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Optimizing carbon emission reduction in hybrid microgrids: A case study integrating photovoltaics and hydrogen energy systems

Hibrit mikro şebekelerde karbon emisyonunun azaltılması: Fotovoltaik ve hidrojen enerji sistemlerinin entegrasyonu üzerine bir vaka çalışması

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Abstract

The reliance on fossil fuels for energy consumption in Diyarbakır leads to environmental pollution and high costs, making the transition to renewable energy imperative. However, the challenges associated with the continuous generation of energy from these sources require sustainable solutions. The simulation results indicate that through the use of hydrogen and renewable energy technologies, 0.0254% of Türkiye's targeted 695 Mt CO_2 reduction by 2030 can be achieved solely through the efforts undertaken within this project. Failure to address this issue will result in increased dependence on fossil fuels and escalating environmental damages. In this study, the integration of hydrogen production and renewable energy was simulated in a neighborhood close to a water source in Diyarbakır using the Homer Pro analysis software. Proximity to the water source facilitates the supply of water required for hydrogen production, making the production processes more economical and sustainable. It also enhances efficiency in the electrolysis process, with the cost of hydrogen production calculated at $4.50/kg and energy cost at $0.08301/kWh. These results demonstrate that the integration of hydrogen and renewable energy offers a sustainable solution both economically and environmentally.

Keywords: Microgrid, HOMER pro, Hydrogen energy, Energy storage

Öz

Diyarbakır'da enerji tüketiminin fosil yakıtlara dayanması, çevre kirliliğine ve yüksek maliyetlere neden olmakta, yenilenebilir enerjiye geçişi zorunlu kılmaktadır. Ancak, bu kaynakların kesintisiz enerji üretimindeki zorlukları sürdürülebilir çözümler gerektirmektedir. Simülasyon sonuçları, hidrojen ve yenilenebilir enerji teknolojilerinin kullanımıyla Türkiye'nin 2030 yılına kadar hedeflediği 695 Mt CO_2 azaltım hedefinin %0.0254'ünün yalnızca bu proje kapsamında gerçekleştirilecek çalışmalarla sağlanabileceğini ortaya koymaktadır. Sorunun çözülememesi durumunda, fosil yakıtlara bağımlılık ve çevresel zararlar artmaya devam edecektir. Bu çalışmada, Diyarbakır'ın su kaynağına yakın bir mahallesinde, hidrojen üretimi ve yenilenebilir enerji entegrasyonu Homer Pro analiz yazılımında simüle edilmiştir. Su kaynağına yakın olmak, hidrojen üretimi için gerekli olan suyun teminini kolaylaştırarak, üretim süreçlerini daha ekonomik ve sürdürülebilir hale getirir. Aynı zamanda elektroliz sürecinde verimlilik sağlanmış ve sistemde üretilen hidrojen maliyeti 4.50 $/kg, enerji maliyeti ise 0.08301 $/kWh olarak hesaplanmıştır. Bu sonuçlar, hidrojen ve yenilenebilir enerji entegrasyonunun ekonomik ve çevresel açıdan sürdürülebilir bir çözüm sunduğunu ortaya koymaktadır.

Anahtar kelimeler: Mikro şebeke, HOMER Pro, Hidrojen enerjisi, Enerji depolama

1 Introduction

The Paris Climate Agreement is the first comprehensive climate agreement accepted on a global scale, signed by 175 countries that collectively produce more than 55% of global greenhouse gas emissions. The agreement aims to raise awareness of climate change and encourage countries to develop climate resilience strategies. In this context, the European Union adopted the 'Green Deal' strategy in 2019, targeting a 50% reduction in greenhouse gas emissions by 2030 and carbon neutrality by 2050 (set at 41% for Türkiye. The long-term goal of the Paris Agreement is to keep the global temperature increase below 2°C above pre-industrial levels, aiming to limit it to 1.5°C if possible. Achieving this target necessitates a gradual reduction in the use of fossil fuels (oil and coal) and a transition to renewable energy sources [1]. The effective use of renewable energy sources and their integration into energy production processes is crucial for a sustainable future. Converting natural resources like solar and wind into energy aims to reduce dependence on fossil fuels and minimize environmental impacts. In this regard, local energy systems known as microgrids promise significant changes to the traditional energy production model. Although the integration of renewable energy sources into energy systems is a critical step, the intermittent nature of these sources creates stability issues within energy systems [2-4].

Electrical storage systems are widely used to address these stability issues; however, they have some

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disadvantages. Traditional battery storage systems face limitations such as high cost, limited lifespan, and environmental concerns related to battery disposal [5]. Furthermore, batteries have relatively low energy density, making it difficult to store large amounts of energy over extended periods.

Nevertheless, hydrogen storage offers an alternative solution to these challenges [6]. Hydrogen produced through electrolysis provides efficient storage for renewable energy while also increasing demand flexibility [7]. Unlike battery storage, hydrogen can store large quantities of energy over long periods without loss and is a scalable solution. Hydrogen storage balances the intermittency of renewable energy, creating a more stable infrastructure and supporting the transition to sustainable energy systems.

This study aims to evaluate hydrogen technology's potential to meet growing energy demand and support sustainable systems in Türkiye's rural areas with limited energy access and high renewable potential. In this study, a rural area in Diyarbakır province has been selected as an ideal site for a hydrogen-based microgrid due to its proximity to the Tigris River and the availability of water resources. A significant portion of the neighborhood's energy needs is currently met by fossil fuels, leading to both environmental issues and rising energy costs. A simulation model for a neighborhood-scale energy system has been developed using hydrogen technologies. Different scenarios related to the production, storage, and use of hydrogen have been evaluated within this model. The results provide valuable insights into the potential of hydrogen technologies to meet the energy needs of the residents, their environmental impacts, and economic benefits. This study will serve as a reference point for other regions in Türkiye with similar geographical and socioeconomic characteristics.

Recent years have seen a rapid increase in research on hydrogen energy. Particularly, numerous studies have focused on the integration of renewable energy sources and energy storage systems. Studies by Xu et al. [8] and Zainal B.S. et al. [9] indicate that recent advancements in electrolyzer technologies have significantly reduced the cost of hydrogen production. J.J. Brey [10] emphasizes that hydrogen is a suitable solution for seasonal energy storage and can help mitigate fluctuations in renewable energy production. A comprehensive review by Ishaq H. et al. [11] analyzes the potential applications of hydrogen across different sectors and the technical challenges in these areas in detail. Notably, Neuwirth M. et al. [12] have highlighted the critical role hydrogen can play in reducing carbon emissions in energy-intensive sectors like steel production. Guilbert and Vitale [13] suggest that hydrogen, when combined with fuel cell technologies, could be utilized to develop zero-emission transportation systems. Modeling studies by Egeland-Eriksen T. et al. [14] and Ge et al. [15] demonstrate that integrating hydrogen into energy systems enhances system flexibility and reliability. Research by Alzoubi [16] and Mijndert van der Spek et al. [17] underscores the importance of infrastructure investments necessary for the development of the hydrogen economy. H. Kılıç [18] emphasizes the significance of using hydrogen and renewable energy technologies in microgrid-based Power-to-X (P2X) systems, showing that this method outperforms traditional algorithms and increases hydrogen production. H. Kılıç et al. [19] analyze the impact of integrating hydrogen fuel cells and D-STATCOM systems on improving power quality by reducing voltage fluctuations in power systems. Integrating hydrogen improves energy access and boosts economic development in rural areas.

Türkiye has set ambitious targets for green hydrogen. As outlined in the Turkish Hydrogen Technologies Strategy and Roadmap, the country aims to reach an electrolyzer capacity of 5 GW by 2035 and 70 GW by 2053. These goals demonstrate the need to develop a comprehensive strategy for the domestic production, storage, and utilization of green hydrogen. Additionally, the report forecasts that the cost of producing green hydrogen will decrease to $2.4 per kilogram by 2035 and to $1.2 per kilogram by 2053 [20]. As of 2024, the cost of producing green hydrogen is estimated to be between $5 and $6 per kilogram, reflecting current production technologies and market conditions. In comparison, the cost of gray hydrogen production in 2024 remains relatively stable, ranging between $1 and $2 per kilogram, primarily due to the use of fossil fuels in its production process. The Development Plan has identified green hydrogen production as a strategic goal to accelerate energy transition. The plan focuses on areas such as the development of domestic electrolyzer technologies, the establishment of necessary infrastructure for transporting and storing green hydrogen, and the widespread implementation of smart grid technologies. Enhancing energy efficiency through the widespread use of smart meters and the development of SCADA systems will ensure grid reliability [21].

