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Renewable Energy and Hydrogen Storage System Analysis for Carbon Neutral Campuses with HOMER

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Keywords
Renewable energy, Hydrogen storage, Hybrid renewable energy system (HRES), Carbon neutrality, Techno-economic analysis, HOMER

Abstract: This study presents a detailed techno-economic analysis of a Hybrid Renewable Energy System (HRES) designed to achieve carbon neutrality for Dicle University in Diyarbakır, Turkey. Leveraging the region's high solar potential and moderate wind availability, the system integrates photovoltaic panels (PV), wind turbines (WT), battery storage systems (BSS), electrolyzers, and hydrogen storage tanks (HST). Despite the wind potential being less pronounced than solar energy in Diyarbakır, wind turbines are included to ensure energy diversity and reliability, particularly during non-sunny periods. The analysis, conducted using HOMER Pro software and local meteorological data, evaluates the system's capacity to meet a daily energy demand of 34.3 kWh. The optimized system comprises an 123 kW PV array, a 10 kW WT, an 1 kWh BSS, a 113 kW electrolyzer, and a 1000 kg hydrogen storage capacity. The economic analysis reveals a total capital cost of $483,650, a Net Present Cost (NPC) of $537.006,57, and a Levelized Cost of Energy (LCOE) of $10.66/kWh. Results demonstrate the feasibility and efficiency of integrating renewable energy sources with hydrogen storage to achieve energy sustainability, reliability, and significant carbon emission reductions. This work provides a scalable model for deploying HRES in similar climates and institutions.

Karbon Nötr Kampüsler için Homer ile Yenilenebilir Enerji ve Hidrojen Depolama Sistemleri Analizi

Anahtar Kelimeler
Yenilenebilir Enerji, Hidrojen depolama, Hibrit yenilenebilir enerji sistemi (HYES), Karbon nötrlüğü, Teknik ve ekonomik analiz, HOMER

Öz: Bu çalışma, Diyarbakır'daki Dicle Üniversitesi için karbon nötrlüğe ulaşmayı hedefleyen Hibrit Yenilenebilir Enerji Sistemi'nin (HYES) ayrıntılı bir teknik ve ekonomik analizini sunmaktadır. Bölgenin yüksek güneş enerjisi potansiyeli ve orta düzeydeki rüzgar potansiyeli değerlendirerek sistem, fotovoltaik paneller (PV), rüzgar türbinleri (WT), batarya depolama sistemleri (BSS), elektrolizörler ve hidrojen depolama tanklarını (HDT) entegre etmektedir. Diyarbakır'da rüzgar potansiyeli güneş enerjisine kıyasla daha düşük olmasına rağmen, rüzgar türbinleri, özellikle güneşsiz dönemlerde enerji çeşitliliği ve güvenilirliği sağlamak amacıyla sisteme dahil edilmiştir. HOMER Pro yazılımı ve yerel meteorolojik veriler kullanılarak gerçekleştirilen analiz, günlük 34,3 kWh enerji talebini karşılayacak sistemin kapasitesini değerlendirmektedir. Optimize edilen sistem, 123 kW PV dizisi, 10 kW WT, 1 kWh BSS, 113 kW elektrolizör ve 1000 kg hidrojen depolama kapasitesinden oluşmaktadır. Ekonomik analiz, toplam sermaye maliyetini 483.650 $, Net Mevcut Maliyeti (NPC) 537.006,57 $ ve Düzlenmiş Enerji Maliyetini (LCOE) 10,66 $/kWh olarak ortaya koymaktadır. Sonuçlar, yenilenebilir enerji kaynaklarının hidrojen depolama ile entegre edilmesinin enerji sürdürülebilirliği, güvenilirliği ve karbon emisyonlarının önemli ölçüde azaltılmasında etkin ve uygulanabilir bir çözüm sunduğunu göstermektedir. Bu çalışma, benzer iklim ve kurumlarda HRES uygulaması için ölçeklenebilir bir model sağlamaktadır

1. INTRODUCTION

The demand for electricity is rising in line with the growth of the global population.[1] The principal factors contributing to this growth can be attributed to the accelerated pace of technological and industrial advancement, as well as the proliferation of electrical devices utilized by consumers across various facets of life [2]. This necessity is typically fulfilled by fossil fuels, which are detrimental to the environment and finite in supply [3]. The global energy crisis has emerged concurrently with the global health crisis triggered by the advent of the COVID-19, the Red Sea crisis, and Russia's invasion of Ukraine [4]. The aforementioned crises have resulted in a scarcity of environmentally detrimental fossil fuels and a surge in their market value. In consequence of this unfavorable situation, investments in renewable energy sources (RES), which consist of environmentally friendly and limited energy sources such as solar, wind, and biomass, have accelerated [5]. For example, the installed capacity of wind power plants worldwide reached 1 TW by the end of 2023 [6]. Furthermore, Turkey, with its growing population and developing industry, derives 44.8% of its energy needs from fossil fuels and 55.2% from renewable sources of energy (RES) as a result of its investments in RES [7].

