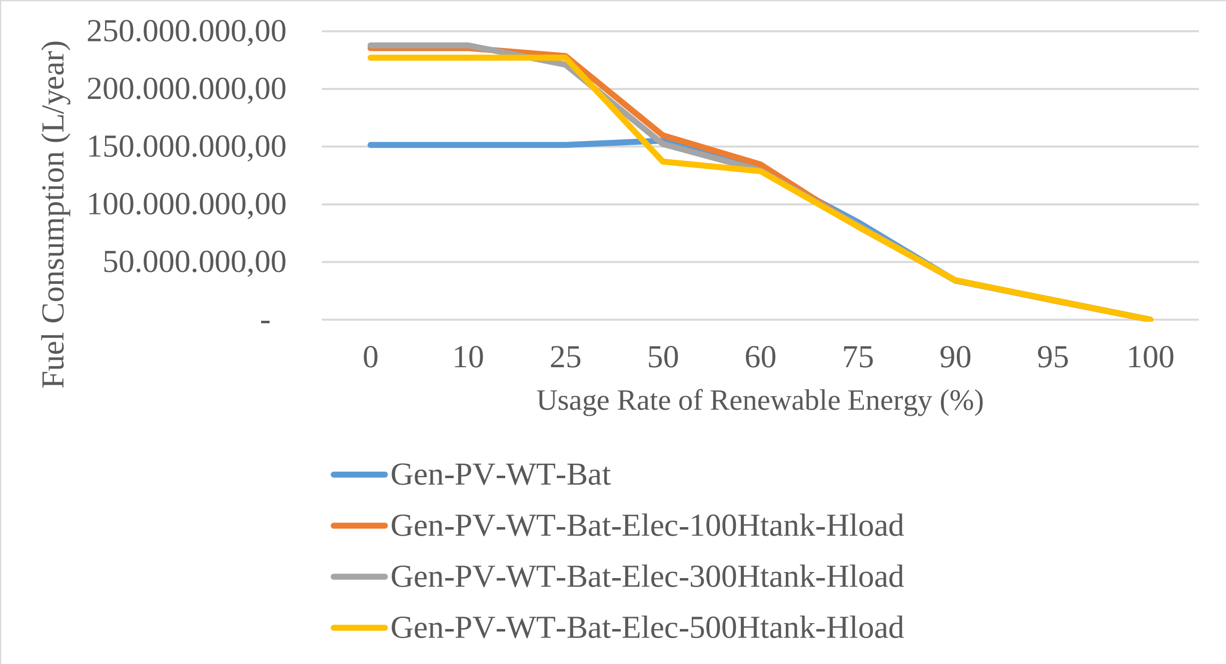


Figure 11. Comparison of fuel consumption of hybrid systems by renewable energy ratio (Hibrit sistemlerin yakıt tüketiminin yenilenebilir enerji oranına göre karşılaştırılması)

