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Energy Storage Performance and Investigation of Usage Potential a PV Combined-Alkaline Electrolysis Hydrogen Production System

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ABSTRACT

Hydrogen fuel has the potential to reduce CO_2 emissions significantly. In this study, PV-alkaline electrolysis cell was combined and during day time it was harvested energy. Some of the deposited energy was used on-grid alkaline electrolysis cell and hydrogen was produced also was stored. In the electrolysis system, Ni-based coatings were operated on steel mesh with the help of the electrodeposition method. It was used re-cycled steel mesh substrates in order to decrease operational costs and also in order to encourage metal-cycling in our country. The relevancy of cathodes was investigated using bulk electrolysis. The characterization was achieved via scanning electron microscopy (SEM), energy dispersive X-ray analysis (EDX). Results define both effects of "lab-made cathodes performance comparison" and "the trend of PV panel under different climate and weather conditions". This system reflects the real-time measurements for Adana, Sarıcam region of Turkey.

Birleşik PV-Alkali Elektroliz Hidrojen Üretim Sisteminin Enerji Depolama Performansı Ve Kullanım Potansiyelinin Araştırılması

Araştırma Makalesi

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ÖZ

Hidrojen yakıtı, CO_2 emisyonlarını önemli ölçüde azaltma potansiyeline sahiptir. Bu çalışmada PV-alkalin elektroliz hücresi birleştirilmiş ve gün boyunca enerji toplanmıştır. Depolanan enerjinin bir kısmı şebekede alkali elektroliz hücresinde kullanılmış ve hidrojen de depolanmıştır. Elektroliz sisteminde Ni esaslı kaplamalar, elektrodepozisyon yöntemi yardımıyla çelik hasır üzerinde çalıştırılmıştır. Ülkemizde işletme maliyetlerini düşürmek ve ayrıca metal çevrimini teşvik etmek amacıyla geri dönüşümlü çelik hasır substratları kullanılmıştır. Katotların uygunluğu, elektroliz yöntemi kullanılarak araştırıldı. Karakterizasyon, taramalı elektron mikroskobu (SEM), enerji dağılımlı X-ışını analizi (EDX) ile sağlandı. Sonuçlar, hem "laboratuvar yapımı katot performans karşılaştırmasının" etkilerini hem de "farklı iklim ve hava koşulları altında PV panelinin eğilimini" tanımlar. Bu sistem, Türkiye'nin

Adana, Sarıçam bölgesi için gerçek zamanlı ölçümleri yansıtmaktadır.

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1.Introduction

The energy requirement resulting from the developments in technology has increased the attention to alternative energy sources. The experimental and numerical studies on the production and storage of hydrogen energy, called fuel for the future, have increased day by day. The many studies have been carried out on environmentally friendly energy generation systems where the energy required to produce hydrogen is obtained from renewable energy sources (Hofbauer et al., 2000; Turner et al., 2008; Balta et al., 2009; Khan et al., 2009; Sopian et al., 2009; Carton et al., 2010; Ghazvini et al., 2019; Kikuchi et al., 2019; Ishaq and Dincer, 2020; Temiz and Javani, 2020). Among these renewable energy sources, solar energy is among the most preferred for hydrogen production. The effect of partial shading from the electrical energy obtained from the 105-Watt solar panel to hydrogen production was investigated. Experimental data were collected at certain time intervals at Adana Alparslan Turkes Science and Technology University. In the study, four different electrodes were used. According to the results obtained Cu/NiMo has better hydrogen production efficiency than Cu/Ni, Cu/NiBi. (Mert et al., 2019). The improved efficiency of the PV-electrolysis system, which obtains the required voltage from the photovoltaic system for the operation of proton exchange membrane (PEM) electrolysers, has been carried out. The production efficiency of the hydrogen produced for use in a fuel cell vehicle has been increased to 12% by making necessary optimizations (Gibson and Kelly, 2008). Alkaline water electrolysis is carried out with the energy source obtained from 30 W solar PV panel and the hydrogen production process is presented in detail without emitting CO_2. 50x50x2 mm Ni metal foam electrodes, 50x50x0,4 mm Zirphon membrane and 25% alkaline (KOH) solution electrolyte are used in this environmentally-friendly hydrogen production system. Also, the effect of distance between different electrodes and electrodes on voltage-electric current (UI) has been experimentally observed (Đukić and Firak, 2011). The experimental and numerical studies have been carried out on the successful integration of hydrogen production with the Photovoltaic (PV) Panel. Two different cases for storage of the produced hydrogen were examined. In the first case, the energy produced from the Photovoltaic Panel is directly connected to the electrolyzer. In the second case, the power converter is integrated into the system to provide energy management and increase efficiency. The experimental and numeric data of these two cases are presented comparatively (Iannuzzi and Pagano, 2009). Hydrogen storage with maximum efficiency from the system where the photovoltaic (PV) panel is directly connected to the Alkaline Electrolyser has been examined. Also, this system is simulated by using MATLAB and Multi-level Genetic Algorithm (GA) based optimization is used for maximum hydrogen production. The obtained results show that the optimal system for a 10 kW electrolyzer can produce Hydrogen of 0,0176 mol/s (Khalilnejad et al., 2016).