In 2035, a peak in energy consumption will be reached, indicating a subsequent increase in greenhouse gas emissions [8]. To address these concerns, countries are formulating policies aimed at eliminating these emissions. These policies are designed to promote carbon neutral transitions across various sectors, including transportation and grid stabilization [9]. A significant approach to achieving this objective involves the utilization of green hydrogen, which involves the storage and transportation of excess energy produced by renewable energy sources [10]. Nuclear energy is poised to emerge as a reliable alternative for reducing greenhouse gas emissions [11].

The immediate fluctuations in RES production levels, which are contingent upon atmospheric and environmental circumstances, diminish the dependability of energy provision. This has a detrimental impact on energy efficiency and sustainability [12]. To address this challenge, hybrid renewable energy systems (HRES), which integrate multiple energy sources, have been developed [13]. The implementation of HRES has resulted in enhanced sustainability, security, and efficiency in energy utilization [14]. Moreover, depending on the design region-specific criteria, a HRES can incorporate some or all of these sources, including wind, biomass, geothermal, hydro, diesel generator (DG), batteries, pumped storage, and flywheel [15], [16] . In light of the region-specific criteria, it is imperative to devise an optimal HRES design for stochastic load cases that is both reliable and cost-effective. To this end, comprehensive technical, economic, and environmental analyses must be conducted, and the most suitable components must be selected and positioned based on the findings of these analyses [17].

A number of commercial software programs are available for designing HRES including Hybrid Optimization of Multiple Energy Resources (HOMER Pro), RETScreen, PVWatts, EnergyPLAN, KomMod, PVSyst software, Hybrid2, Helioscope, iHOGA software, and TRNSYS [18]. These software programs facilitate the design, sizing, technical, and economic evaluation of HRES [19]. HOMER Pro offers notable advantages, including a straightforward user interface, effective graphical representation of results, and an hourly data processing capacity [20]. Moreover, in comparison to other software programs, HOMER Pro boasts a more extensive repository of renewable resources, the capacity to model grid-connected or standalone systems, and the capability to conduct economic assessments. However, the most significant advantage of HOMER Pro over other programs is its ability to simulate and optimize according to techno-economic evaluations in varying scenarios [21].

In [22], conducted a technical and economic analysis of an electric vehicle charging station in Karampura, Delhi, for three different cases of photovoltaic (PV)-Hydrogen, Wind (WTG)-Hydrogen and PV-WTG-Hydrogen, employing the use of HOMER Pro software. In [23], a techno-economic analysis was conducted utilising the HOMER Pro software for a wind-powered hydrogen refuelling station in seven South African cities, designed to serve 25 hydrogen vehicles with a tank capacity of 5 kg per day. In [24], A technical and economic analysis was conducted of three different systems, namely a PV-Hydrogen system, a Wind-Hydrogen system and a PV-WTG-Hydrogen system, using the HOMER Pro software. In [25], provides financial resources for investment in clean energy infrastructure in Australia. For this purpose, the technical and economic viability of the WTG-Hydrogen system and the PV-WTG-Hydrogen system has been evaluated using HOMER Pro software, with the expectation that they will facilitate the production of hydrogen in Australia. In [26], conducted a technical and economic analysis of a HRES consisting of PV, WTG, electrolyser, hydrogen tank, battery, fuel cell (FC), hydrogen boiler and thermal load in Northern Alberta, Canada. This was achieved through the utilisation of the HOMER Pro software, with five different scenarios being considered. In [27], a HRES model comprising PV system, WTG, biogas generator (BGG) and battery storage system (BSS) was subjected to technical and economic analysis using the HOMER Pro software. The model was designed for a village situated in the rural Bingöl province. In [28], a technical and economic analysis of four different scenarios was conducted using HOMER Pro software: grid-connected grid-DG, grid-DG-PV, grid-DG-PV-BSS and grid-DG-BSS. In [29], conducted a technical and economic analysis for an off-grid HRES in Afyon province of Turkey using the HOMER Pro software, comprising PV system, electrolyser, hydrogen tank and FC. In [30], conducted a technical and economic analysis utilising HOMER Pro software for an off-grid HRES comprising PV, WTG, DG and BSS for the Navajo region in New Mexico.

In this study, a HRES system was developed in the software platform HOMER Pro for the purpose of reducing the carbon emissions of the Dicle University campus in Diyarbakır province. The system comprises PV, WTG, BSS, hydrogen, a hydrogen tank and an electrolyser. Diyarbakır province is distinguished by its considerable solar potential. The objective is to utilise the surplus or irregular output generated by PV and WTG at the appropriate juncture by storing hydrogen. Consequently, techno-economic analyses have been conducted and evaluated for the system to be devised.