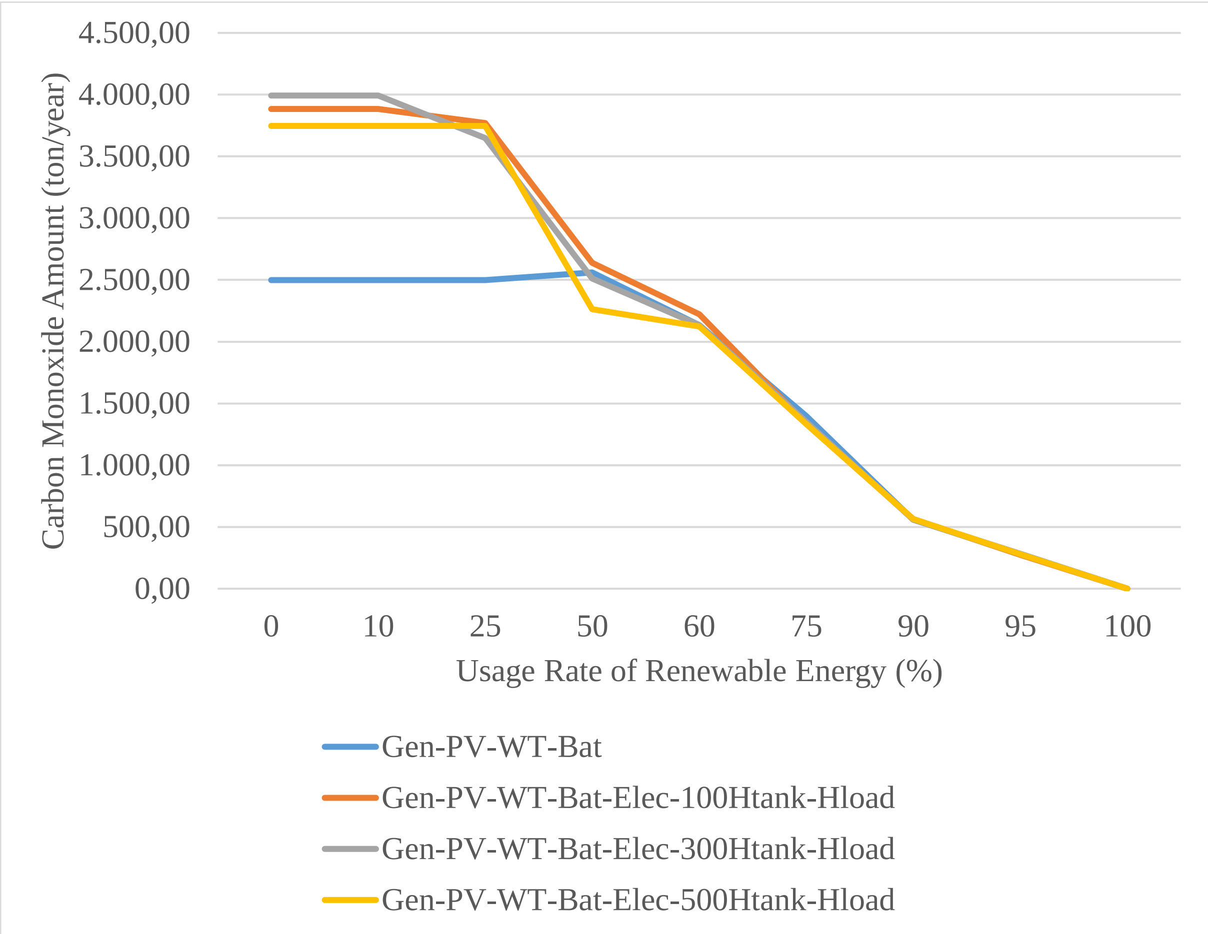


Figure 12. Carbon monoxide emissions of hybrid systems by renewable energy ratio (Yenilenebilir enerji oranına göre hibrit sistemlerin karbonmonoksit emisyonları)

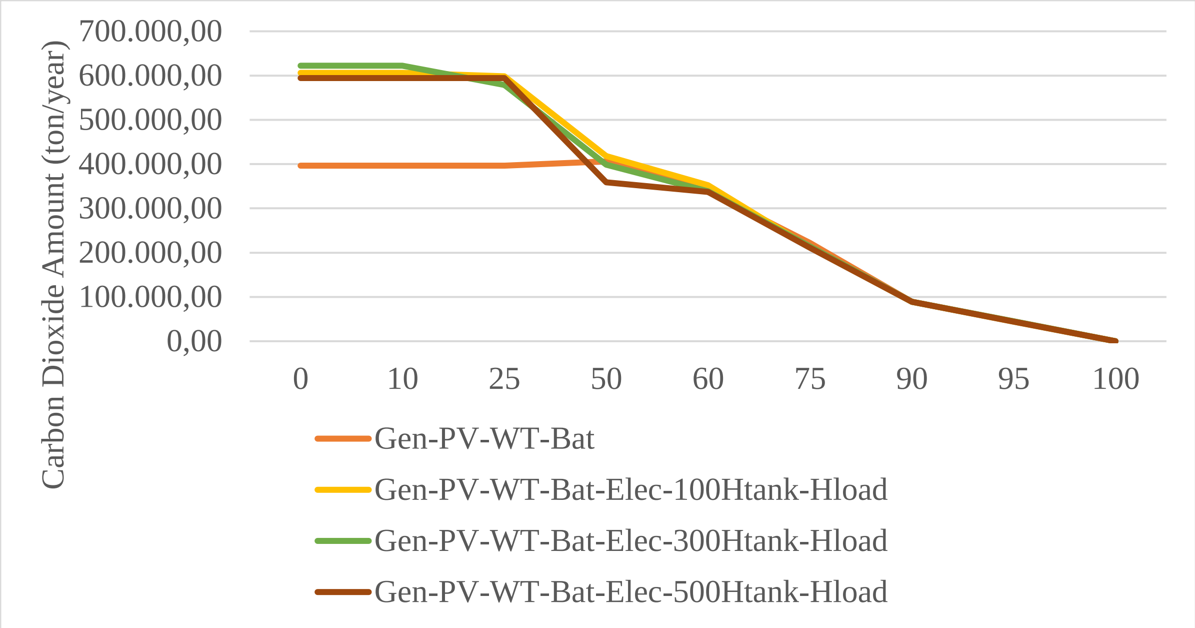


Figure 13. Carbon dioxide emissions of hybrid systems by renewable energy ratio (Yenilenebilir enerji oranına göre hibrit sistemlerin karbon dioksit emisyonları)