In the present work, the environmentally friendly energy system proposed is explained in detail sections which solar PV panel and characteristics, DC-DC step-down converter and hydrogen production by alkaline electrolysis.

2. Material and Method

The renewable energy-based electrolysis system is as shown in Figure 1. The system consists of solar PV panel, DC-DC step down converter, electrolysis process and measurements. The DC-DC step-down converter is directly connected to the 80 W solar PV panel. With the help of the DC-DC step down converter, the open-circuit voltage produced from the PV panel is decreased to the necessary voltage levels required for the electrolysis system. The power used to produce hydrogen and the solar radiation intensity reflected on the panel and the temperature values of the panel were measured momentarily. Thus, the hydrogen production rate is calculated. In this study, it was aimed to reveal the effectiveness of the location of the region for hydrogen production with the proposed renewable energy system.

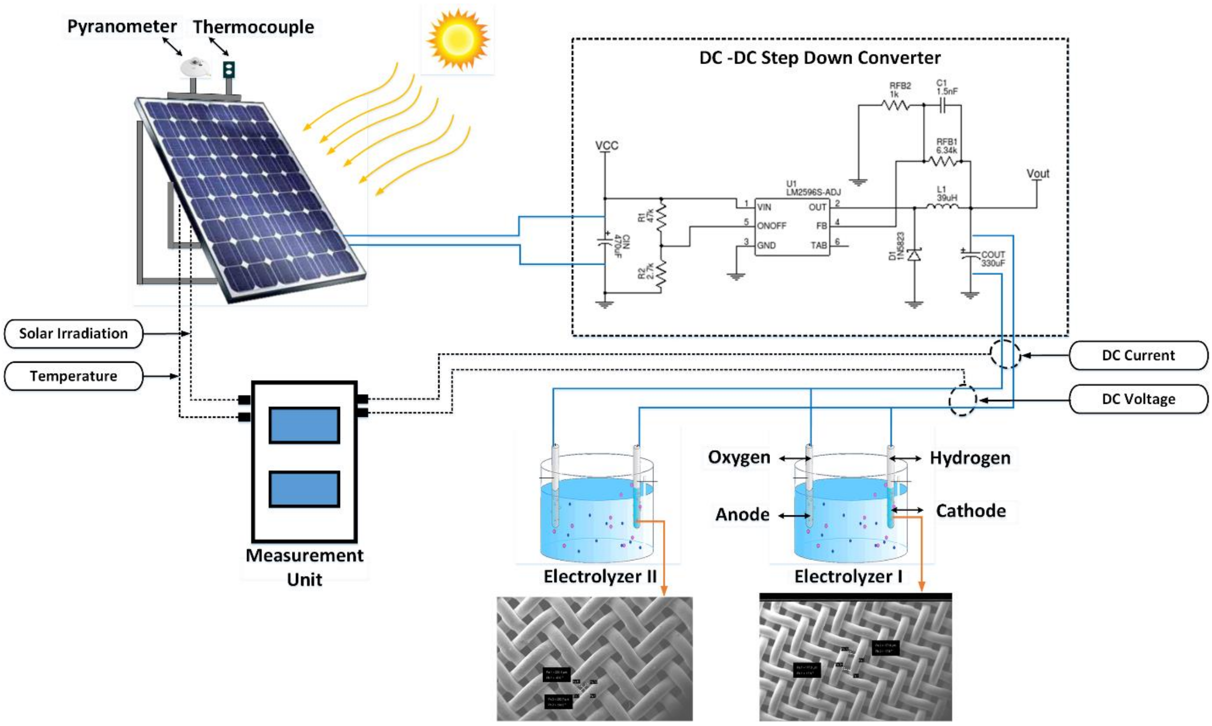


Figure 1. A solar PV combined-alkaline electrolysis hydrogen production system

2.1. Solar PV Panel and Characteristics

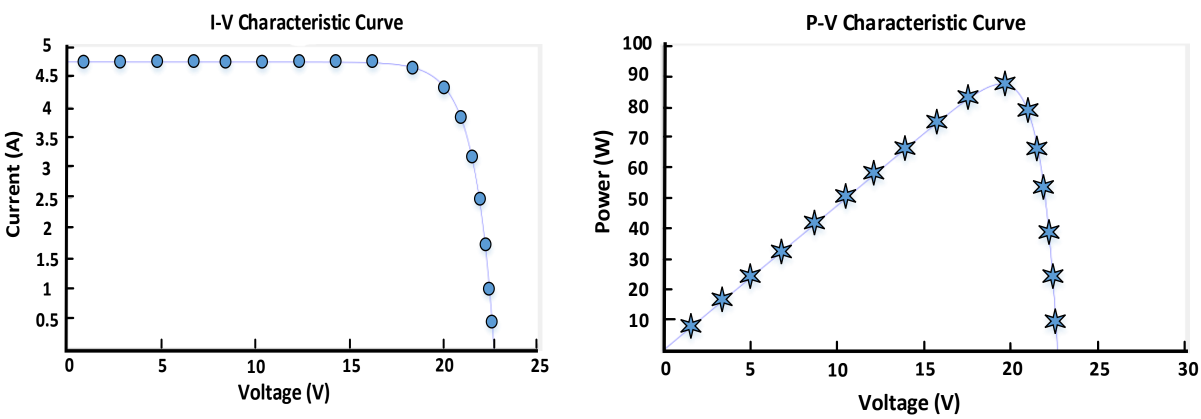
Semiconductor materials are also employed in today's electrical devices, such as solar cells, transistors, and rectifier diodes. Silicon, gallium arsenide, and cadmium telluride are the most appropriate semiconducting materials for manufacturing solar cells. The additive determines whether the semi-conductor is of the "n" or "p" type. Semiconductor joints are created by combining the appropriate additives into the "p" or "n" type main material. Electrons