2. MATERIAL AND METHOD

The planned HRES system of Dicle University is situated at the following geographical coordinates: 40°16′ N longitude and 37°54′ N latitude. According to data from the General Directorate of Renewable Energy, Turkey and, in particular, the Southeastern Anatolia Region is a region with a high level of total global solar radiation, with a solar radiation of 1460 kWh/m²-year and an average sunshine duration of 2993 hours/year [31]. Figure 1 illustrates the fluctuations in global radiation and sunshine duration across months in Diyarbakır province. It can be observed that Diyarbakır receives approximately eight hours of sunshine annually on average. The province's higher sunshine levels than the national average in Turkey highlight the potential for effective utilisation of this energy source [32].

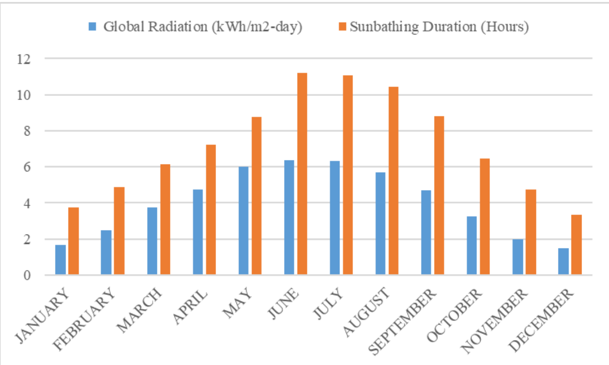


Figure 1. Average Global Radiation Values and Sunrise Durations

2.1. HOMER Pro

HOMER Pro is a user-friendly software, the use of which is free of charge, that has been developed for the purpose of facilitating the design of electric renewable energy systems. The software was designed in 1993 by the US National Renewable Energy Laboratory (NREL) for use with both on-grid and off-grid systems, and has since become widely used worldwide. The software simulates system configurations and provides optimised results in terms of net present cost, which can be analysed in tabular and graphical form. HOMER Pro is developed in C++ on the Windows platform and employs the HDKR anisotropic model for solar energy systems. The software allows users to input component costs, energy sources and other technical data in order to analyse different system configurations. The software is capable of simulating 8,760 hours per year and provides comprehensive outputs for economic and technical assessments. However, it should be noted that HOMER Pro has certain limitations. These include the fact that it only works with a single objective function, does not consider battery depth of discharge (DOD), and ignores intra-hour variations and bus voltage variations. It may therefore be beneficial to enhance the flexibility and support for different optimisation techniques, which could further expand the use of HOMER [18], [33].

2.2. PV system

In this study, 8 Kw flat plate PV panel is used. HOMER Pro software calculates the power output of the PV array according to Equation 1 [7].

$$P_{PV} = A_{PV} k_{pv} \left(\frac{H_L}{H_{L,STC}}\right) \left[1 + \beta_P \left(L_c - L_{c,STC}\right)\right] \quad (1)$$

In this context, A_{PV} represents the power output under test conditions (kW), k_{PV} denotes the PV depreciation factor [%], and H_L signifies the solar radiation incident on the PV array at the current time step [kW/m²]. $H_{L,STC}$ represents the incident radiation under standard test conditions, which is defined as 1 kW/m². β_P denotes the power temperature coefficient. L_c signifies the temperature of the PV cell at the current time step, whereas $L_{c,STC}$ denotes the temperature of the PV cell under standard test conditions, which is set at 25°C.

2.3. WTG System

The WTG utilised in the HOMER Pro simulation model from this study has a rotor diameter of 15.81 m, a nominal capacity of 10 kW, an on-start wind speed of 2.75 m/s and an off-start speed of 20 m/s. The HOMER Pro software employs the logarithmic law, as outlined in Equation 2, to calculate the wind speed at the hub height of the WTG.

$$H_b = H_m x \left(\frac{w_b}{w_m}\right) \gamma \quad (2)$$

In this context, H_b represents the wind speed at the hub height of the wind turbine (m/s). H_m denotes the wind speed at the anemometer height (m/s). w_b signifies the hub height of the wind turbine (m). w_m is the anemometer height (m), and γ is the power law exponent [7].

2.4. Converter System

Converter technology facilitates bidirectional energy transfer, enabling the fulfilment of energy loads. This is achieved by converting energy generated from wind turbines from alternating current (AC) to direct current (DC) and power from photovoltaic (PV) panels from DC to AC. The HOMER software employs a comprehensive evaluation process to assess the performance of converters, taking into account key parameters such as efficiency, lifetime and cost [23].