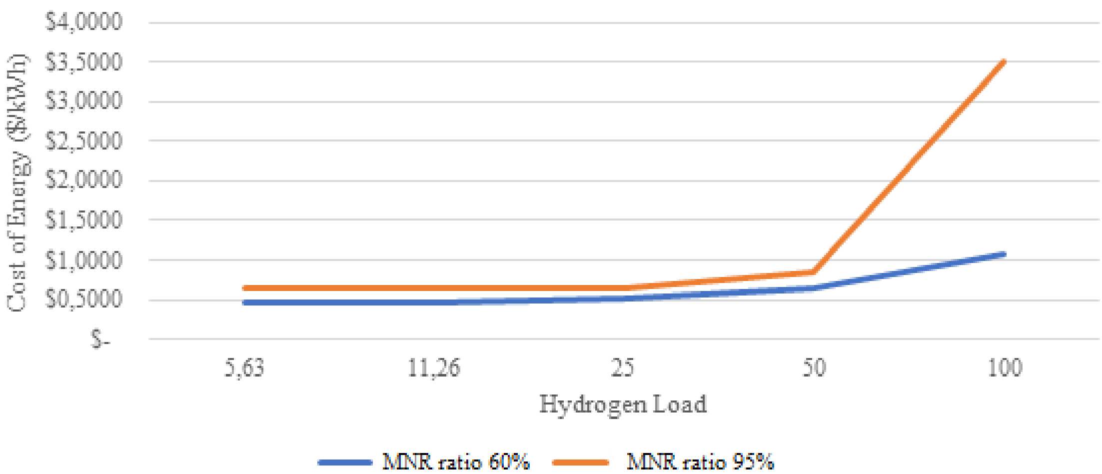


Figure 14. Electric load 3997104 kwh/day, variable hydrogen load system design cost variation by MNR ratio (Elektrik yükü 3997104 kwh/gün, değişken hidrojen yüklü sistem tasarım maliyetinin MNR oranına göre değişimi)

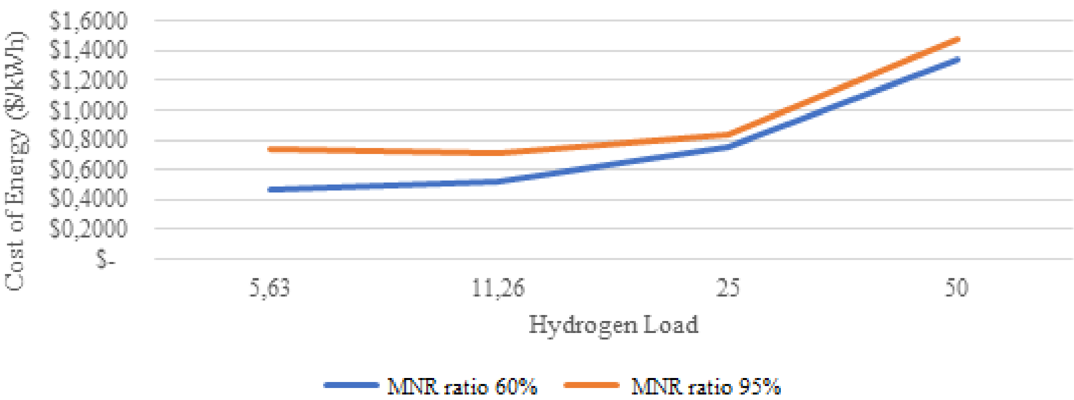


Figure 15. Cost variation of electric load 1000 kwh/day, variable hydrogen load system design according to MNR ratio (Elektrik yükünün maliyet değişimi 1000 kwh/gün, MNR oranına göre değişken hidrojen yüklü sistem tasarımı)

Table 1. system specifications with 500 kg hydrogen tank capacity for Yenice district (Yenice ilçesi 500 kg hidrojen tankı kapasiteli sistem özellikleri)

System Component	Name	Size	Unit
Generator	Autosize Genset	700,000	kW
Solar Panel	Generic Flat Plate PV	836,266	kW
Storage System	Generic 1 kWh Li -On	6,561,842	strings
Wind Turbine	Generic 3 kW	905.895	ea.
Converter	System Converter	912.915	kW
Electrolyzer	Generic Electrolyzer	100	kW
Hydrogen Tank	Hydrogen Tank	500	kg