In this study, a rural neighborhood in Diyarbakır province was modeled as a microgrid using Homer Pro software. The model addressed a typical example of energy issues commonly encountered in rural areas, considering the neighborhood's current energy consumption profile, region-specific renewable energy potential, and different configurations of hydrogen production and storage systems. Various scenarios were created to examine the impact of hydrogen on system performance. Notably, the ability of hydrogen to store and transport energy has helped stabilize the system by reducing the effects of fluctuations in renewable energy production. Economic analyses have demonstrated the long-term cost-effectiveness of hydrogen technologies. However, there are challenges to the widespread adoption of hydrogen technologies in rural areas, including limited infrastructure investments, high initial capital costs, and a lack of awareness. To overcome these challenges, it is crucial for local governments and the national government to develop supportive policies, create financing mechanisms, and conduct awareness-raising activities for the local community. Moreover, investing in research and development in hydrogen technologies is essential to make these technologies more efficient and cost-effective.

2 Materials and methods

Microgrids offer a flexible and efficient solution to energy production, providing an alternative to traditional energy systems [22]. These systems are classified into three main categories based on their topological structures:

Alternating Current (AC) Microgrids: The most commonly used type, where DC sources such as solar panels (PV) and batteries are connected to the AC grid through AC inverters. This structure ensures compatibility with existing electrical grids.

Direct Current (DC) Microgrids: These systems operate entirely on direct current, with DC sources connected directly to the DC bus. This setup reduces AC/DC conversions, thereby minimizing energy losses. However, the limited availability of DC loads and the lack of widespread adoption of DC distribution systems restrict the use of these microgrids.

Hybrid Microgrids: These systems integrate both AC and DC components, creating a more complex but flexible structure. This configuration allows for the combination of different types of loads and energy sources within a single system.

In this study, a hybrid microgrid design was developed and analyzed using the Homer Pro software.

2.1 Homer Pro software

HOMER Pro is a powerful software used for the design and analysis of hybrid energy systems. It is widely utilized for modeling and optimizing systems that combine renewable energy sources like solar, wind, and biomass with traditional energy sources. This software helps determine the most suitable solution by evaluating the system's performance under different scenarios. By considering factors such as energy cost, environmental impacts, and reliability, it enables users to make the best decisions for their energy systems. HOMER Pro offers innovative solutions for meeting energy needs, particularly in remote areas, islands, and developing countries.

Studies conducted by Vendoti et al. [23], Dawood et al. [24], and Xia et al. [25] demonstrate the use of this software to meet energy needs in remote and isolated regions, while research by Çetinbaş et al. [26], Güven et al. [27], and Suresh et al. [28] provide significant findings on the integration of renewable energy sources. Bhattacharjee et al. [29] have focused on the optimization of hybrid systems for regions with different climatic conditions. Basheer et al. [30] have made important contributions to the design and evaluation of hybrid energy systems for industrial areas. These studies highlight the flexibility and broad range of applications of HOMER Pro. In the study conducted by Jahangir and Cheraghi, an economic and environmental assessment of a hybrid renewable energy system consisting of solar, wind, and biomass was carried out to meet the energy needs of a rural settlement. The study highlights the feasibility of such systems in rural areas while providing a comparative analysis of economic costs and environmental impacts. This approach serves as an important reference for developing sustainable energy solutions for settlements [31]. In the study conducted by Amupolo et al., the techno-economic feasibility of off-grid renewable energy electrification schemes was assessed for an informal settlement in Namibia. The research provides a comprehensive analysis of the applicability of renewable energy sources in such settlements from both economic and technical perspectives. This work offers valuable insights into the development of sustainable energy solutions for underserved communities [32]. In the study conducted by Palanichamy et al. the development of a microgrid for the secluded Paana Theertham Kani settlement in India was explored. The research focuses on integrating renewable energy sources to enhance energy access and meet the sustainable energy needs of the community. This study provides valuable insights into the feasibility of microgrid solutions for rural and isolated settlements [33]. In the study conducted by El Hassani et al., the techno-economic feasibility and performance of an islanded hybrid renewable energy system with hydrogen storage were analyzed for a specific settlement in Morocco. The research highlights the integration of renewable energy sources with hydrogen storage to provide sustainable and reliable energy solutions for isolated communities. This study offers significant insights into the development of renewable energy systems tailored to meet the unique energy needs of such settlements [34]. Although previous research has generally focused on specific geographical regions or energy sources, this study adopts a more comprehensive approach aimed at addressing common energy challenges encountered in rural areas of Türkiye.

This study introduces a comprehensive approach that significantly contributes to the literature by integrating hydrogen technologies with renewable energy systems. Unlike many existing studies that focus on individual renewable energy sources or limited technologies, this work provides a holistic analysis of a hybrid system design, emphasizing the synergy between hydrogen technologies and renewable resources like solar energy.

The methodology employed in this research optimizes hydrogen production in proximity to water sources, considering both economic and environmental aspects. Utilizing HOMER Pro software, the study conducts detailed simulations to evaluate energy production, storage, and cost dynamics while also calculating the potential for carbon emissions reduction. These features make the study stand out as it combines technological feasibility with concrete environmental and economic metrics.

Moreover, the proposed method not only enhances energy access but also reduces energy costs for local communities while promoting environmental sustainability. The findings of this study address a significant gap in the literature regarding the application of hydrogen-based hybrid systems in rural settlements and are expected to serve as a valuable reference for future research in the field.

2.2 Site selection and data collection

2.2.1 Site selection

A rural settlement, known by various names and located in one of the central districts of Diyarbakır, has been selected as the pilot implementation area. The geographical location of this region played a significant role in its selection. The area has a high solar energy potential, which, when combined with the hydrogen-integrated microgrid design, enhances its capacity to meet the region's energy needs. Additionally, the density and social structure of the settlement provide a valuable opportunity for the pilot project's results to be disseminated to a broader audience and to contribute to the energy transition in the area. Its proximity to a water source, in particular, offers significant advantages for hydrogen production processes, thereby increasing the system's efficiency. This pilot implementation aims to demonstrate the feasibility of sustainable energy solutions in areas close to the city center and to contribute to the region's journey toward energy independence. Figures 1, 2, and 3 illustrate the neighborhood's grid connection model, the supply area, and the feeder information, respectively.