2.5. Battery Storage System (BSS)

As the system is off-grid, 1 kWh of lead-acid batteries are employed for energy storage. The HOMER Pro software calculates the charge and discharge states of the BSS in accordance with Equations 3 and 4 [7].

$$O_n(t) = \frac{gR_1(t)e^{-g}+R(t)gc(1-e^{-g\Delta t})}{1-e^{-g\Delta t}+c(g\Delta t-1+1-e^{-g\Delta t})} \quad (3)$$

$$O_n(t) = \frac{-gR_{max}(t)+gR_1(t)e^{-g\Delta t}+R(t)gc(1-e^{-g\Delta t})}{1-e^{-g\Delta t}+c(g\Delta t-1+1-e^{-g\Delta t})} \quad (4)$$

In this context, R_{max} represents the total storage capacity, R_1 denotes the amount of energy stored in the batteries (kWh), R signifies the total amount of energy (kWh), c is the storage capacity ratio, g is the storage rate constant, and Δt is the time interval.

2.6. Electrolyser (ELC)

Electrolysers are instrumental in the field of energy storage, facilitating the splitting of water into hydrogen and oxygen. During daylight hours, the system produces hydrogen using solar energy and demineralised water. The hydrogen is then compressed and stored in the tank, ready for use in energy production when required. PEM (Proton Exchange Membrane) electrolysers offer several advantages over conventional alkaline electrolysers, including higher efficiency, faster response times and the production of hydrogen with a purity level of 99.999%. PEM technology addresses the limitations of alkaline electrolysers, such as low pressure operation and low current, thereby enabling a wide operating range. Furthermore, the utilisation of materials such as platinum as electrodes confers a distinct advantage in terms of performance. In the study, the PEM electrolyser was identified as the optimal choice due to its high efficiency and superior features. The capital cost of the system was calculated to be $80,000, the replacement cost was calculated to be $44,926.71, and the operation and maintenance cost was determined to be $30 with 85% efficiency [34]–[36].

2.6. Hydrogen Tank (HST)

Once the hydrogen has been produced by the electrolyser, it is stored in hydrogen tanks for subsequent use. The most common storage method is that of high-pressure gas cylinders. In recent years, technological advances have made it possible to use lightweight composite cylinders that can withstand 800 bar pressure and allow hydrogen to reach a density of 36 kg/m³ [37].

2.7. Economic Modeling

The economic viability of hydrogen refuelling stations was evaluated using the HOMER Pro software. The analysis was based on key economic indicators, including the net present cost (NPC), the levelised cost of energy (LCOE), and the hydrogen production cost (LCOH) [38], [39].

Net present cost:
The net present cost (NPC) can be calculated in accordance with equation 5 by subtracting the present value of the costs incurred over the life cycle of a project from the present value of the revenues to be generated over the same period. The calculation is made using the total annual cost (D_T) and the capital recovery factor ($DFG(j,K)$). $DFG(j,K)$ is a factor used to determine the present value of annual revenues and can be calculated in accordance with equation 6:

$$D_{NPC} = \frac{D_T}{DFG(j,K)} \quad (5)$$

$$DFG(j,K) = \frac{j\,(1+j)^K}{(1+j)^K-1} \quad (6)$$

In this equation, the variable "j" represents the real interest rate, expressed as a percentage, while the variable "K" denotes the lifespan of the component, expressed in years.

Levelised cost of energy

The term 'Levelised Cost of Energy' (LCOE) is used to describe the average cost per kWh of useful energy produced by a power generation system. The LCOE is calculated in accordance with equation 7, where B_r represents the total electrical energy (kWh/year) required to maintain the operation of the hydrogen refuelling station [38], [39]

$$LCOE = \frac{D_T}{B_r} \quad (7)$$

Levelised cost of hydrogen production

The levelised cost of hydrogen production (LCOH) is a metric used to assess the economic efficiency of hydrogen production processes. In the HOMER Pro software, LCOH is calculated as the difference between the total annual cost and the annual cost of electricity, divided by the annual hydrogen production [40]. This metric is used to optimise the production costs of a hydrogen production system per kWh or kilogram, and is calculated according to equation 8:

$$LCOH = \frac{D_T-D_{elec}}{M_H} \quad (8)$$

This calculation method assesses the cost-effectiveness of the system, taking into account both capital investment and operating costs. Furthermore, it provides a basic tool for analysing the impact of hydrogen production costs on energy demand and production capacity. Consequently, it offers a comprehensive view of the long-term economic feasibility of the system [40]. In this context, D_T represents the total annual capital cost of the refuelling station, expressed in dollars per year. D_{elec}, on the other hand, denotes the annual revenue generated from electricity sales, also expressed in dollars per year. Finally, M_H represents the annual mass of hydrogen produced, expressed in kilograms per year.

3. RESULTS

The design of a microgrid for hydrogen production has been realized with Homer Pro to be used for various purposes on the Dicle University campus. In the designed system, temperature, solar, and wind data were obtained from NASA data in Homer Pro software. The hybrid energy system designed with Homer Pro software was analyzed. In this study, two different scenarios were considered. The unit costs of renewable energy equipment used for these scenarios are given in Table 1.