The system specifications with the 100% renewable energy rate used for the design of the Gen-PV-WT-Elec-Bat-500Htank-H loaded system of Yenice district were shown in Table 1. The system consisted of 700,000 kW diesel generators, 836,266 kW solar panels, 6,561,842 kWh Li-On batteries of 1kWh, 905,895 wind turbines of 3 kW each, 912,915 kW converters, 100 kW electrolyzer, 500 kg hydrogen storage. In case of that the system cannot meet the demand, it was met by using hydrogen energy to meet the energy demand. Although the cost of using hydrogen energy was higher at the moment, this situation would change with the damage to the environment and the developing technology. With this change, energy production costs would decrease and hydrogen usage capacity would increase or decrease with the reduce in energy production unit costs and the reduce in the use of fossil fuels. When it came to the cost of the renewable energy system, the capital cost, operating cost, replacement cost, recovery cost, and resource cost were given in Figure 16. When the costs were examined, the highest capital cost consisted of wind turbines and batteries.

Among the designed systems, the PV power output with a 500 kg hydrogen tank was seen in Figure 15 and the WT power outputs were shown in Figure 16. While the PV system was operated for 4375 hours in a year and provided an average hourly energy production of 235,988 kW, it operated with a capacity factor of 14.7% and contributed to the total production of 2,067,250,845 kWh/year. While the WT system operated for 6673 hours in a year and provided an average hourly energy production of 46.313 kW, it worked with a capacity factor of 13.3% and contributed to the total production of 405.706.044 kWh/year.

The hourly occupancy rate of the hydrogen tank in the system, which had a 500 kg hydrogen tank, was shown in Figure 17. The hydrogen tank storage capacity was 500 kg, while the capacity at the beginning of the year was 250 kg, it was filled with a capacity of 202 kg at the end of the year. In addition to these features, the hydrogen storage capacity was 16,667 kWh, while the hydrogen tank capacity appeared to be at full capacity with 500 kg in August, September, and October.

Li-On batteries with 2,982,871 kWh were used in the hybrid system. The graph showing the hourly charge capacity of these batteries in a year was depicted in Figure 18. The average energy production of the batteries was 542,221,781 kWh/year. When the graph was examined, it was seen that their capacity was usually full annually between 12:00 and 18:00. It was determined that it consumed energy between 18:00 and 11:00.

The graph that deals with the energy output of the renewable energy production of the whole system was shown in Figure 19. 81.6 % of the total energy production was obtained from solar panels with a production of 2.067.250.845 kWh/year, 16% from wind turbines with 405.706.044 kWh/year, 2.43% from 61,718.347 kWh/year. Production was made from the generator with annual production. The ratio of the renewable energy capacity used to the total capacity was 97.6% as instant renewable energy output. The monthly average representation of electricity production was given in Figure 20. While solar panels had the highest share in electricity production, it was followed by wind turbines. It turned out that the generator had the lowest share in electricity production.

It was observed that the filling capacity of the hydrogen tank increased when the MNR Ratio was changed. When the MNR ratio was 60%, the occupancy rate decreased. In this context, the occupancy rate according to the variable hydrogen load with the 300 kg hydrogen tank and the MNR rate of the fixed electrically loaded system was shown in Figure 23.

In this study, the occupancy rate according to the variable hydrogen load of the 300 kg hydrogen tank and the MNR rate of the fixed electrically loaded system is shown in Figure 24. When the electric load is 1000 kWh/day and the hydrogen load is 5.63-11.26-25-50, 8 cases are examined as MNR Ratio 60-95. As a result of this modelling, the filling capacity of the hydrogen tank was examined. When the occupancy rate of the hydrogen tank capacity is controlled, it has been observed that when the hydrogen load is low, the occupancy rate is high, and when the hydrogen load is high, there are fluctuations in the occupancy rate. The investigations have shown that the filling capacity of the hydrogen tank increases when the MNR Ratio is changed. When the MNR ratio is 60, the occupancy rate decreases.

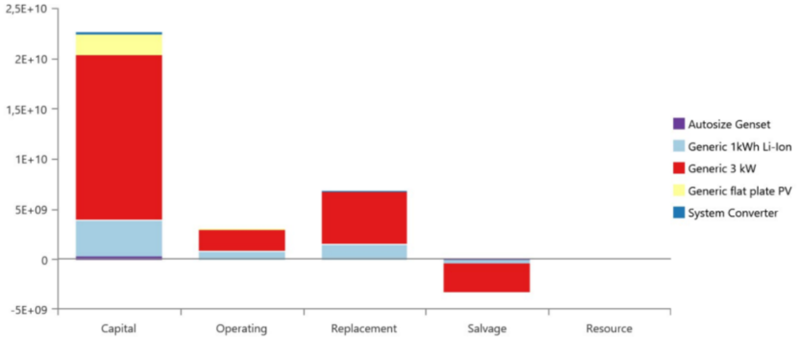


Figure 16. Cost summary of hybrid system for 100% renewable energy ratio (%100 yenilenebilir enerji oranı için hibrit sistemin maliyet özeti)

