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An Analysis of Green Hydrogen Production Using Solar Energy in Angola

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Anahtar Kelimeler

Güneş Enerji
Angola
Yeşil Hidrojen
Enerji Geçiş
Net Sıfır

Graphical/Tabular Abstract (Grafik Özet)

This study investigated the feasibility of green hydrogen production in Angola using a photovoltaic-powered alkaline electrolysis system in Benguela Province. / Bu çalışmada, Benguela ilinde fotovoltaik destekli alkali elektroliz sistemi kullanılarak Angola'da yeşil hidrojen üretiminin uygulanabilirliği araştırıldı.

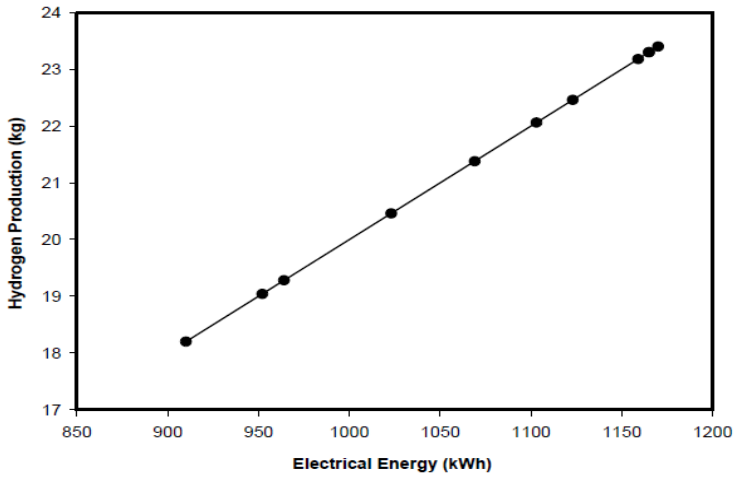


***Figure A**: Hydrogen Production vs. Electrical Energy Input /**Şekil A:** Elektrik enerjisi girdisine karşılık hidrojen üretimi*

Highlights (Önemli noktalar)

- *A PV system was designed using PVsyst and AutoCAD to supply two alkaline electrolysers. / İki alkali elektrolizörü beslemek için PVsyst ve AutoCAD kullanılarak bir PV sistemi tasarlanmıştır.*
- *Annual electricity production was determined as 12,775 kWh and estimated hydrogen production as 255.5 kg/year. / Yıllık elektrik üretimi 12775 kWh ve tahmini hidrojen üretimi 255,5 kg/yıl olarak belirlenmiştir.*
- *Solar-based hydrogen production was shown to be technically feasible in Angola. / Güneş tabanlı hidrojen üretiminin Angola'da teknik olarak uygulanabilir olduğu gösterilmiştir.*

***Aim (Amaç):** Supporting Angola as a green energy leader in Sub-Saharan Africa through solar-based green hydrogen production. / Güneş tabanlı yeşil hidrojen üretimi ile Angola'nın Sahra Altı Afrika'da yeşil enerji lideri olarak desteklenmesi.*

***Originality (Özgünlük):** Solar-based hydrogen production in Angola is assessed using PVsyst and AutoCAD system design. / Angola'da güneş tabanlı hidrojen üretimi, PVsyst ve AutoCAD sistem tasarımı kullanılarak değerlendirilmektedir.*

***Results (Bulgular):** With solar energy availability, the technical feasibility of green hydrogen production in Angola has been demonstrated. / Güneş enerjisi kullanılabilirliği ile Angola'da yeşil hidrojen üretiminin teknik uygulanabilirliği gösterilmiştir.*

***Conclusion (Sonuç):** Solar-based hydrogen production in Angola will enable 12,775 kWh/year energy generation and 255.5 kg/year hydrogen production, supporting renewable energy and economic development. / Angola'da güneş tabanlı hidrojen üretimi, 12775 kWh/yıl enerji üretimi ve 255,5 kg/yıl hidrojen üretimi sağlayarak yenilenebilir enerji ve ekonomik gelişimi destekleyecektir.*