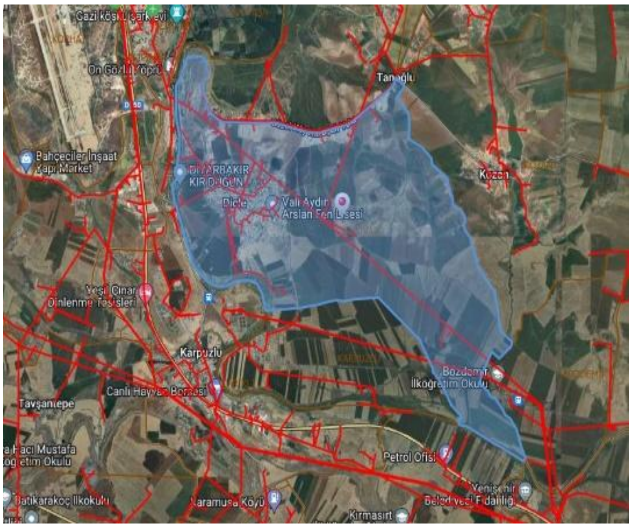

Figure 1. Geographic information systems (GIS) grid connection model

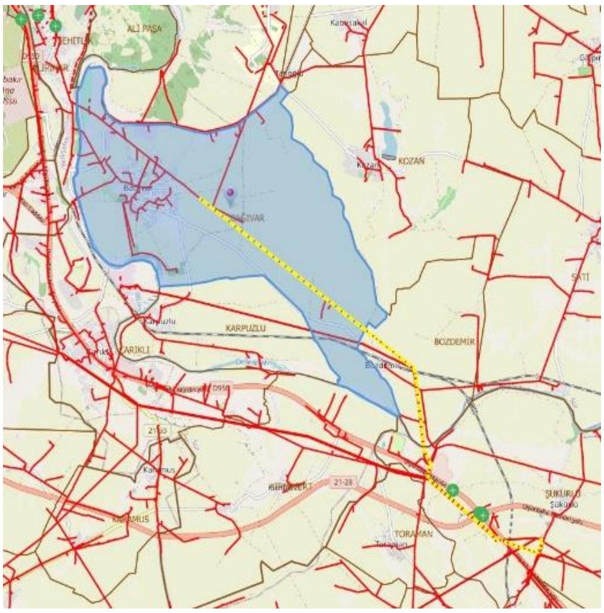

Figure 2. Geographic supply area

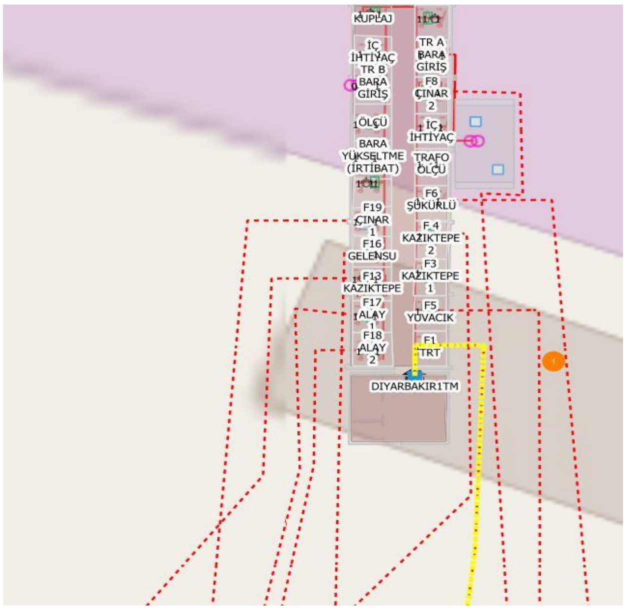

Figure 3. Feeder supplying the neighborhood

The specification of the supply area in square kilometers allows readers to better understand the coverage of the energy distribution network, providing clarity regarding the system's geographical context. For this study, the selected area covers a surface area of 17390 decares. Furthermore, including the demand power of the feeder enhances the understanding of energy flow and capacity requirements, contributing to the evaluation of system reliability and performance. The daily load for the study area has been calculated as 13407.45 kWh.

The area under study is supported by a range of transformers with varying capacities to meet the energy demand and ensure system reliability. The transformer capacities include units ranging from 50 kVA to 1000 kVA, strategically distributed throughout the network to optimize energy distribution and accommodate the load requirements. For confidentiality purposes, the exact quantities and locations of these transformers are not disclosed.

Geographical and climatic data are critical for simulating the performance of a hybrid energy system using HOMER Pro. These factors directly influence the design and optimization of the system for a specific location [35]. The exact latitude and longitude coordinates of the study area determine the solar radiation patterns. Detailed information on location-specific average daily and monthly solar radiation, obtained from NASA's Prediction of Worldwide Energy Resources (POWER) database, is essential [36]. In this context, the combined graph presenting the monthly temperature data and Solar GHI (Global Horizontal Irradiance) for the application site is displayed in Figure 4, providing a comprehensive overview of both metrics in a single visualization. [37, 38].

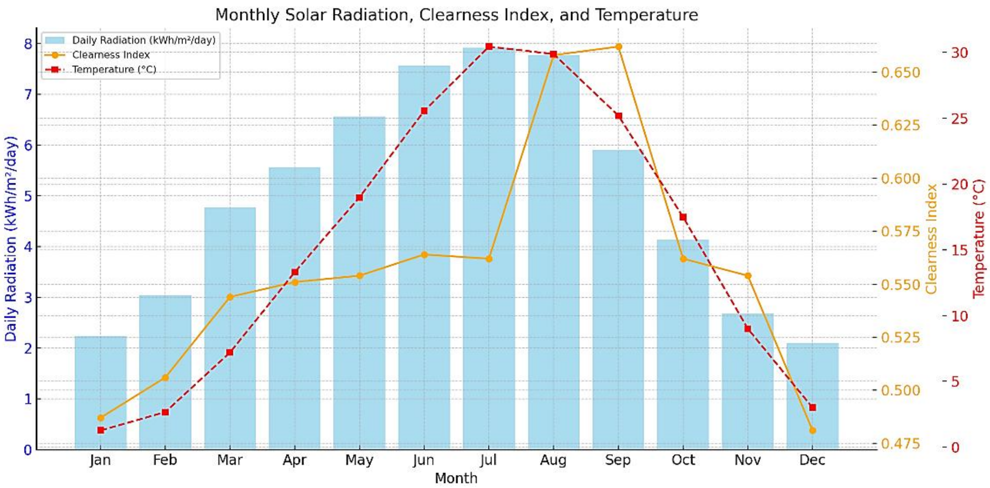

Figure 4. Monthly solar radiation, clearness index and temperature

2.2.2 Data collection

In the study, one year of active energy consumption data (July 2023 - July 2024) for the rural settlement under investigation, obtained from the electricity distribution company was subjected to a detailed analysis by disaggregating it into 24-hour periods on a monthly and daily basis.

This comprehensive dataset enabled the examination of both daily load variations and seasonal differences, allowing for an in-depth analysis of the load profile. The completeness and accuracy of the data increased the reliability of the results and ensured the precision of the calculations. The dataset was uploaded to the HOMER Pro software, and the disaggregated profile data shown in Figure 5 was obtained. Additionally, the data classified by month is presented in Figure 6.

2.3 System Design

In HOMER Pro, a system design was developed for our neighborhood, characterized as a residential area, using July — the month with the highest energy demand — as the reference. This design integrates multiple components, including PV, an electrolyzer, a hydrogen tank, an energy converter, and the grid, as shown in Figure 7. The electrical energy generated from the PV panels is converted into hydrogen through the electrolyzer and stored. When needed, this hydrogen is converted back into electricity using the energy converter to meet the electrical load. The hybrid microgrid's load group was selected as Bağıvar neighborhood. The cost of energy supplied from the local grid to the microgrid was set at \$0.067 per kWh, and the sale price of energy fed back from the microgrid to the grid was fixed at \$0.050 per kWh. These values were derived based on an analysis of market price ranges and were calculated as an average using data from a one-year period spanning both 2023 and 2024, ensuring a comprehensive and representative cost basis for this study.