in the semiconductor type "N" and halls in the semiconductor type "p" are the majority carriers. Both p-type and n-type semiconductors are electrically neutral before they come together. In the p-type, negative energy levels and hall numbers are equal, while positive energy levels and electron numbers are equal in the n-type. Electrons, which are the majority carrier of type n, produce current towards type p when a PN junction is constructed.

In this study, an 80-Watt solar PV panel was used for the electrolysis process. The characteristic features of the solar panel obtained by connecting 36 solar cells in series are given in Table 1.

Table 1. The electrical and mechanical features of the proposed solar PV panel

Solar PV Panel	Value	Solar PV Panel	Value
Rated Power	80 Wp	Power tolerance	%±2.4
Open circuit voltage (Voc)	22.68 V	MPPT operating voltage	31.7 V
Voltage value at MPPT	18.5 V	Protection class	IP65
Short circuit current (Isc)	4.75 A	Size	800x670x30 mm
Current value at MPPT	4.38 A	Series Fuse Rating	15 A
Cell efficiency	%16.7	Service temperature	-40°C…+80°C
Efficiency of the PV cell	%13.6	Weight	8.5 kg

Solar PV panels formed by connecting a solar cell with serial or parallel connection of these cells are composed of a current source electrically, serial/parallel resistors and parallel diodes. The relationship between the voltage of solar cell cells and the current it gives to the load gives the I-V and P-V characteristics of the cell. These two characteristics provide important clues about the conditions under which the power received from the panel should reach its highest value. The I-V and P-V characteristics of the proposed solar PV panel are given in Figure 2.