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Abstract

This study looks at the potential for producing green hydrogen in Angola using solar energy, focusing on Benguela Province because of its high solar radiation. A PV system was designed using PVsyst and AutoCAD to supply two alkaline electrolysers. The PVsyst simulation gave an annual electricity production of 12,775 kWh. The software already includes typical system losses like temperature effects, inverter efficiency, and wiring losses, but it does not model detailed real-time interaction with the electrolyser. Hydrogen production was estimated in a simplified way based on annual energy, giving 255.5 kg/year. The results also reflect seasonal changes in solar availability. The LCOH ranges between 3.50 and 10.40 USD/kg. Overall, the study shows that solar-based hydrogen production in Angola is technically feasible.

Angola'da Güneş Enerjisi Kullanılarak Yeşil Hidrojen Üretiminin Analizi

Makale Bilgisi

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Öz

Bu çalışma, yüksek güneş radyasyonuna sahip Benguela ili'ne odaklanarak, Angola'da güneş enerjisi kullanarak yeşil hidrojen üretme potansiyelini incelemektedir. İki alkali elektrolizöre enerji sağlamak için PVsyst ve AutoCAD kullanılarak bir fotovoltaik (PV) sistem tasarlanmıştır. PVsyst simülasyonu, yıllık 12.775 kWh elektrik üretimi vermiştir. Yazılım, sıcaklık etkileri, invertör verimliliği ve kablolama kayıpları gibi tipik sistem kayıplarını zaten içermektedir, ancak elektrolizörle gerçek zamanlı etkileşimi ayrıntılı olarak modellememektedir. Hidrojen üretimi, yıllık enerjiye dayalı olarak basitleştirilmiş bir şekilde tahmin edilmiş ve 255,5 kg/yıl olarak bulunmuştur. Sonuçlar ayrıca güneş enerjisinin mevsimsel değişimlerini de yansıtmaktadır. LCOH (Hidrojen Üretim Maliyeti) 3,50 ile 10,40 USD/kg arasında değişmektedir. Genel olarak, çalışma Angola'da güneş enerjisine dayalı hidrojen üretiminin teknik olarak mümkün olduğunu göstermektedir.

1. INTRODUCTION (GİRİŞ)

Hydrogen is a practical energy carrier that supports energy security due to the wide range of domestic energy resources available for its production [1]. Therefore, prioritizing renewable energy is essential to reduce climate change impacts, and hydrogen systems are expected to supply about 12% of global energy use by 2050 [2-3]. In 2019, solar PV was the leading renewable energy source in markets like Japan, India, China, and the USA. About 115 GW of new capacity was added globally, increasing the total to nearly 627 GW [4]. Water electrolysis is a well-established method for producing hydrogen and can be easily combined with appropriate power sources. In this process, electrical energy splits water into hydrogen and oxygen gases [5-6]. Alkaline electrolyzers and Proton Exchange Membrane (PEM) electrolyzers are two mature technologies widely used on a commercial scale for hydrogen production [7]. One way to produce green hydrogen is by using solar PV plants to power electrolysis systems, creating a zero-emission energy process [8]. Clean hydrogen produced via renewable-powered electrolysis (such as solar and wind) is increasingly seen as a key low-emission energy solution. Expanding these technologies is important for achieving a sustainable energy transition and reducing climate change impacts. By combining renewable energy benefits with advanced storage systems, clean hydrogen can significantly support net-zero emissions across multiple sectors [9-12]. Angola has strong potential for hydrogen development, supported by abundant water resources and ideal climatic conditions for renewable energy projects. At present, only about 5% of its 47 major water catchment areas are being used, leaving substantial untapped water reserves.