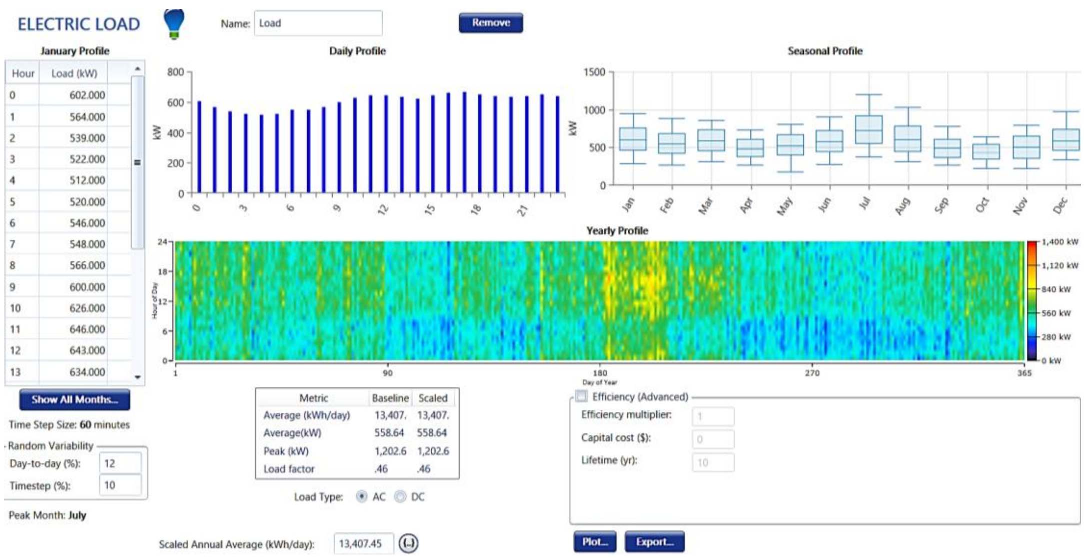

Figure 5. Load profile visualized by HOMER Pro

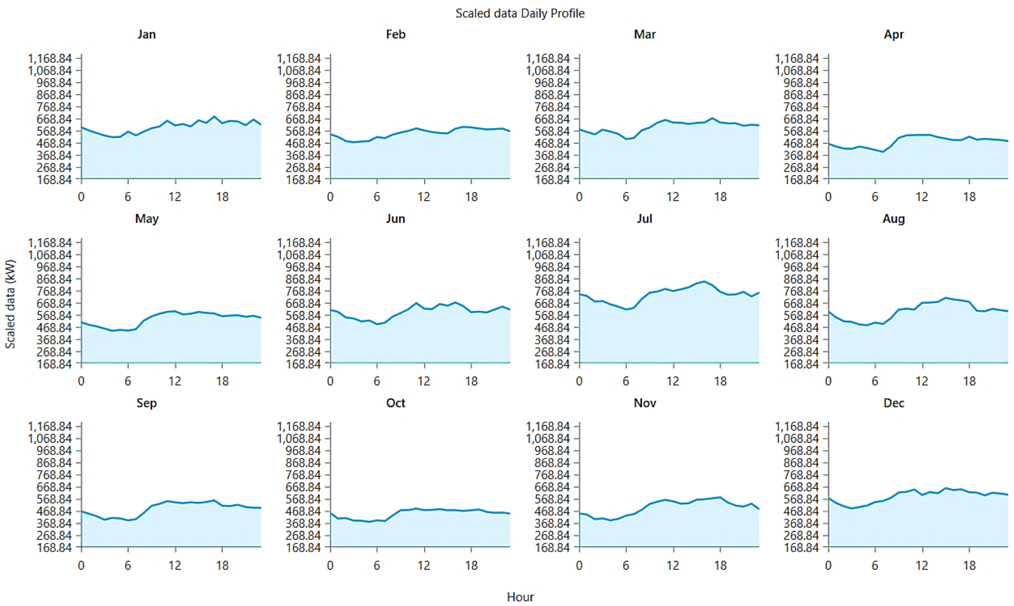

Figure 6. Load profile by month visualized by HOMER Pro

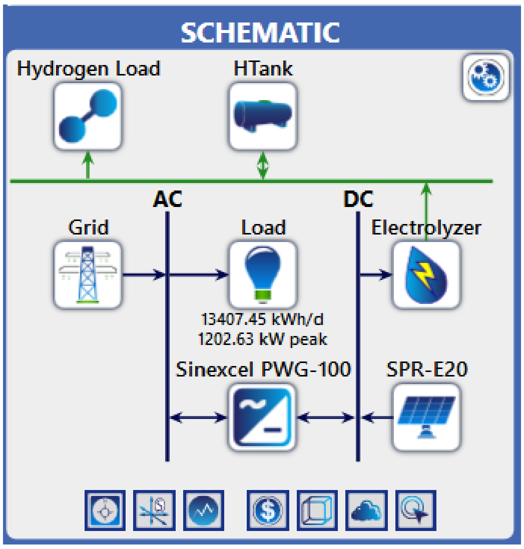

Figure 7. Microgrid structure designed in HOMER Pro

2.4 PV system

The amount of electrical energy generated by PV modules constantly varies depending on many factors. These factors include a range of parameters such as the structure of the solar cell, the nominal power of the panel, the derating factor, the intensity of solar radiation, cell temperature, temperature coefficient, the geographical location of the panel, and environmental conditions. For instance, an increase in solar radiation generally enhances the power produced by the panel, while high temperatures can reduce its efficiency.

The mathematical model expressed as Equation (1) aims to represent these complex relationships with a certain level of accuracy.

$$P_{PV} = Y_{PV} f_{PV} \left(\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right) \left[1 + \alpha_p \left(T_c - T_{c,STC} \right) \right] \tag{1}$$

where:

$\mathbf{Y_{PV}}$ = The rated capacity of the PV array, meaning its power output under standard test conditions [kW]

$\boldsymbol{f_{PV}}$ = The PV derating factor [%]

$\boldsymbol{\bar{G}_T}$ = The solar radiation incident on the PV array in the current time step [kW/m^2]

$\boldsymbol{\bar{G}_{T,STC}}$= The incident radiation at standard test conditions [1 kW/m^2]

$\boldsymbol{\alpha_p}$ = The temperature coefficient of power [%/°C]

$\mathbf{T_c}$ = The PV cell temperature in the current time step [°C]

$\mathbf{T_{c,\ STC}}$= The PV cell temperature under standard test conditions [25°C]

For the hybrid microgrid, the SunPower E20-327 PV module has been selected. The cost of the module is specified per 1 kW of power. The capital cost of this module is $600, the replacement cost is $420, and the O&M (Operation and Maintenance) cost is $6 per year. The lifespan of the modules is set at 25 years.

2.5 Converter

It is used to convert alternating current (AC) to direct current (DC) or vice versa. This is necessary to convert the direct current from solar panels into the alternating current used by households or to transform the direct current drawn from batteries into alternating current through inverters. The Sinexcel PWG-100 converter has been selected. The converter cost for the hybrid microgrid is specified per 1 kW of output power. The capital cost of this converter is $400, the replacement cost is $280, the operation and maintenance cost is $15, and its lifespan is 10 years. The efficiency of the converter is taken as 98%.

2.6 Electrolyzer

HOMER Pro is a useful tool for modeling the key performance and cost characteristics of the electrolyzer in our hybrid energy system. In our system, where we plan to use either Proton Exchange Membrane (PEM) or alkaline electrolyzers, hydrogen production efficiency and economies of scale are significant factors. The efficiency of the electrolyzer is defined as the ratio of the energy content of the hydrogen produced to the electrical energy consumed. Parameters such as hourly hydrogen production capacity (Nm³/hour) and specific energy consumption (kWh/Nm³) are used to assess the electrolyzer's performance. Additionally, the amount of water consumed for each cubic meter of hydrogen produced is important in terms of both operational logistics and the system's environmental impact. The electrolyzer model in HOMER is based on a constant efficiency assumption, and its minimum load level feature ensures that the electrolyzer operates within its efficient operating range.

HOMER Pro models the electrolyzer with a constant efficiency, assuming that a given input of electricity always results in the same amount of hydrogen production. Due to the minimum load limitation, the electrolyzer only operates efficiently when at least 75% of its nominal capacity is used. The electrolyzer, which typically consumes excess electricity, becomes active when there is demand for hydrogen or electricity.

The selected electrolyzer has a capital cost of $600, a replacement cost of $360, an operation and maintenance cost of $30, and a lifespan of 15 years. The efficiency of the converter is considered to be 95%, with a minimum load ratio set at 50%.

2.7 Hydrogen tank

HOMER Pro enables a comprehensive simulation of hydrogen storage within hybrid energy systems by allowing users to define cost curves for storage capacity through a detailed cost table. For the grid model we designed, a hydrogen tank with a capacity of 1200 kg was specified with a capital cost of $600, a replacement cost of $480, and an O&M cost of $20. The key parameters for defining hydrogen storage behavior include a tank lifetime of 20 years, an initial hydrogen level (e.g., 50% of the tank's capacity or an absolute value of 50 kg), and the requirement that the end-of-year tank level meets or exceeds the initial level. For instance, the system's daily average hydrogen consumption could be set at 10 kg, with a target of having at least 60% of the tank's capacity filled by the end of the year. These parameters facilitate accurate performance and economic simulations, enabling the optimization of hybrid energy systems to meet energy demands with cost-effectiveness and adequate hydrogen storage capacity. The frequency of hydrogen tank charging and discharging in the simulation study is shown in Figure 8.

2.8 Evaluation criteria

2.8.1 Net present cost (NPC)

The total net present cost (NPC) of a system represents the present value of all expenses incurred throughout its lifetime, reduced by the present value of all revenues generated during the same period. These expenses include capital costs, replacement costs, operation and maintenance (O&M) costs, fuel costs, emissions penalties, and the cost of purchasing power from the grid. Revenues comprise salvage value and income from grid sales. The costs of the designed system are presented in Table 1.

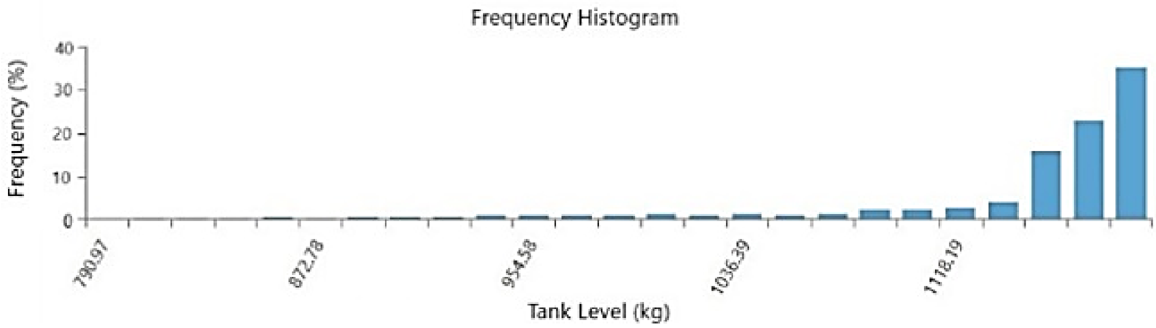

Figure 8. Hydrogen tank charging and discharging frequency

Table 1. Cost summary of the system designed in HOMER Pro

Component	Economic Life (Year)	Capacity	Effiency (%)	Capital ($)	Replacement ($)	O&M ($)	Salvage ($)	Total ($)
Generic Electrolyzer	15	1500 kW	95	900000.00	229107.87	581738.24	(43120.41)	1667725.70
Grid	-	-	-	0.00	0.00	482726.68	0.00	482726.68
Homer Cycle Charging	25	-	-	5.00	0.00	12.93	0.00	17.93
Hydrogen Tank	20	1200 kg	N/A	720000.00	183633.03	310260.40	(103488.99)	1110404.44
Sinexcel PWG-100	10	3000 kW	98	1200000.00	742087.61	581738.24	(100614.30)	2423211.55
SunPower E-20-327	25	3000 kW	98	1800000.00	0.00	232695.30	0.00	2032695.30
System				**4620005.00**	**1154828.51**	**2189171.79**	**(247223.70)**	**7716781.60**

HOMER determines the total NPC by aggregating the discounted cash flows for each year over the project's lifetime.