(a) (b)

Figure 2. (a) P-V and (b) I-V Characteristics of the proposed solar PV Panel under loaded condition (1000 W/m^2–25°C)

2.2. DC-DC Step-Down Converter

DC-DC step-down converters are systems that reduce the direct voltage at the converter input to a lower direct voltage level and transfer it to its output. The step-down converter circuit consists of a capacitor, a coil, a switching element and a diode. When the switching element is ON (i.e. in transmission), the diode will be OFF. The switching element is opened and closed according to the switching frequency ratio of Pulse Width Modulation (PWM). There is a voltage set so that the output voltage is lower than the input voltage.

In this study, the LM2596 series DC-DC step down converters are used to the conversion process of solar PV panel generated voltage. On the DC-DC step-down voltage converter, there is LM2596 integrated, which is a switched voltage regulator. Up to 3A current can be flowed through the regulator. Input voltage is between 4-35V. Depending on the voltage applied in this range, an output voltage of 1.25-30V can be obtained by using the trimpot on the card. In applications made with the card, the input voltage must always be higher than the output voltage. Because the LM2596 converter is a switched-mode power supply, its efficiency is significantly higher, especially when compared to popular three-terminal linear regulators with higher input voltages. The proposed converter features are shown in Table 2.

Table 2. Technical properties of the proposed DC-DC step-down converter

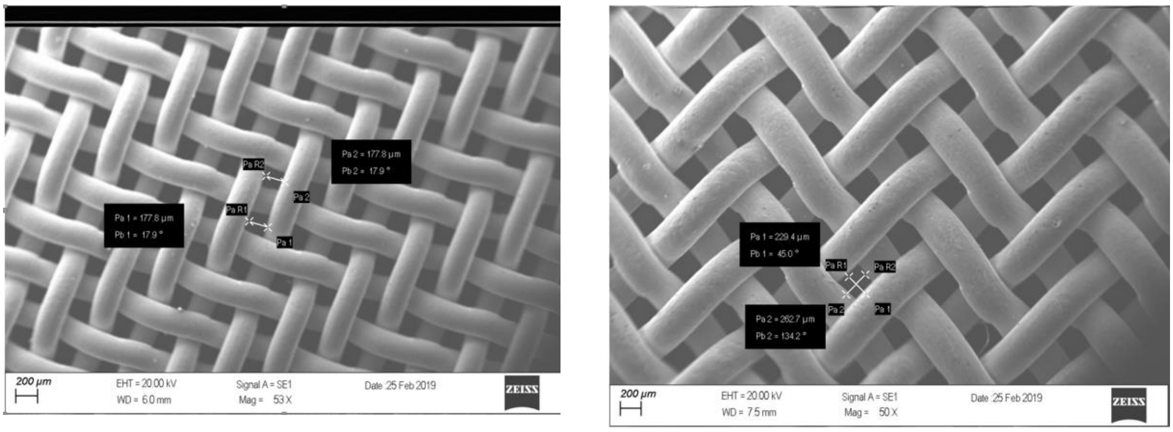
Definition	Characteristics	Definition	Characteristics
Supply voltage	4-35V	Generated voltage	1,23V-30V
Rectifier	Non-Synchronous Rectification	Service temperature	(-38°Cto +84°C)
Module Feature	Non-isolated step-down module (buck)	Conversion efficiency	Up to 92.4%
Load regulation	±0,49%	On-Off Frequency	150KHz
Voltage regulation	±2,48%	Dimension	47*24*13 mm

2.3. Hydrogen Production by Alkaline Electrolysis

The electrochemical tests are realized by using the 178 micron and 250-micron iron mesh electrodes as a cathode. These electrodes were symbolized as EI and EII, respectively. The electrode surface was 1x1 cm^2. In order to activate EI and EII surface, the 10 mA cm^{-2} constant cathodic current was applied during 600 s in 1 M KOH before the electrolysis. Then electrolysis was obtained with a two-electrode configuration. The system was set up on Renewable Energy Investigation Lab. on the ATU roof. In this system, the graphite electrode with 0,5 cm^2 surface area was used as the anode, EI and EII electrodes were used as a cathode. The PV panel output provided as 0.3 W for the electrolysis system. The produced hydrogen gas was measured by using a graduated cylinder. 1M KOH electrolyte was added into the graduated cylinder. The electrochemical test solutions were obtained from analytical grade KOH in distilled water. In order to obtain SEM analysis results, It was received support from the Leo 440 device. An energy dispersive X-ray (EDX) detector was coupled to the device.