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The government is pursuing a long-term decarbonization plan, targeting a 70% renewable share in the energy mix by 2025, where hydrogen is expected to play an important role [13].

Power electronic converters, such as hydrogen power supplies, are essential for meeting the operational requirements of industrial electrolyzers. Their stable operation ensures safe and efficient performance, while instability can reduce hydrogen purity and production efficiency [14-15]. This study used an AC direct-linked hydrogen production system.

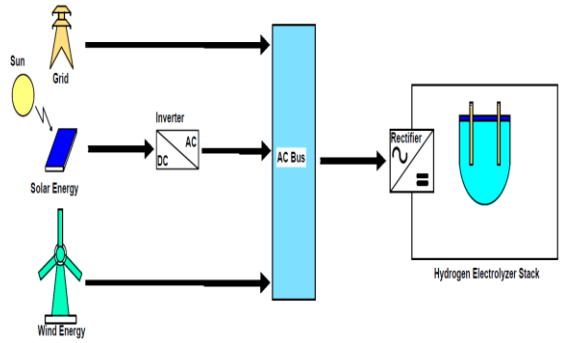


Figure 1. Schematic of an AC-linked Hydrogen production system topology (AC bağlantılı hidrojen üretim sistemi topolojisinin şeması)

2. MATERIALS AND METHODS (MATERYAL VE METOD)

The performance of the 7.7 kW off-grid solar power plant was analyzed using PVsyst 7.4 software, while the general system layout was designed using AutoCAD software. A total of 14 AE MD-144 Series 550 W solar panels connected in series were used to generate DC power, one Three-Phase Hybrid Inverter (SUN-5K-SG04LP3-EU-AM2-P) was used to convert the generated DC power into AC power, and two SUNGREENH2 ELECTROLYZER AES0002-2.1 alkaline electrolyzer stacks was employed for the production of green hydrogen. The detailed technical characteristics of the PV modules, the inverter, and the electrolyzer are provided separately in Tables 1, 2, and 3.

The off-grid solar layout plan was designed using AutoCAD in Baía Farta district, Benguela province. The layout is shown in Figure 2.

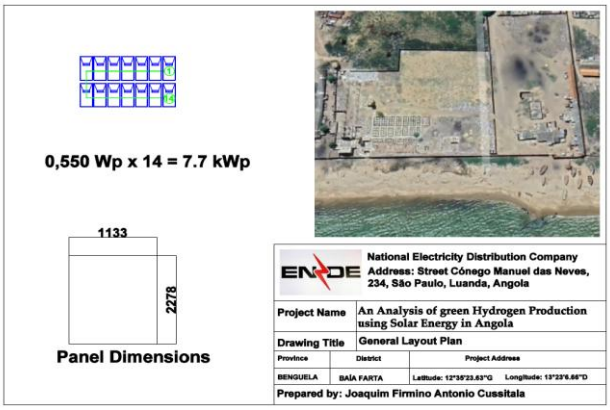


Figure 2. General PV layout Plan (FV genel yerleşim planı)

The hydrogen production quantity was calculated based on annual electricity generation. The following assumptions were used in the system performance analysis: electrolyzer specific energy consumption of 50 kWh/kg H_2 [16], a system lifetime of 20 years, operation and maintenance costs of 2% of the annual investment cost, electricity cost of 0.04 USD/kWh, and the assumption that system performance does not change over time. These assumptions are based on standard values commonly used in the literature.

The hydrogen production quantity was calculated using the following equation, which is commonly used in the literature [17].

$$H_2 = \frac{E_{annual}}{50} \quad (2.1)$$

Where Eannual is the annual energy generated from the PVsyst simulation.

The economic performance of the system was evaluated using the Levelized Cost of Hydrogen (LCOH). LCOH was calculated using the following equation [17].

$$LCOH = \frac{C_{inv}+C_{O\&M}+C_E}{H_2} \quad (2.2)$$

Where, H_2 (kg) represents the total hydrogen produced in present value terms, CO&M (USD) is the present value of operation and maintenance expenses, CE (USD) stands for the present value of electricity costs, and Cinv (USD) refers to the initial investment cost (CAPEX) over the project's lifetime.