The total NPC serves as HOMER's primary economic output, used to rank all system configurations in the optimization results. It also forms the basis for calculating the total annualized cost and the levelized cost of energy.

NPC, also referred to as the life-cycle cost, is the present value of all expenses incurred for installing and operating a Component throughout the project's lifetime, reduced by the present value of all revenues generated by the Component during the same period. HOMER computes the net present cost for each Component individually as well as for the entire system.

HOMER utilizes the discount factor to account for the time value of money rather than inflation. The impact of inflation is excluded from the analysis by employing the real discount rate instead of the nominal discount rate. Nevertheless, even with inflation removed, the principle of the time value of money dictates that a future cash flow is less valuable than an equivalent cash flow in the present. The discount factor reflects this effect, decreasing in value as the number of years from the project's inception increases.

The discount factor represents a ratio utilized to determine the present value of cash flows occurring at any point during the project's lifetime. HOMER computes this value using the following formula Equation (2):

$$f_d = \frac{1}{(1+i)^N} \qquad (2)$$

where:

$\boldsymbol{i}$ =Real discount rate [%]

$\boldsymbol{N}$ =Number of years

2.8.2 Levelized cost of energy (LCOE)

It defines the LCOE as the average cost per kWh of useful electrical energy produced by the system. HOMER determines the COE value of the system by subtracting the cost of meeting the thermal load from the annual electricity production cost, and then dividing the resulting net electricity production cost by the total electricity demand. The equation for this calculation is provided in Equation (3).

$$COE = \frac{c_{ann,t\circ t} - c_{b\circ iler} H_{served}}{E_{served}} \qquad (3)$$

Where:

$\boldsymbol{c_{ann,t\circ t}}$ =Total annualized cost of the system [\$/yr]

$\boldsymbol{c_{b\circ iler}}$ =Boiler marginal cost [\$/kWh]

$\boldsymbol{H_{served}}$ =Total thermal load served [kWh/yr]

$\boldsymbol{E_{served}}$ =Total electrical load served [kWh/yr]

The second term in the numerator represents the annual cost component associated with meeting the thermal load of the system. For systems that do not have a thermal load (Hthermal = 0), such as those that only produce electricity (like wind or photovoltaic systems), this term is not considered. The Levelized Cost of Energy (COE) is a metric commonly used to evaluate the economic performance of different energy systems. However, HOMER does not rank systems solely based on their COE values; it also considers other factors. As a result of the LCOE of the designed system, a cost of \$0.08301 per kilowatt-hour was obtained. This value is higher than the cost of a similarly scaled system powered by grid electricity. However, improvements in current costs and/or the selection of products with different power and cost characteristics in the system design could make this value competitive with grid prices.

2.8.3 Levelized cost of hydrogen (LCOH)

HOMER uses Equation (4) to calculate the Levelized Cost of Hydrogen (LCOH).

$$COH = \frac{c_{ann,t\circ t} - v_{elec}\,(E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales})}{M_{hydrogen}} \qquad (4)$$

here, $c_{ann,t\circ t}$ represents the total annual cost, v_{elec} is the value of electricity (which is entered in the Hydrogen Load Inputs window), E_{prim} denotes the primary electrical load, E_{def} is the deferrable load, $E_{grid,sales}$ refers to the total energy sold to the grid, and $M_{hydrogen}$ is the total hydrogen production. In the numerator, we aim to determine the annual cost of producing hydrogen by subtracting the annual cost of electricity production. If your system does not meet any electrical load and does not export electricity to the grid, then all these electricity terms will reduce to zero. The value of electricity was entered as \$0.067/kWh. According to HOMER simulation results, the LCOH value of the designed system was calculated to be \$4.50/kg.

2.9 Methodology for carbon emission reduction calculation

This study calculates carbon emission reductions by comparing baseline emissions from fossil fuel consumption with the emissions resulting from the integration of renewable energy and hydrogen technologies. The methodology and formulas used are detailed below:

2.9.1 Baseline emissions calculation

Baseline emissions are calculated by multiplying energy consumption by the carbon intensity of the electricity source Equation (5):

$$E_{baseline} = C_{total} \; x \; F_{grid} \qquad (5)$$

where:

$\boldsymbol{E_{baseline}}$ =Baseline carbon emissions [kg CO_2]

$\boldsymbol{C_{total}}$ =Total energy consumption [kWh]

$\boldsymbol{F_{grid}}$ =Grid electricity carbon emission factor [e.g., 0.4 kg CO_2/kWh]

2.9.2 Project emissions calculation

Emissions from the project, including renewable energy and hydrogen utilization, are calculated as follows Equation (6):

$$E_{prj} = (\, C_{grid} \; x \; F_{grid} \,) + (\, C_{hydrogen} \; x \; F_{hydrogen} \,) \qquad (6)$$

Where:
$\boldsymbol{E_{prj}}$ =Total project emissions [kg CO_2]
$\boldsymbol{C_{grid}}$ =Energy supplied by the grid [kWh]
$\boldsymbol{F_{hydrogen}}$ =Carbon emission factor for hydrogen production [e.g., 0 kg CO_2/kWh for renewable energy, 0.4 kg CO_2/kWh for grid electricity]

Data Source: Energy data derived from HOMER Pro simulations.

2.9.3 Carbon Emission Reduction Calculation

The reduction in carbon emissions is calculated using the formula Equation (7):

$$E_{reduction} = E_{baseline}\ x\ E_{prj} \tag{7}$$

Where:
$\boldsymbol{E_{reduction}}$ = Reduction in carbon emissions [kg CO_2]

2.9.4 Temporal and Source Analysis

Grid Electricity: The emission factor for grid electricity is assumed to be 0.4 kg CO_2/kWh.

Renewable Energy: Emissions for PV and hydrogen generated from renewable sources are assumed to be zero.

Hydrogen Production: Emissions are adjusted based on the energy source used for the electrolyzer.

2.10 Sensitivity analysis

A sensitivity analysis examines how key parameter changes impact system outputs after modeling and evaluation. By examining the impact of variations in different input parameters on system performance, the sensitivity of the system to uncertainties was assessed. HOMER Pro offers various methods for sensitivity analysis. The most commonly used methods include single parameter variation, Monte Carlo simulation, and scenario analysis. In single parameter variation, one parameter in the system is altered by a fixed amount while all other parameters are kept constant, and the system's performance is re-simulated. In Monte Carlo simulation, a probability distribution is defined for each parameter, and multiple simulations are performed using random samples, allowing the investigation of the effects of different parameter combinations on the system. Scenario analysis, on the other hand, involves running simulations under different assumptions (e.g., various climate scenarios) to evaluate the system's performance under varying conditions.

In this study, both sensitivity to uncertainties and fixed parameter-based analysis were performed, taking the values considered to be optimal as the baseline.

3 Findings and discussion

This study employs a comprehensive methodology to optimize the integration of renewable energy sources with hydrogen storage technologies. Initially, data related to the load profile, solar radiation, and temperature of the study area were collected and defined as input parameters for the HOMER Pro software. Subsequently, a hybrid microgrid system was designed, incorporating photovoltaic panels, electrolyzers, hydrogen tanks, energy converters, and grid connections. To evaluate the system's performance, a detailed simulation was conducted using HOMER Pro, analyzing energy production, storage capacity, and cost dynamics.

The simulation results were assessed in terms of energy production and cost-effectiveness, while the potential for reducing carbon emissions was also examined. Optimization efforts were undertaken to enhance the system's environmental and economic efficiency. The findings were validated by comparing them with similar studies in the literature, demonstrating the system's applicability for rural areas. The outcomes of this study provide concrete recommendations for sustainable energy solutions and serve as a valuable reference for future research in the field. The algorithm flow chart is given in (Figure 9).