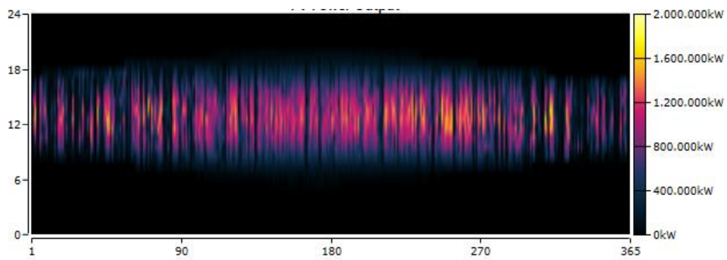


Figure 17. PV energy output of the hybrid system (kW) (Hibrit sistemin PV enerji çıkışı)

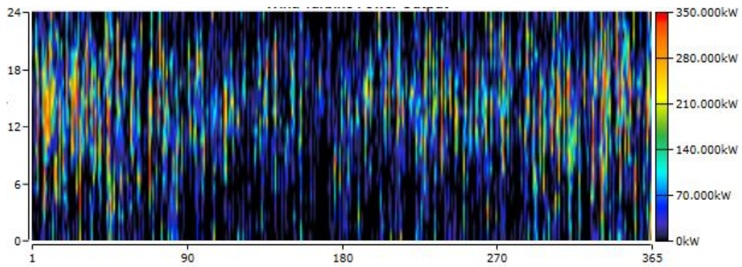


Figure 18. WT energy output of the hybrid system (kW) (hibrit sistemin WT enerji çıkışı)

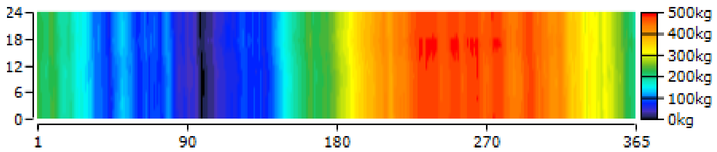


Figure 19. Hydrogen tank capacity of the hybrid system (hibrit sistemin hidrojen tankı kapasitesi)

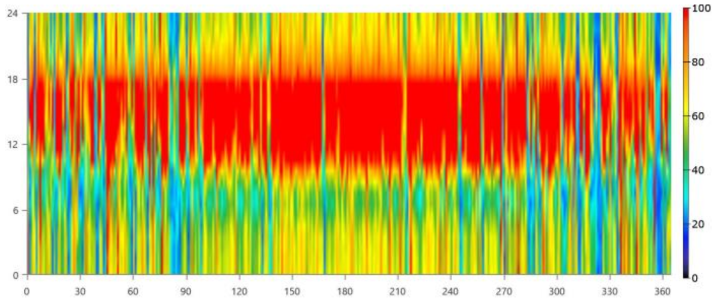


Figure 20. 1 kWh li-ion battery charge status used in system design (Sistem tasarımında kullanılan 1 kwh li-ion akü şarj durumu)

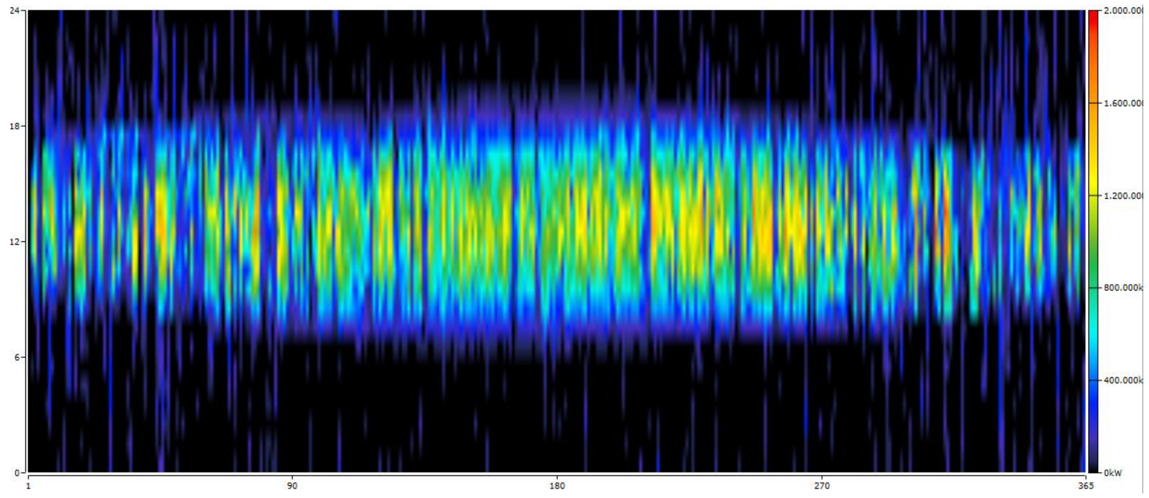


Figure 21. Renewable energy output of total hybrid system (Toplam hibrit sistemin yenilenebilir enerji çıkışı)