Table 1. Unit cost values

Component	Capital ($)	Replacement ($)	O&M ($)	Salvage ($)	Total ($)
Generic 10 Kw	50,000.00	15,590.00	6,391.68	8,737.45	63,244.47
Generic 1kWh Lead Acid	3,300.00	6,297.73	1,406.17	380.93	10,622.97
Generic Electrolyzer	5,250.00	2.190.64	536.90	407.75	7,569.79
Generic Flat Plate PV	369,000.00	0.00	15,723.53	0.00	384,723.53
Hydrogen Tank	31,500.00	0.00	6,391.68	0.00	37,891.68
System Converter	24,600.00	10,264.72	0.00	1,910.59	32,954.13
System	483,650.00	34,343.09	30,449,96	11,436.72	537,006,57

The present study is grounded in the same coordinates of the Dicle University campus depicted in Figure 2 for both scenarios, thereby ensuring the consistency of the simulation results.

In the present study, the utilization of a singular load model is advocated for two discrete scenarios. The annual modification of this load model is delineated in Figure 3.

Figure 2. Homer Pro Model Dicle University coordinates

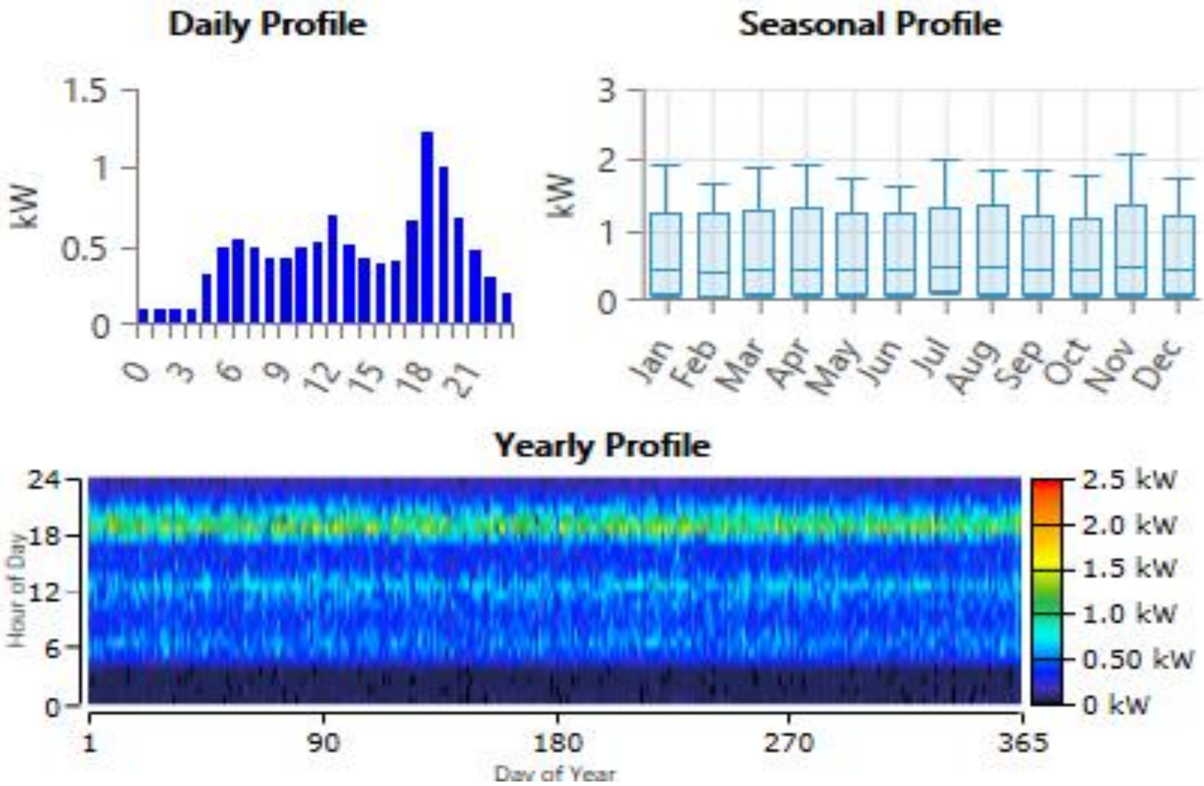
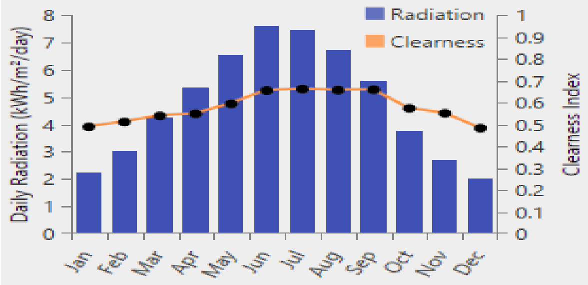
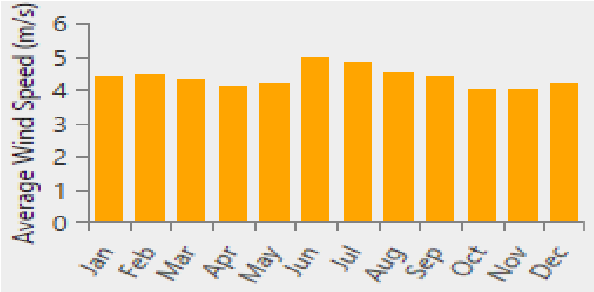