Table 1. PV modules technical characteristics (FV modül teknik özellikleri)

Nominal Max. Power (STC) Pmax (Wp)	550
Maximum operating voltage V_{MPP} (V)	42.57

Maximum operating current I_{MPP} (A)	12.92
Open-circuit voltage Voc (V)	51.44
Short-circuit current Isc (A)	13.67
Module efficiency (η%)	21.31

Table 2. Inverter technical characteristics (İnvertör karakteristik özellikleri)

No. of MPP Trackers/ No. of Strings MPP Tracker	2/2+1
MPPT Voltage Range (V)	200-650
Rated PV Input Voltage (V)	550
Max. Operating PV Input Current (A)	36+20
Max. Input Short-Circuit Current (A)	54+30
Max. Efficiency (η%)	97.6

Table 3. Electrolyzers technical characteristics (Elektrılizör karakteristik özellikleri)

Production Rate (Nm^3/h = @ 25°C & 1 ATM)	0.496Nm^3/hr (1kg /day)
Hydrogen Purity (Without Purifier)	99.9%
Hydrogen Purity (With Purifier)	99.999%
Output Pressure	<10 Bar
Efficiency (HHV)	82%
Stack Energy Consumption per kg H2	48 kWh/kg
System Energy Consumption per kg H2	50.4 kWh/kg
Power Supply	3 Phase 400 VAC 50/60 Hz
Electrolyte	1M KOH (5.34wt%)

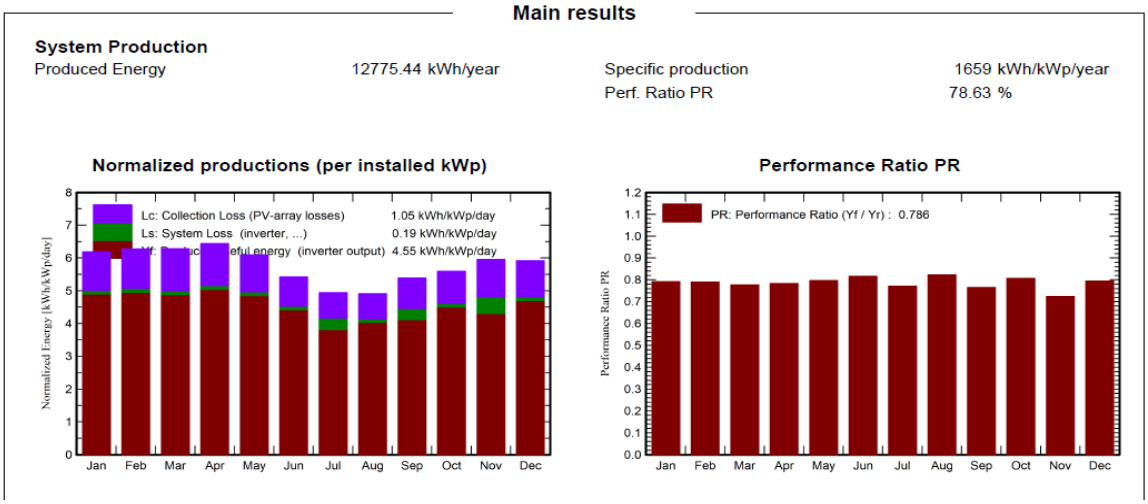


Figure 3. Analysis of the Solar PV Plant: (a) System performance assessment; (b) Performance ratio evaluation. (Güneş Enerjisi Santrali Performans Analizi: (a) Sistem performansının değerlendirilmesi; (b) Performans oranının değerlendirilmesi)

3. RESULTS AND DISCUSSION (SONUÇLAR VE TARTIŞMA)

According to the PVsyst simulation, the highest energy production occurs in April, while the lowest is in July. This clearly shows how changes in solar irradiation throughout the year directly affect the performance of the PV system. Figure 3 presents the overall performance assessment and performance ratio of the AE SOLAR 550 W solar power plant.