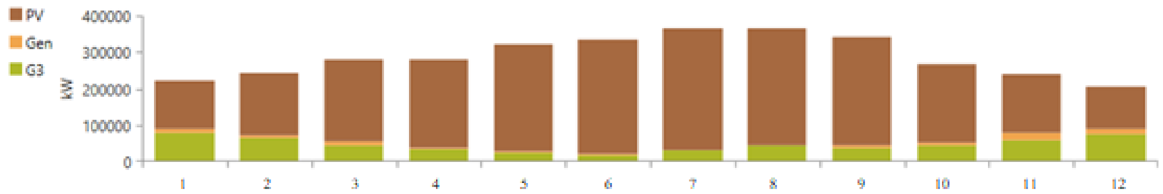
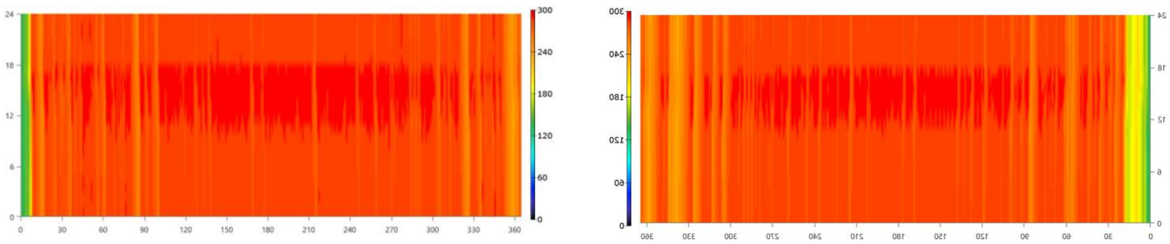
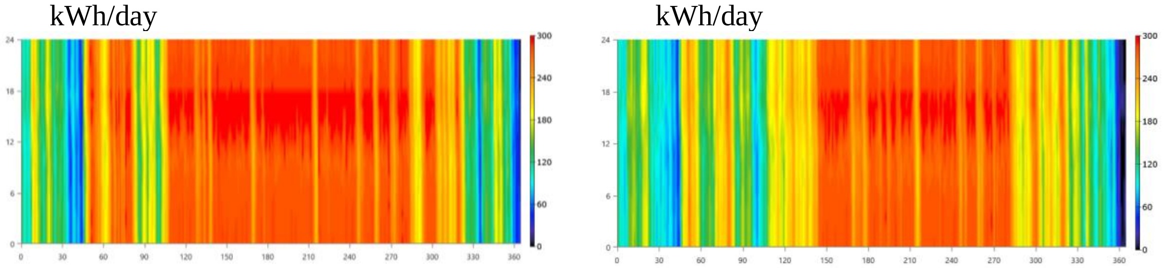


Figure 22. Monthly average electricity production (Aylık ortalama elektrik üretimi)



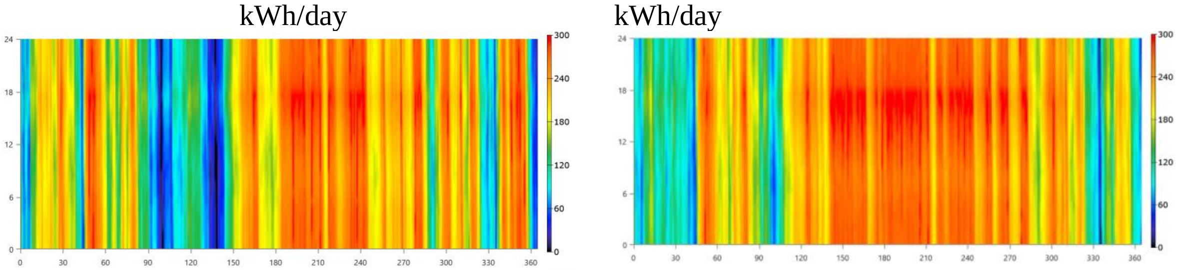
a) MNR: 95% – HL: 5.63 kg/day EL:3997104 kWh/day