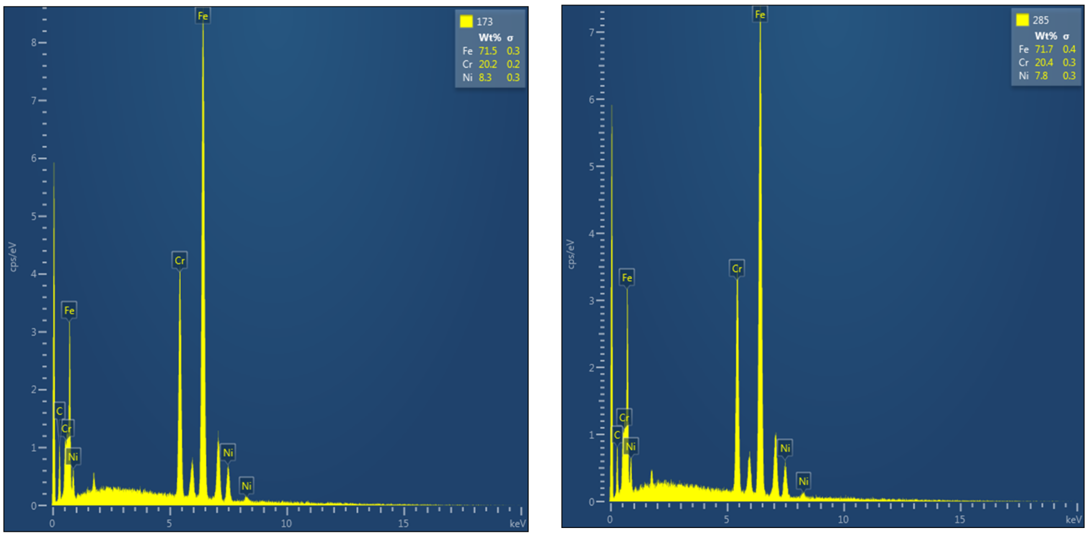
3.Results and Discussion

Considering the conditions of our country (Turkey), we may claim that solar energy is a promising alternative (Benli, 2016; Omar and Altinisik, 2016; Ozcan and Ersoz, 2019). We have great potential to produce energy from photovoltaic panels in Turkey. According to 1996 data (Demirbas and Bakis, 2004), the electricity generated in Turkey, where about 11 thousand times the equivalent of sunlight received have been identified. Furthermore, (Keles and Bilgen, 2012) declared that in Turkey, we have a higher potential for renewable energy, which meets almost 37% of total energy production and 10% of total energy consumption. In fact, energy demands in Turkey are resolves by imports. The location of Turkey has many advantages; it is a natural bridge between the energy-rich Middle East and Central Asian regions. We can have more advantageous positions to support energy production via solar energy. The highest average temperatures which are varied between 28.1-32.8 °C, in summer for some cities where locate South Eastern Anatolia Region and Mediterranean Region. Also besides temperatures, the solar irradiation data proves these regions are suitable solar energy harvesting, especially via photovoltaic panels. Turkey has almost 2460 days of sunshine and 1311 kW h/m^2 average solar radiation/year. (Kaygusuz, 2011) called sun-belt cities for the Mediterranean Region and he declared that Adana has the best DNI resource in Turkey. Therefore, we decided to investigate the optimal usage of solar energy for Adana region. In this study, we set up the PV panels and we operated part of harvested energy for the input of alkaline electrolysis for hydrogen production. As seen from Figure 3 the re-cycled iron mesh electrodes were used as cathodes. They have different mesh sizes. And the elemental composition of these electrodes was given in Figure 4 as EDX results.



(a) (b)

Figure 3. The SEM images of EI (a) and EII (b) electrodes



(a) (b)