Hydrogen production is directly proportional to electrical energy generation because the hydrogen output depends on the available PV energy supplied to the electrolyzer. With a constant specific energy consumption of 50 kWh/kg H_2, changes in energy

production lead to corresponding changes in hydrogen yield. Higher solar irradiation increases hydrogen production, while lower irradiation periods reduce it.

As shown in Figure 4, hydrogen production follows the same seasonal pattern as energy generation, confirming that solar resource availability is the main factor affecting system performance in an off-grid configuration.

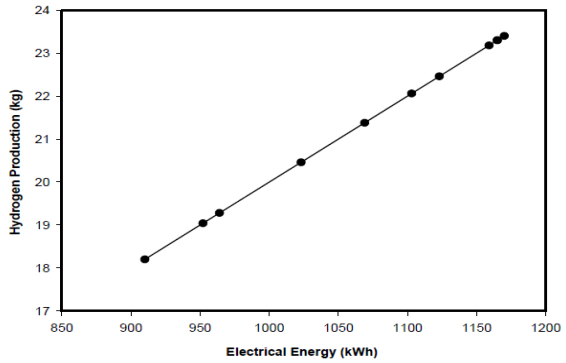


Figure 4. Hydrogen Production vs. Electrical Enrgy Input (Elektrik enerjisi girdisine karşılık hidrojen üretimi)

As shown in Figure 5, system utilization strongly affects economic performance, confirming that improving hydrogen yield and proper system sizing are key factors in reducing LCOH.

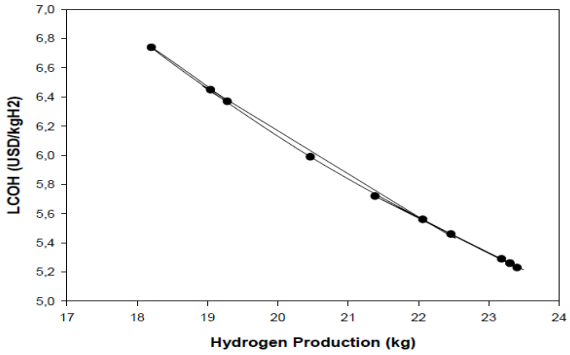


Figure 5. Hydrogen Production vs. Electrical Energy Input (Hidrojen üretimi girdisine karşılık LCOH maliyeti)

4. CONCLUSION (SONUÇ)

This study evaluated the technical and economic feasibility of solar-based green hydrogen production using an off-grid PV system with electrolyzers, where the system generated about 12,775 kWh of electricity annually according to PVsyst simulations and annual hydrogen production was estimated at approximately 255.5 kg/year based on a 50 kWh/kg H_2 consumption rate. Hydrogen output varies seasonally depending on solar irradiation levels, while the LCOH was calculated between 3.50 and 10.40 USD/kg, consistent with small-scale systems in the literature. The results show that higher solar resources, especially in regions like Benguela, improve system performance and feasibility, confirming that solar-driven hydrogen production is technically viable in Angola and supports sustainable energy development. Further improvements are possible through system optimization and the use of more efficient components.

DECLARATION OF ETHICAL STANDARDS
(ETİK STANDARTLARIN BEYANI)

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

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

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

***Joaquim CUSSITALA*:** He conducted the system design, simulations and the writing of the article.

Sistem tasarımını, simülasyonları ve makalenin yazımını gerçekleştirmiştir.

***Hacı Mehmet ŞAHİN*:** He reviewed all the concepts presented in the article and analyzed the results.

Makalede sunulan tüm kavramları gözden geçirmiştir ve sonuçları analiz etmiştir.

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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