b) MNR: 60% – HL:5.63kg/day EL:3997104 kWh/day



MNR: 95% – HL: 25 kg/day EL:3997104 kWh/day

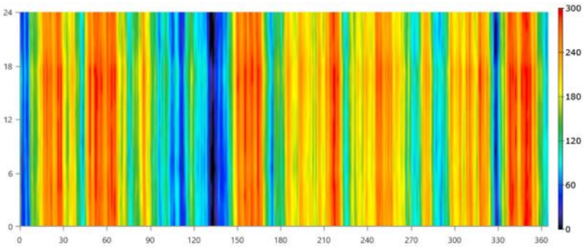
MNR: 60% – HL:25 kg/day EL:3997104 kWh/day



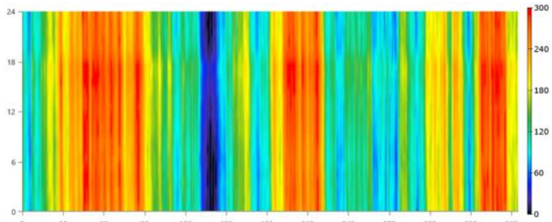
MNR: 95% – HL: 50 kg/day EL:3997104 kWh/day

MNR: 60% – HL:50 kg/day EL:3997104 kWh/day

Figure 23. Display of hydrogen tank level at variable MNR rate with electric load 3.997.104 kwh/day and different hydrogen load (3.997.104 kWh/gün elektrik yükü ve farklı hidrojen yükü ile değişken MNR oranında hidrojen tankı seviyesinin gösterimi)

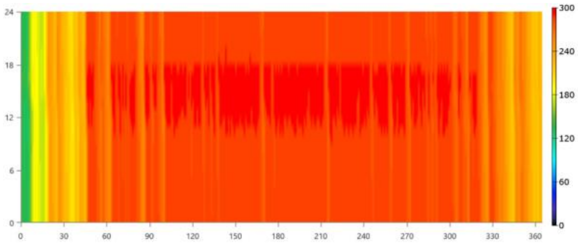


a) MNR: 95% – HL:100 kg/day EL:3997104 kWh/day

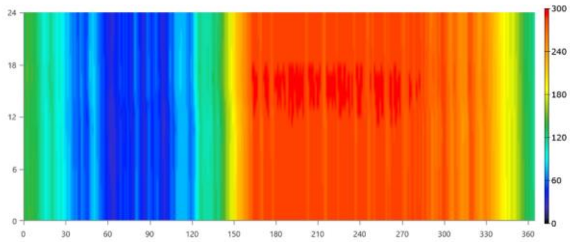


b) MNR: 60% – HL:100 kg/day EL:3997104 kWh/day

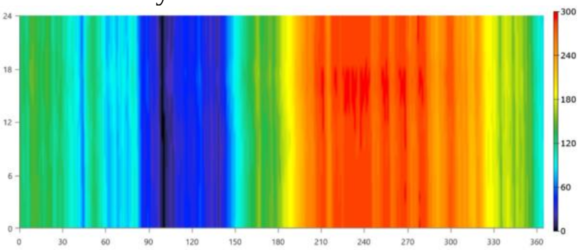
Figure 23. Continued (Devamı)



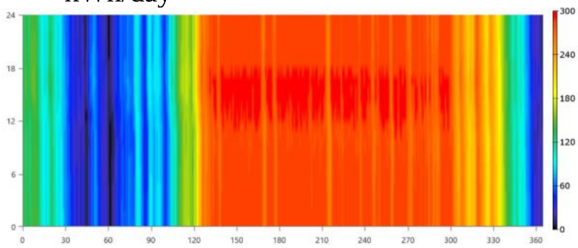
a) MNR: 95% – HL: 5.63 kg/day EL:1000 kWh/day



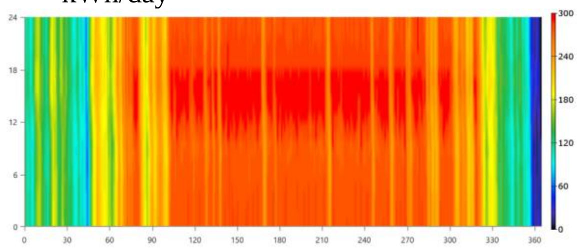
b) MNR: 60% – HL:5.63 kg/day EL: 1000 kWh/day