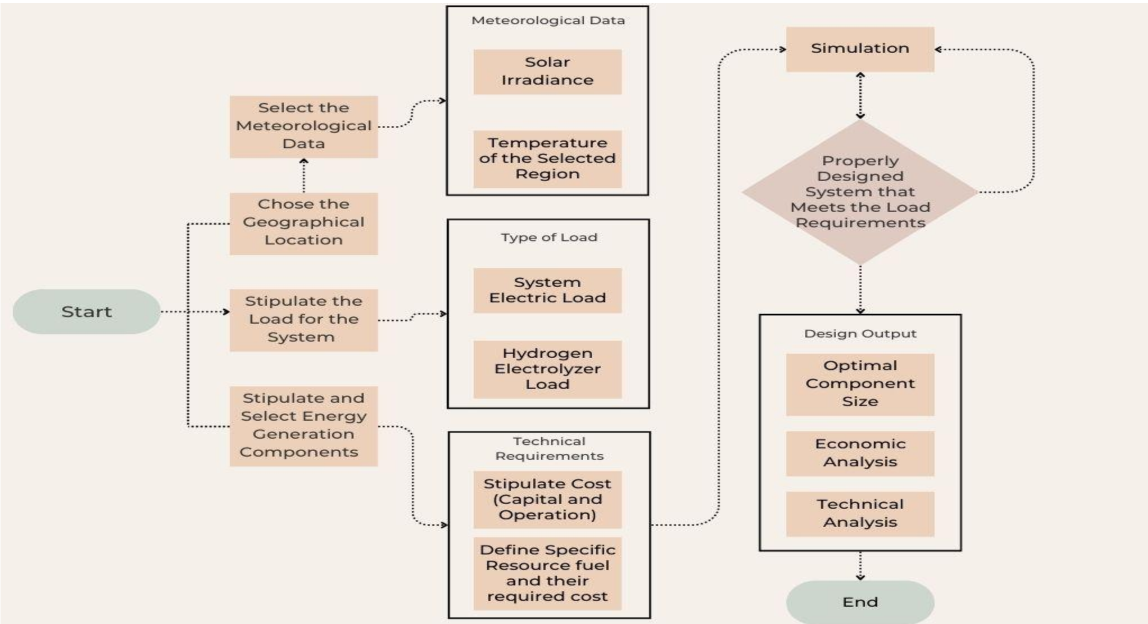

Figure 9. Algorithm flow chart

In this study, it is acknowledged that electrolyzers require deionized water for hydrogen production. Depending on the salinity level of the water source near the pilot area, a desalination system may be necessary. However, no cost analysis related to a desalination system has been conducted in this study, and this aspect has been omitted from the scope. This assumption was made to perform the analysis within defined boundaries and to focus on the economic feasibility of the current system configuration. Future studies may investigate the impact of desalination requirements on cost calculations based on water quality. It should be noted that this factor could significantly alter total cost estimations, especially for large-scale systems.

In this study conducted in a rural neighborhood of Diyarbakır, a hydrogen-based microgrid model was developed. The simulation results indicated that 61.2% of the system's annual energy demand could be met with renewable energy sources. The hydrogen produced by the electrolyzer met the system's energy storage needs, mitigating the effects of fluctuations in renewable energy generation.

The total capital cost of all components was determined to be $4620005.00, with total maintenance/repair costs amounting to $1154828.51, and total fuel costs calculated at $2189171.79. Disposal costs were calculated to be -$247223.70. Consequently, the total cost for the system amounted to $7716781.60. In the graphical representation (Figure 10), the costs of each component are visualized using bar charts, providing a clearer illustration of the cost distribution and the share of each component in the overall cost.

3.1 Grid and PV Performance

The system generates approximately 8345476 kWh of electricity annually. Of this production, 66.5% (around 5553834 kWh) is supplied by solar panels, with the remaining portion met through grid purchases. Electricity production varies significantly with the seasons due to its reliance on solar energy. Production peaks during the sunny summer months, while a decline is observed in the winter (Figure 11) The total annual electricity consumption is approximately 8252687 kWh, with the majority of this consumption classified as an AC primary load. In some months, the system produces more electricity than it consumes. The excess electricity is either stored or sold to the grid. The system includes a hydrogen storage unit, which enables the storage of surplus production for later use. Although the system is not entirely independent, it does purchase electricity from the grid, enhancing its reliability during periods of reduced production. For example, in April, 180579 kWh of energy was purchased and 228710 kWh of energy was sold, resulting in a net sale of 48131 kWh and generating revenue of $2406.53. In May, 198210 kWh of energy was purchased, while 241126 kWh was sold, leading to a net sale of 42916 kWh and revenue of $2145.81.

On an annual basis, a total of 2791642 kWh of energy was purchased, and 2296895 kWh was sold. The net energy load amounted to 494747 kWh, with the total grid cost of the system calculated to be $37342.02.

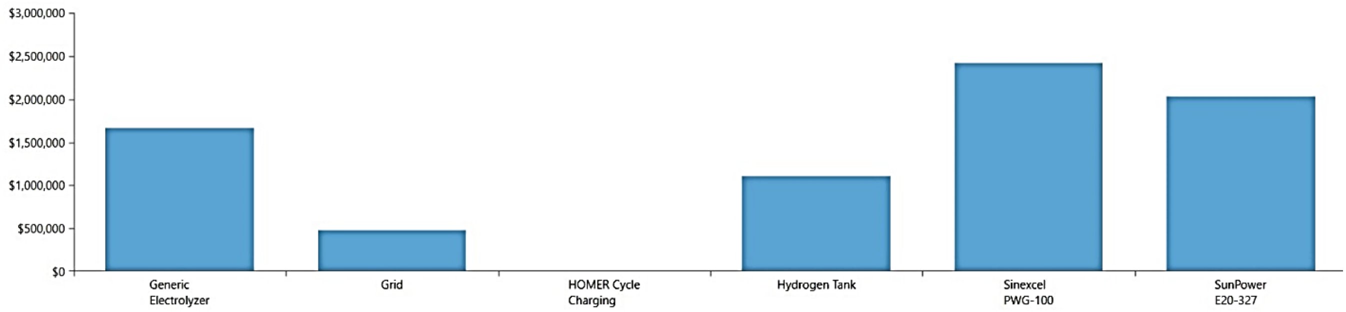

Figure 10. Monthly production graph for grid and PV of the system designed in HOMER Pro

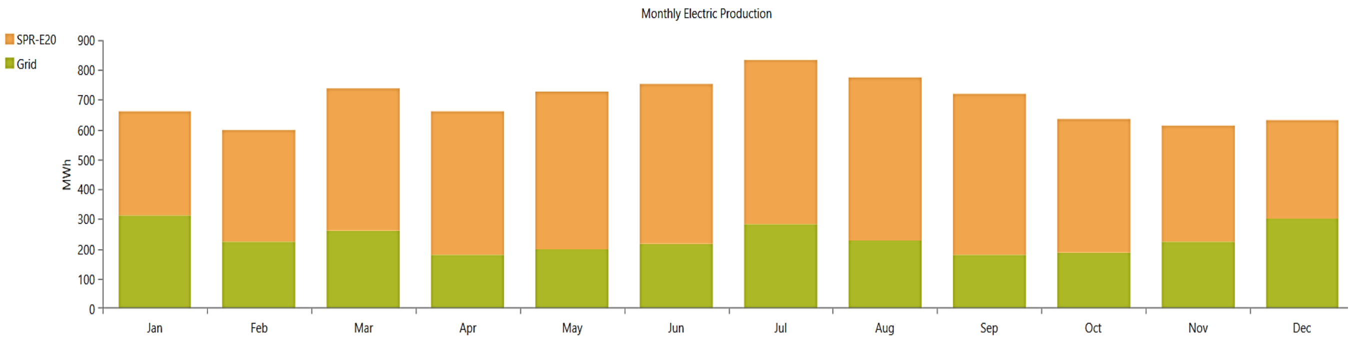

Figure 11. Monthly production graph for grid and PV of the system designed in HOMER Pro

3.2 Electrolyzer performance

In the conducted analysis, the variations in hydrogen load on daily, seasonal, and annual scales have been examined in detail. In the daily profile, the hydrogen load has been determined as a constant 12 kg/hour, indicating a continuous consumption model throughout the analysis. In the seasonal profile, it has been identified that the monthly variations are minimal, and the load exhibits a generally stable demand. In the annual profile, it has been observed that the hydrogen load is distributed uniformly throughout the year, with minor fluctuations due to random variability.

The scaled annual average hydrogen load has been calculated as 70 kg/day, representing the overall demand level of the hydrogen system. The maximum load has been determined as 20.92 kg/hour, while the average load has been identified as 8.05 kg/hour. Additionally, the "Value of Electricity" parameter has been specified as $0.07/kWh, serving as a critical factor in assessing the cost of hydrogen production. The results demonstrate that the hydrogen demand is consistently met throughout the year, and the costs are maintained at an optimizable level. An annual production of 25579 kg of hydrogen was achieved by the electrolyzer in the system. On the consumption side, the hydrogen load was recorded as 25550 kg, indicating that almost all the hydrogen produced by the system was consumed. These figures, which point to a minimal difference between annual energy consumption and production, demonstrate that the system operates with high efficiency.