Figure 3. Daily/monthly/annual change of load

The coordinates for the Dicle University campus were entered into the Homer Pro simulation program, which provides daily changes in radiation and average wind speed, as illustrated in Figure 4.



(a)



(b)

Figure 4. a) Daily Radiation Change b) Average Wind Speed Change

Given the application of identical coordinates in both scenarios examined in this study, it is reasonable to conclude that the weather change coordinates are equivalent in both scenarios.

3.1. Scenario 1

In this particular scenario, the HRES campus model, which consists of off-grid photovoltaics (PV), wind turbines (WTG), and electrolyzers (ELC), was developed in Homer Pro. This model encompasses 123 kW PV panels, 10 kW WTG, 1 kWh battery storage system, 113 kW electrolyzer, and a 1000 kg hydrogen storage tank (HST) for hydrogen production from solar energy.Homer Pro proposes an 82 kW converter to store electrical energy and meet energy demand. The Homer Pro campus model is depicted in Figure 5.

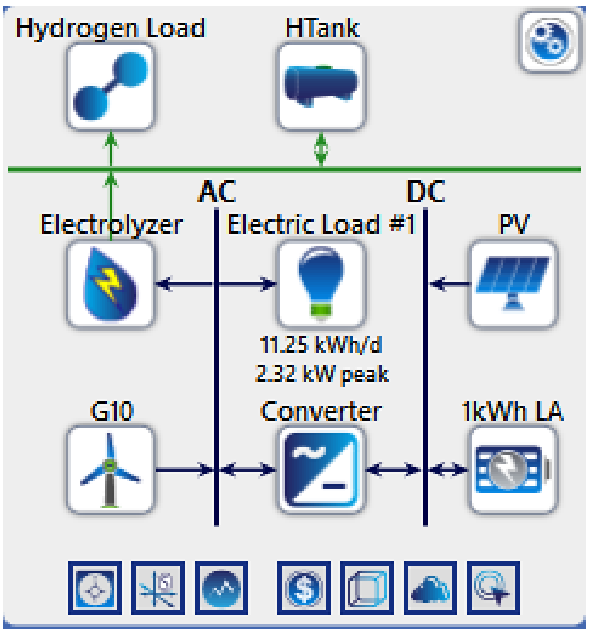


Figure 5. Off-grid HOMER Pro HRES model at Scenario 1

The proposed HRES system is designed to meet daily energy production of 34.3 kWh and peak energy demand of 4,102 kW.The capital cost of the system is calculated to be $483,650.00, while the operation and maintenance costs are calculated to be $30,449.96. The net present cost (NPC) of the system is $537,006.57, while the levelized cost of energy (COE) is $10.66/kWh.The off-grid PV-WTG system designed at Homer Pro is estimated to generate 202,302.31 kW of energy for one year. The PV component of the system is responsible for meeting 95% of the total energy demand, while the WTG component accounts for the remaining 5%.The energy production from each energy source over a one-year period is illustrated in Figure 6.

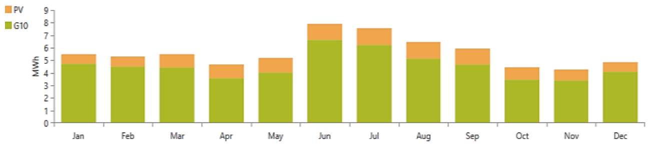


Figure 6. Production Quantities according to HOMER Pro

As illustrated in Figure 7, the power output of the PV exhibits a notable increase, particularly during the summer months. However, the presence of black gaps in the graph indicates a reduction in output on cloudy days. The PV contributes a significant amount to the annual electricity production, with a total of 192,583.60 kW.

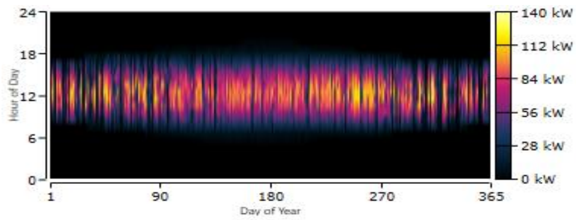


Figure 7. PV Generated Power Amount

The power output of the WTG is illustrated in Figure 8. Despite intermittent periods, the turbine generated electricity almost continuously throughout the year, contributing a total of 9,718.71 kW.