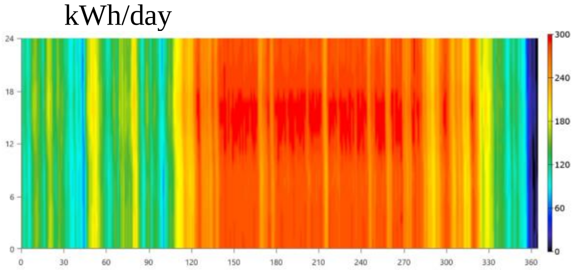
c) MNR: 95% – HL: 11.26 kg/day EL:1000 kWh/day



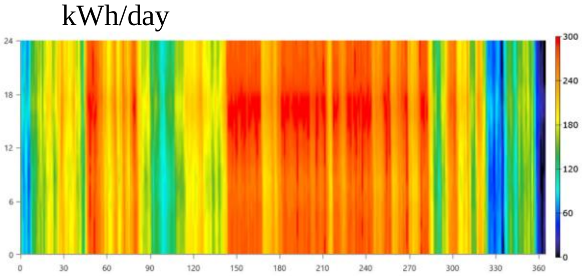
d) MNR: 60% – HL:11,26 kg/day EL:1000 kWh/day



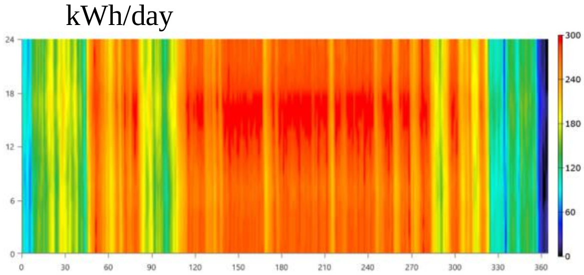
e) MNR: 95% – HL: 25 kg/day EL:1000 kWh/day



f) MNR: 60% – HL:25 kg/day EL:1000 kWh/day



g) MNR: 95% – HL:50 kg/day EL:1000 kWh/day



h) MNR: 60% – HL:50 kg/day EL:1000 kWh/day

Figure 24. Hydrogen tank level display at variable MNR rate with electric load 1000 kwh/day and different hydrogen load (1000 kWh/gün elektrik yükü ve farklı hidrojen yükü ile değişken mnr oranında hidrojen tankı seviye gösterimi)

4.CONCLUSIONS (SONUÇLAR)

In this study, an optimum hybrid system research was carried out to meet the energy demand of the Yenice district of Karabük province with a capacity of 3.997.104 kWh/day. In the hybrid system design, in addition to the hydrogen tank with different capacities, a system design was made from a generator, a solar panel, a wind turbine, and batteries. Energy costs and environmental damages were evaluated according to the percentage of using renewable energy. The most cost-effective system was the Gen-PV-WT-Bat system with $7,069,438, ignoring the damage to the environment where there was no renewable energy usage. The unit energy cost of this system was $ 0.4410, while the damage be caused to the environment emitted 396,209.06 tons/year of carbon dioxide gas and 2,497.48 tons/year of carbon monoxide gas. When the renewable energy rate of the same system was 100%, the damage to the environment could not be found, while the unit energy cost was $1.82. According to the evaluation of the simulation results, Gen-PV-WT-Bat-Elec-300Htank-H was the most cost-effective system despite having the highest fuel consumption. While the unit energy cost of this system was $0,6322.

When the electric load was 3.3997.104 kWh/day and the hydrogen load was 5.63-25-50-100, 8 cases were examined as MNR Ratio with 60%-95%. As a result of this examination, the filling capacity of the hydrogen tank was considered. When the occupancy rate of the hydrogen tank capacity was controlled, it was observed that when the hydrogen load was low, the occupancy rate was high, and when the hydrogen load was high, there were fluctuations in the occupancy rate.

According to the results of all system simulations, although the use of renewable energy sources caused an increase in the unit energy cost and net present cost, when the effect of damage to the environment was deducted, hybrid systems using 95% renewable energy could be installed. In addition to all these, it was revealed that off-grid hybrid systems would not be suitable for having a single energy source because they were far from the grid, and systems that complement each other would be beneficial for uninterrupted energy production. Hybrid Renewable Energy Systems (HRES) have proven to be a viable solution to meet local loads in off-grid, rural, or privately owned residential or agricultural use. According to the results of the study, it was found that it was suitable for use by making optimum sizing.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Esra BAYIR*:** She performed the simulations in the research, analyzed the results and contributed to the writing of the article.

Araştırmadaki simülasyonları yapmış, sonuçlarını analiz etmiş ve makalenin yazımına katkıda bulunmuştur.

***Halil Hakan AÇIKEL*:** He performed the simulations in the research, analyzed the results and contributed to the writing of the article.

Araştırmadaki simülasyonları yapmış, sonuçlarını analiz etmiş ve makalenin yazımına katkıda bulunmuştur.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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