Additionally, when examining the monthly hydrogen production graph of the electrolyzer (Figure 12), it is observed that the highest production occurred at the beginning of the year (in January) with approximately 90 kW of energy, while production stabilized around 50 kW in the subsequent months. An increase was observed again in December, which may be due to seasonal conditions or changes in operational requirements.

Such data are crucial for understanding the operational efficiency of the electrolyzer, its sensitivity to seasonal effects, and its capacity to meet energy demands throughout the year. Specifically, the Levelized Cost of Hydrogen (LCOH) for the electrolyzer was calculated to be $4.50 per kg. This value reflects the cost of hydrogen production and can be considered an important indicator in managing system costs. Notably, this calculated LCOH is below the current market price for green hydrogen, which ranges between $5 and $6 per kg in 2024, demonstrating the potential economic competitiveness of the system under the modeled conditions.

4 Conclusions

The conducted HOMER simulation yielded a LCOE of $0.08301 per kilowatt-hour for the designed hybrid energy system. This result provides significant insights into the economic performance of the system. The LCOE value of $0.08301 indicates that the system remains competitive when compared to the average grid electricity price in the region. However, if a lower LCOE value is targeted, some improvements may be necessary. For example, technological innovations such as increasing the efficiency of solar panels, using more efficient electrolyzers, or advancements in hydrogen storage technologies could significantly contribute to reducing costs. Additionally, seeking more cost-effective alternatives for system components or optimizing the purchasing and installation processes could help lower costs. Finding long-term, low-interest financing options is another factor that can reduce the overall cost. Furthermore, optimizing the system to better meet energy demand could help reduce LCOE by minimizing energy losses.

Along with these improvements, closely monitoring fluctuations in the energy market and reassessing the system when necessary is crucial for ensuring the long-term economic sustainability of the system.

In conclusion, while the LCOE value of $0.08301 demonstrates the economic potential of the system, it also indicates that there is room for improvement. Detailed analyses and optimization efforts could enhance the system's performance and make it more competitive.

The Levelized Cost of Hydrogen (LCOH) for the designed system was calculated to be $4.50 per kg. This value is above the typical cost range for gray hydrogen but is at a competitive level for green hydrogen production.

The study demonstrates that using renewable energy sources for hydrogen production can reduce carbon emissions and decrease dependence on fossil fuel imports. It is estimated that 0.0254% of Türkiye's target of 695 Mt CO_2 reduction by 2030 could be achieved through the efforts carried out within this project alone. These results could serve as an important reference point for policymakers, investors, and stakeholders who are considering hydrogen investments in urban areas and nationwide.

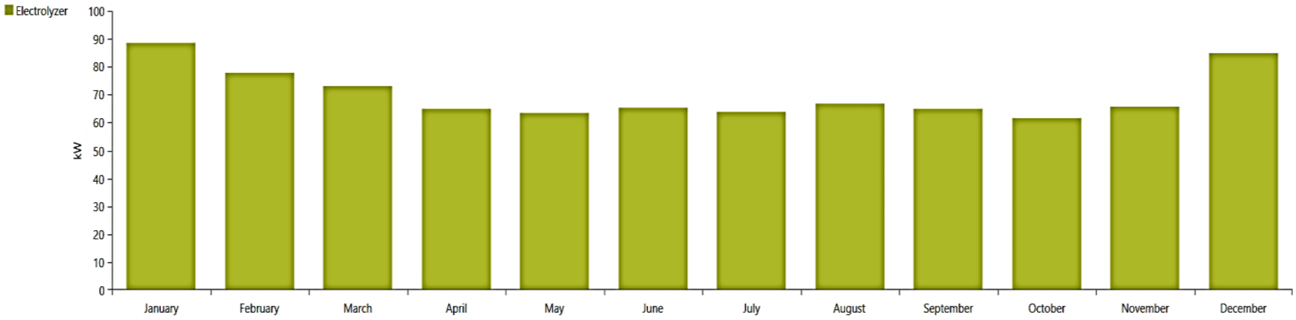

Figure 12. Monthly production graph for the electrolyzer of the system designed in HOMER Pro

For future studies, a sensitivity analysis using HOMER software could be conducted to examine the system's responsiveness to different variables. Further research could also focus on topics such as the use of intelligent control methods in hybrid systems and the analysis of different control techniques. Factors like project lifespan and salvage values are significant areas of investigation for researchers to understand their impact on the techno-economic outcomes of hybrid systems. Such studies could contribute to determining the optimal configuration of hybrid systems created by integrating different technologies, thereby reducing project investment risks. Additionally, they could enhance analysis efficiency, leading to more accurate and reliable results.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding this study.

Similarity Rate (iThenticate): 17%

References

[1] R.A. Satır, 100. Yılında Türkiye Cumhuriyeti'nin Yeni Ekonomik Yol Güzergahı: Yeşil Mutabakat Süreci ve Döngüsel Ekonomi Üzerine Bir Değerlendirme. Süleyman Demirel Üniversitesi Fen-Edebiyat Fakültesi Sosyal Bilimler Dergisi, Cumhuriyet'in 100. Yılı Özel Sayısı, 211-224, 2023. https://dergipark.org.tr/en/pub/sufesosbil/issue/80623.

[2] Y. Demir, Türkiye'de Yenilenebilir Enerji Tüketimi Ekonomik Büyümeye Katkı Sağlar Mı? Doğuş Üniversitesi Dergisi, 24(2), 271-281, 2023. https://doi.org/10.31671/doujournal.1209964.

[3] D. E. Olivares, A. Mehrizi-sani, A. H. Etemadi, C. A. Canizares, R. Iravani, M. Kazerani, A. H. Hajimiragha, O. G. Bellmunt, M. Saeedifard, R. P. Behnke, G. A. J. Estevez, and N. D. Hatziargyriou Trends in Microgrid Control. IEEE Transactions on Smart Grid, 5(4), 1905-1919, 2014. https://doi.org/10.1109/TSG.2013.2295514.

[4] M.A. Basit, S. Dilshad, R. Badar and S.M. S. Rehman, Limitations, challenges, and solution approaches in grid-connected renewable energy systems. International Journal of Energy Research, 44, 4132-4162, 2020. https://doi.org/10.1002/er.5033.

[5] A. M. Ferrario, A. Bartolini, F.S. Manzano, F. J. Vivas, G. Comodi, S.J. McPhail and J. M. Andujar, A model-based parametric and optimal sizing of a battery/hydrogen storage of a real hybrid microgrid supplying a residential load: Towards island operation. Advances in Applied Energy, 3, 100048, 2021. https://doi.org/10.1016/j.adapen.2021.100048.

[6] Q. M. Hassan, A. Abdulateef, S. A. Hafedh, A. Al-samari, J. Abdulateef, A. Z. Sameen, H. M. Salman, A. K. Al-Jiboory, S. Wieteska, and M. Jaszczur, Renewable energy-to-green hydrogen: A review of main resources routes, processes and evaluation. International Journal of Hydrogen Energy, 2023. https://doi.org/10.1016/j.ijhydene.2023.01.175.

[7] F. Gutiérrez-Martín, J.M. García-De María, A. Baïri, and N. Laraqi, Management strategies for surplus lectricity loads using electrolytic hydrogen. International Journal of Hydrogen Energy, 8468-8475, 2009. https://doi.org/10.1016/j.ijhydene.2009.08.018.

[8] X. Xu, Q. Zhou, and D. Yu, The future of hydrogen energy: Bio-hydrogen production technology. International Journal of Hydrogen Energy, 33677-33698, 2022. https://doi.org/10.1016/j.ijhydene.2022.07.261.

[9] B.S. Zainal, P.J. Ker, H. Mohamed, H.C. Ong, I.M.R. Fattah, S.M. Ashrafur Rahman, L. D. Nghiem, and T. M. I. Mahlia, Recent advancement and assessment of green hydrogen production Technologies. Renewable and Sustainable Energy Reviews, 113941, 2024. https://doi.org/10.1016/j.rser.2023.113941.

[10] J.J. Brey, Use of hydrogen as a seasonal energy storage system to manage renewable power deployment in Spain by 2030. International Journal of Hydrogen Energy, 17447-17457, 2021. https://doi.org/10.1016/j.ijhydene.2020.04.089.