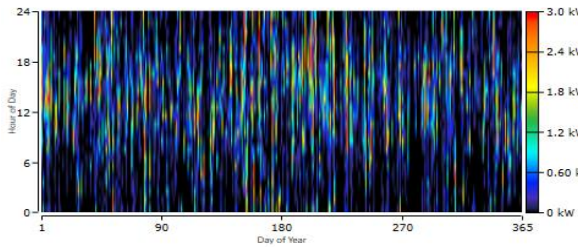


Figure 8. WTG Power Production Quantity

The purpose of the designed off-grid system is to utilize excess energy generated from PV, WTG and BSS. The system also employs an electrolyzer to store excess energy and produce hydrogen. Figure 9 illustrates the monthly energy consumption of the electrolyzer. Over the course of a year, the energy consumption amounted to 190,936.60 kW.

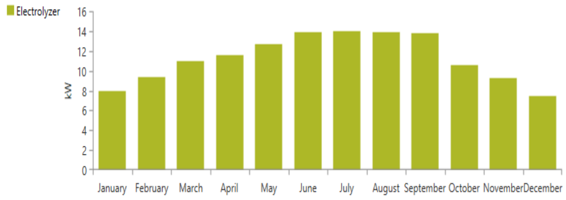


Figure 9. Electrolizer energy consumption change

It has been demonstrated that the electrolyzer functions at maximum capacity and produces hydrogen, particularly during daylight hours. In the off-grid PV-WTG system designed in the Homer Pro simulation program, the surplus energy is stored as hydrogen through the electrolyzer. Subsequently, the hydrogen is utilized to satisfy the energy requirements of the system via the fuel cell. The power input graph of the electrolyzer is depicted in Figure 10.

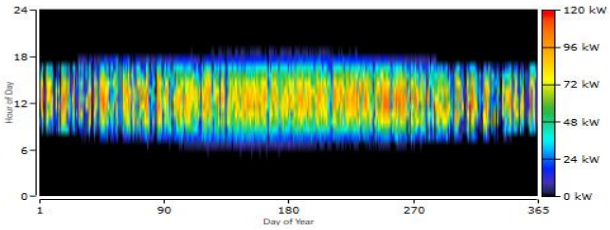


Figure 10. Electrolyzer Power Change Quantity

In scenarios where energy is inadequate for the load, the stored hydrogen is utilized to generate electricity through fuel cells. This system necessitates daily replenishment of the hydrogen tank, as illustrated in Figure 11. The total amount of hydrogen stored throughout the year is 1756,470.00 kilograms.

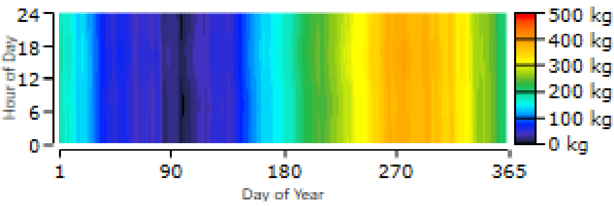


Figure 11. Hydrogen tank filling change

The charge change of the battery used in the off-grid PV-WTG system throughout the year is illustrated in Figure 12.

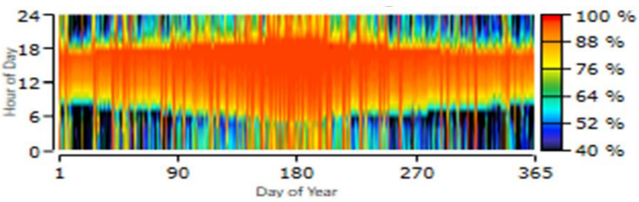


Figure 12. Battery Charge Replacement (SoC)

3.2. Scenario 2

In this scenario, the HRES campus model, consisting of off-grid PV and ELC systems, is constructed in Homer Pro. The model encompasses 123 kW PV panels, a 1 kWh battery storage system, an 113 kW electrolyzer, and a 1000 kg hydrogen storage tank (HST) for hydrogen production from solar energy. Homer Pro proposes an 82 kW converter to store electrical energy and meet energy demand. The Homer Pro campus model is depicted in Figure 13.