Figure 4. The EDX results of EI (a) and EII (b) electrodes

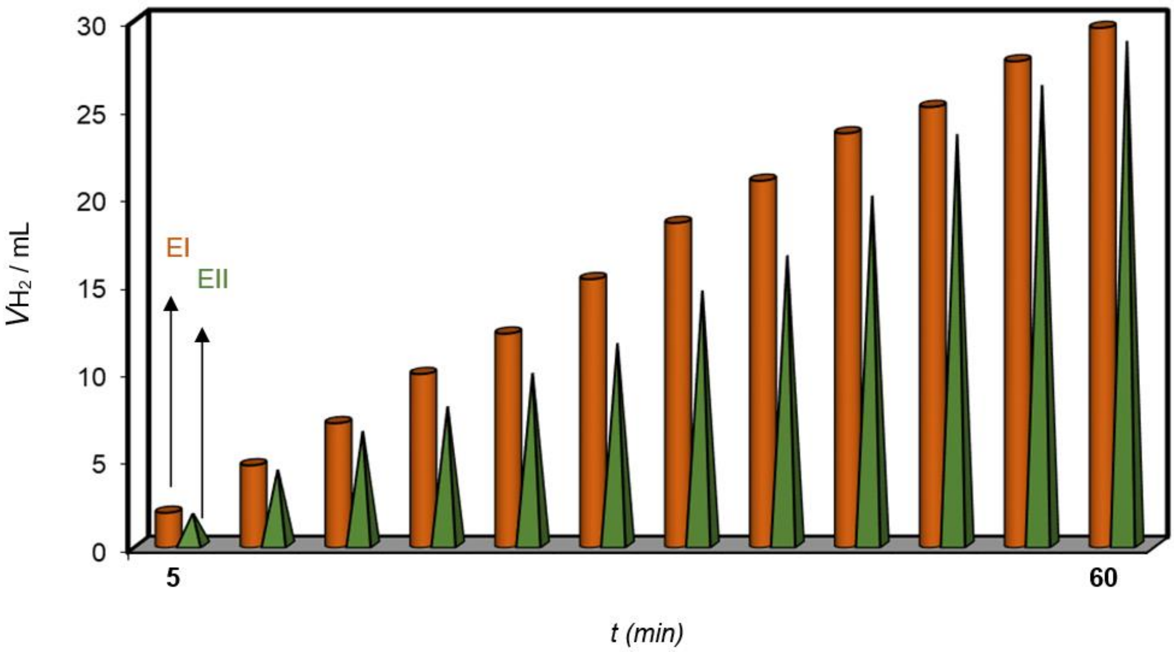


Figure 5. The produced hydrogen gas volumes by EI (a) and EII (b) electrodes

The EI has a higher Ni percentage than EII and we expected that it has a higher hydrogen evolution reaction (HER) activity. We set the alkaline electrolysis and we determined the hydrogen gas volumes in case 0.3 W input, the obtained data were presented in Figure 5. As seen in Figure 5, the HER activity of EI is higher than EII and produced hydrogen gas volumes are 29.6 mL and 28.7 mL after 1-hour electrolysis time, respectively. The HER activities of EI and EII is comparable with the efficiency of the electrodes used by (Demirdelen et al., 2020). Mert (2018) utulized chronoamperomety technique to generate a nickel-cobalt-bismuth (NiCoBi) layer on the copper surface. The electrochemical decomposition experiments were done in alkali water. The two electrode set up was conducted to examine the coating's performance for hydrogen production. The amount of hydrogen obtained after 30 minutes when bare copper (Cu) was employed as the cathode and a 3 V constant potential was applied was 8.43 mL. In the same potential and time as nickel plated copper, this amount increased to 11.52 mL, 15.33 mL hydrogen was obtained with Nickel-Bismuth coated copper, and 18.61 mL hydrogen was obtained with Nickel-Cobalt coated copper. The maximum hydrogen volume of 20.51 mL was determined when Cu/NiCoBi cathode was utulized in the same system. As seen from Figure 5, the comparable results were obtained in this study with literature.

4.Conclusion

The world needs to evolve new routes seeking alternative roads to meet energy demands. Because limited fossil sources are not sufficient for the next generations and they also accompany carbon dioxide emission. In order to overcome problems, alternative energy sources have been extensively investigated but suitable recipes are variable and they depend on many factors i.e.; location of the region, climate - weather conditions, investment cost – strategies, etc. The temperatures and solar irradiation data prove that Sarıcam region is suitable for solar energy harvesting, especially via photovoltaic panels. It was revealed to reveal the effectiveness of the location of the region for hydrogen production with the proposed renewable energy system. Results define both effects of "lab-made cathodes performance comparison" and "the trend of PV panel under different climate and weather conditions". In addition, the EI and EII electrodes may prefer because of rough, large surface area and low cost furthermore these electrodes should be used with graphite anode for PV-alkaline electrolysis systems.

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Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author’s Contributions

The contribution of the authors is equal.

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