[11] H. Ishaq, I. Dincer, and C. Crawford, A review on hydrogen production and utilization: Challenges and opportunities. International Journal of Hydrogen Energy, 26238-26264, 2022. https://doi.org/10.1016/j.ijhydene.2021.11.149.

[12] M. Neuwirth, T. Fleiter, P. Manz, and R. Hofmann, The future potential hydrogen demand in energy-intensive industries – A site-specific approach applied to Germany. Energy Conversion and Management, 115052, 2022. https://doi.org/10.1016/j.enconman.2021.115052.

[13] D. Guilbert and G. Vitale, Hydrogen as a Clean and Sustainable Energy Vector for Global Transition from Fossil-Based to Zero-Carbon. Clean Technologies, 881-909, 2021. https://doi.org/10.3390/cleantechnol3040051.

[14] T. Egeland-Eriksen, A. Hajizadeh, and S Sartori, Hydrogen-based systems for integration of renewable energy in power systems: Achievements and perspectives. International Journal of Hydrogen Energy, 31963-31983, 2021. https://doi.org/10.1016/j.ijhydene.2021.06.218.

[15] P. Ge, Q. Hu, Q. Wu, X. Dou, Z. Wu and Y. Ding, Increasing operational flexibility of integrated energy systems by introducing power to hydrogen. IET Renewable Power Generation, 14, 372-380, 2020. https://doi.org/10.1049/iet-rpg.2019.0663.

[16] A. Alzoubi, Renewable Green Hydrogen Energy Impact on Sustainability Performance. International

Journal of CIM, 1(1), Dec. 2021. https://doi.org/10.54489/ijcim.v1i1.46.
[17] M. V. D. Spek, C. Banet, C. Bauer, P. Gabrielli, W. Goldthorpe, M. Mazzotti, S. T. Munkejord, N. A. Røkke, N. Shah, N. Sunny, D. Sutter, J. M. Trusler, and M. Gazzani, Perspective on the hydrogen economy as a pathway to reach net-zero CO_2 emissions in Europe. Energy & Environmental Science, 15, 1034-1077, 2022. https://doi.org/10.1039/D1EE02118D.
[18] H. Kilic, Improving the performance of microgrid-based Power-to-X systems through optimization of renewable hydrogen generation. International Journal of Hydrogen Energy, 75, 106-120, 2024. https://doi.org/10.1016/j.ijhydene.2024.01.066.
[19] H. Kilic, M. E. Asker, and C. Haydaroglu, Enhancing power system reliability: Hydrogen fuel cell-integrated D-STATCOM for voltage sag mitigation. International Journal of Hydrogen Energy, 75, 557-566, 2024. https://doi.org/10.1016/j.ijhydene.2024.03.313.
[20] Türkiye Hidrojen Teknolojileri Stratejisi ve Yol Haritası. ETKB, 2023. https://enerji.gov.tr/Media/Dizin/SGB/tr/Kurumsal_Politikalar/HSP/ETKB_Hidrojen_Stratejik_Plan2023.pdf
[21] On İkinci Kalkınma Planı (2024-2028). T.C. SBB, 2023. https://www.sbb.gov.tr/wp-content/uploads/2023/12/On-Ikinci-Kalkinma-Plani_20242028_11122023.pdf.
[22] İ. Çetinbaş, B. Tamyürek, and M. Demirtaş, Design, Analysis and Optimization of a Hybrid Microgrid System Using HOMER Software: Eskişehir Osmangazi University Example. International Journal of Renewable Energy Development, 8(1), 65-79, 2019. https://doi.org/10.14710/ijred.8.1.65-79.
[23] S. Vendoti, M. Muralidhar and R. Kiranmayi, Techno-economic analysis of off-grid solar/wind/biogas/biomass/fuel cell/battery system for electrification in a cluster of villages by HOMER software. Environment Development and Sustainability, 23, 351–372, 2021. https://doi.org/10.1007/s10668-019-00583-2.
[24] F. Dawood, G. Shafiullah and M. Anda, Stand-Alone, Microgrid with 100% Renewable Energy: A Case Study with Hybrid Solar PV-Battery-Hydrogen. Sustainability, 12, 2047, 2020. https://doi.org/10.3390/su12052047.
[25] T. Xia, M. Rezaei, U. Dampage, S.A. Alharbi, O. Nasif, P. F. Borowski and M.A. Mohamed, Techno-Economic Assessment of a Grid-Independent Hybrid Power Plant for Co-Supplying a Remote Micro-Community with Electricity and Hydrogen. Processes, 9(8), 1375, 2021. https://doi.org/10.3390/pr9081375.
[26] İ. Çetinbaş, B. Tamyürek, and M. Demirtaş, Design, Analysis and Optimization of a Hybrid Microgrid System Using HOMER Software: Eskişehir Osmangazi University Example. International Journal of Renewable Energy Development, 8(1), 65-79, 2019. https://doi.org/10.14710/ijred.8.1.65-79.
[27] A. F. Güven and M. Mete, Balıkesir İli Erdek İlçesi için Bağımsız Hibrit Enerji Sisteminin Fizibilite Çalışması ve Ekonomik Analizi. KONJES, 9(4), 1063–1076, 2021. https://doi.org/10.36306/konjes.978002.
[28] V. Suresh, M. Muralidhar, and R. Kiranmayi, Modelling and optimization of an off-grid hybrid renewable energy system for electrification in rural areas. Energy Reports, 6, 594-604, 2020. https://doi.org/10.1016/j.egyr.2020.01.013.
[29] S. Bhattacharjee, S. Chakraborty and C. Nandi, An Optimization Case Study of Hybrid Energy System in Four Different Regions of India. In: A. Bhoi, K. Sherpa, A. Kalam, and G.S. Chae (Eds.), Advances in Greener Energy Technologies, Green Energy and Technology, Springer, Singapore, pp. 399-437, 2020. https://doi.org/10.1007/978-981-15-4246-6_23.
[30] Y. Basheer, A. Waqar, S. M. Qaisar, T. Ahmed, N. Ullah and S. Alotaibi, Analyzing the Prospect of Hybrid Energy in the Cement Industry of Pakistan, Using HOMER Pro. Sustainability, 14(19), 12440, 2022. https://doi.org/10.3390/su141912440.
[31] M. H. Jahangir and R. Cheraghi, Economic and environmental assessment of solar–wind–biomass hybrid renewable energy system supplying rural settlement load. Sustainable Energy Technologies and Assessments, 42, 100895, 2020. https://doi.org/10.1016/j.seta.2020.100895.
[32] A. Amupolo, S. Nambundunga, D.S.P. Chowdhury, and G. Grün, Techno-Economic Feasibility of Off-Grid Renewable Energy Electrification Schemes: A Case Study of an Informal Settlement in Namibia. Energies, 15(12), 4235, 2022. https://doi.org/10.3390/en15124235.
[33] C. Palanichamy, T. W. Wen and P. Naveen, A microgrid for the secluded Paana Theertham Kani settlement in India. Clean Energy, 6(1), 43–58, 2022. https://doi.org/10.1093/ce/zkab055.
[34] S. El Hassani, F. Oueslati, O. Horma, D. Santana, M. A. Moussaoui and A. Mezrhab, Techno-economic feasibility and performance analysis of an islanded hybrid renewable energy system with hydrogen storage in Morocco. Journal of Energy Storage, 68, 107853, 2023. https://doi.org/10.1016/j.est.2023.107853.
[35] M. Yılmaz, B. Gümüş, H. Kılıç and M. E. Asker, Chaotic analysis of the global solar irradiance. IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), San Diego, CA, USA, pp. 1058-1066, 2017. https://doi.org/10.1109/ICRERA.2017.8191219.
[36] M. A. G. Dahmani and M. Arfa, The Analysis of the Integration of Green Hydrogen Into Energy Networks Using HOMER PRO, 2024. https://www.researchgate.net/publication/382241730_The_Analysis_of_the_Integration_of_Green_Hydrogen_Into_Energy_Networks_Using_HOMER_PRO.
[37] H. Kılıç, B. Gümüş and M. Yılmaz, Güneydoğu Anadolu bölgesi için global güneş ışımasının ve güneşlenme süresinin istatiksel metodlar ile tahmin edilmesi ve karşılaştırılması. Dicle Üniversitesi Mühendislik Fakültesi Mühendislik Dergisi, 7(1), 73-

83, 2016. https://dergipark.org.tr/en/download/article-file/302870.

[38] H. Kılıç, B. Gümüş, ve M. Yılmaz, Diyarbakır İli İçin Güneş Enerjisi Verilerinin Meteorolojik Standartlarda Ölçülmesi ve Analizi. EMO Bilimsel Dergi, 5(10), 15–19, 2016. https://dergipark.org.tr/tr/pub/emobd/issue/26509/278951.