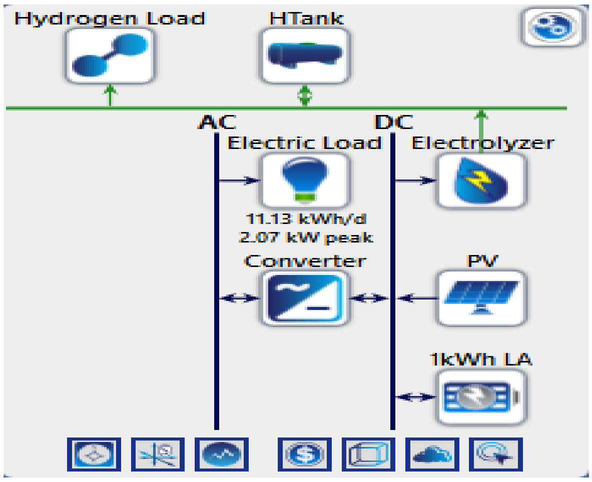


Figure 13. Off-grid HOMER Pro HRES model at Scenario 2

The capital cost of the proposed HRES system was calculated to be $433,650.00, while the operation and maintenance costs were calculated to be $24,058.28. The net present cost (NPC) of the system is thus $473,762.1, and the levelized cost of energy (COE) is $8.96/kWh.

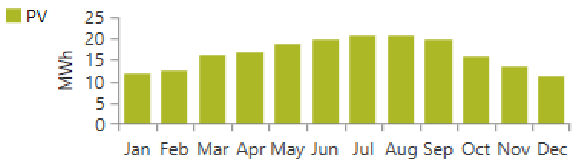


Figure 14. Of-grid PV system monthly generation change

The PV energy production for the Off-grid PV system designed in this scenario is shown in Figure 14. It produced a total of 197,280.75 kW of energy for one year.

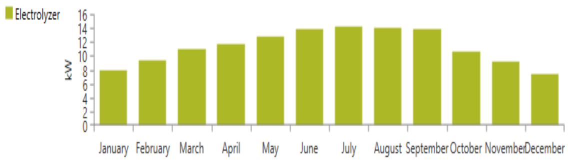


Figure 15. Electrolizer energy consumption change

In the designed off-grid system, the excess energy produced by the PV system is utilized to store hydrogen through an electrolyzer. Figure 15 illustrates the monthly energy consumption of the electrolyzer. Over the course of a year, the energy consumption was 191,852.28 kW.

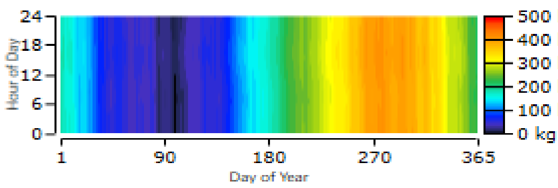


Figure 16. Hydrogen tank filling change

In scenarios where energy is limited or insufficient to meet the load, stored hydrogen is utilized to generate electricity through the means of fuel cells or batteries, thereby supplying the system with energy. The necessity of daily replenishment of the hydrogen tank is illustrated in Figure 16. The total amount of hydrogen stored throughout the year is 1838,205.00 kilograms. Consequently, the average annual storage is 209.86 kilograms of hydrogen.

4. DISCUSSION AND CONCLUSION

Hydrogen has emerged as a pivotal energy carrier in the global transition towards sustainable and low-carbon energy systems. This study demonstrates the techno-economic feasibility of a hybrid renewable energy system (HRES) for Dicle University, integrating photovoltaic (PV) panels, wind turbines (WT), battery storage systems (BSS), and hydrogen storage technologies. By leveraging Diyarbakır's abundant solar potential and incorporating wind energy for diversity, the proposed system achieves a reliable and sustainable energy solution with minimized carbon emissions. The integration of hydrogen storage, particularly during surplus energy generation, addresses variability in renewable resources and ensures a stable energy supply.

This study investigates two distinct scenarios.In the first scenario, a fully independent hybrid energy system is modeled by integrating photovoltaic (PV), wind turbine (WTG), biomass-to-energy (BESS), electrolyzers, and hydrogen storage tanks. The excess electrical energy generated in this system is converted into hydrogen gas through electrolysis and stored. When energy demand arises, the system is sustained by converting the hydrogen back into electricity. The capital cost of this model was calculated as $483,650.00, while the levelized cost of energy (LCOE) was determined as $10.66/kWh.In the second scenario, an energy model was created using only PV panels. Wind turbines were removed from the system, and the role of the hydrogen storage system was increased. In this scenario, excess electricity is stored as hydrogen to ensure uninterrupted energy supply. The capital cost of this system was calculated as $433,650.00, and the LCOE value was determined as $8.96/kWh.In terms of hydrogen storage capacity, Scenario 2 increased the security of energy supply by producing and storing more hydrogen per year.
Hydrogen production through Proton Exchange Membrane (PEM) electrolyzers significantly enhances system performance with high efficiency and purity levels. The stored hydrogen provides flexibility for various applications, contributing to energy resilience during periods of low renewable energy availability. Future advancements in electrolyzer technology and reductions in storage costs are critical for further optimizing the system’s economic and environmental benefits. Supportive policies and financial incentives can accelerate the adoption of similar HRES solutions in academic institutions and rural areas.

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