

GREEN HYDROGEN PRODUCTION FROM PHOTOVOLTAIC POWER STATION AS A ROAD MAP TO CLIMATE CHANGE MITIGATION

K. R. Kamil^{1*}, A. Regillo², A. O. Yusuf³

¹Fellow, Open Africa Power (OAP 2022), Enel Green Power, Rome, Italy.

²Head of Enel Open Innovation, Hubs and Startups, Enel Green Power, Enel Foundation, Rome, Italy.

³Department of Electrical and Electronics Engineering, Faculty of Engineering and Technology, University of Ilorin, Ilorin, Nigeria

*Email: kehinde.kamil@nbbri.gov.ng

ABSTRACT

Hydrogen is increasingly recognized as a critical element in the global net-zero transition. Addressing climate change is increasingly urgent, and hydrogen's role as a decarbonization vector in hard-to-abate sectors is clear. Africa enjoys high renewable energy capacity factors ranging from 28% to 36% for solar according to global solar irradiance index report. According to IRENA, 96% of all hydrogen produced today comes from fossil fuels. Only 4% is produced by water electrolysis. Realizing green hydrogen fuel ambition would have significant positive socio-economic effects across the continent. This study discuss the Africa green hydrogen production industry using Nigeria as a case study to enunciate the possibility of generating clean hydrogen vectors from a percentage of the Photovoltaic power output of a standalone solar grid electrification project in different regions in the country. The usage analysis and effectiveness of the produced hydrogen fuel in each region is carried out with the highest region having an annual output of 12,247,278 kg of green hydrogen and 8,573,094 kg of ammonia, expected production from the proposed usage of 50 % of the power generation output of the installed 1.6 MWp solar power mini-grid in the region. The analysis was repeated for the other considered regions in the country. The results showcased the enormous advantages of electrolytic production of hydrogen and how the greener economy project can play a major role in mitigating climate change effects and overreliance on fossil fuels as the driver of the economy in many Africa countries.

KEYWORDS: renewable energy, photovoltaic, climate change, green hydrogen vector, fossil fuels, electrolysis

1. INTRODUCTION

The increasing reliance on fossil fuels and the associated problems have spurred a greater interest in the production and utilization of clean energy sources (IEA G20, 2020). Non-renewable energy sources like gas, oil, and coal make up a significant portion of total energy consumption, which can lead to various economic, political, and environmental issues (IEA Renewable, 2023). Therefore, in recent years, there has been a growing focus on hydrogen as an efficient and clean energy source, which has the potential to mitigate the negative impacts of fossil fuel usage on the environment (Fereidooni et al, 2018). Although the primary applications of hydrogen currently include the production of ammonia, soil enrichment, and the production of methanol and other chemical compounds, it is increasingly being recognized as a viable source of clean energy (Mostafaeipour et al, 2020).

The competitiveness of producing green hydrogen can vary depending on several factors, including local resources, proximity to demand, and infrastructure availability, at regional, national, and project-specific levels. Sunlight represents a crucial and sustainable energy source, and the energy it provides to the Earth's surface is many times greater than the total energy consumption of humans (RAYmaps, 2022). The issue of global warming and the affordability of modern photovoltaic (PV) systems, as opposed to traditional ones, have encouraged the use of PV cells to increase the production of clean energy. While there has been substantial progress in the efficiency of PV cells, with current efficiency reaching around 29%, their efficiency in commercial applications remains in the 10-20% range, and they are not yet capable of fully replacing fossil-fuel-based electricity. Factors such as temperature and shading can affect the efficiency of PV cells, and thus, it is critical to accurately forecast and estimate the efficiency of PV systems under realistic weather conditions (Yohannes et al, 2022).

1.1 Solar Renewable Resources Potentiality in Africa Countries

The Sustainable Energy for All (SE4All) initiative, led by the United Nations (UN) and the World Bank in partnership with other organizations, aims to ensure access to sustainable energy for all by 2030, as part of a global effort. Sub-Saharan Africa's geographic location offers the potential for a significant contribution to global energy supply through solar energy, provided that adequate infrastructure is available (Climate-Champion, 2023 and Siemens Gamesa, 2023).

Nigeria, located in West Africa and with a landmass of 923,768 square kilometers, benefits from abundant sunshine throughout the year, as it is situated just above the equator. On average, Nigeria receives 6.5 hours of sunshine per day, with an average flux of 5.55 kWh per square meter per day. This means that Nigeria receives 4.851×10^{12} kWh of energy per day from the sun. Solar radiation intensities range from 3.5-7.0 kWh per square meter per day, increasing from south to north. This energy source could be available for 26% of the day, from 9:00 am to 4:00 pm. Given these facts and figures regarding Nigeria's geographic location, the potential for significant generation of electrical energy from solar power is very high in Nigeria (Kamil et al, 2021).

1.2 Relevant Properties of Hydrogen

Hydrogen contains more energy per unit of mass than natural gas or gasoline, making it attractive as a transport fuel. Nevertheless, being the lightest element, hydrogen has a lower energy density per unit of volume. Therefore, more significant volumes of hydrogen are required to meet the same energy demands as other fuels.

The different types of hydrogen vectors, classified by color, have varying degrees of CO₂ emissions and environmental impact. Green hydrogen, obtained from water electrolysis powered by renewable energy, has a very low environmental impact and generates zero CO₂ emissions. The colors classification of hydrogen vectors is as shown in Table 1.

Table 1. Type and properties of hydrogen vectors (Ferrara et al, 2023).

Hydrogen Vector Type	Properties
Brown Hydrogen	Obtained from coal gasification with more than 20 kg of CO ₂ emitted for every kg of hydrogen produced.
Grey Hydrogen	Obtained from steam reforming of natural gas with more than 9 kg of CO ₂ emitted for every kg of hydrogen produced.
Blue Hydrogen	Obtained with the same production method of grey hydrogen but with a partial capture, transport and storage of CO ₂ . It emits up to 5kg of CO ₂ not captured for every kg of hydrogen produced
Pink Hydrogen	Obtained from the water electrolysis powered by nuclear energy. It has high environmental impact due to the production of nuclear waste even if it does not emit CO ₂ .
Green Hydrogen	Obtained from the water electrolysis powered by renewable energy. It has very low environmental impact and generates zero CO ₂ emissions.

1.4. Green Hydrogen as a pathway to Sustainable Power Generation in Africa

Africa, as a continent, has a comparatively low contribution to global warming, responsible for less than 3% of the world's energy-related carbon dioxide (CO₂) emissions to date. It also has the lowest emissions per capita of any continent (IEA, 2022). Despite this, Africa is among the most severely affected by the consequences of climate change, including increased frequency of extreme weather events, such as drought, delayed rainy seasons, or flooding due to excessive rains. Table 2 shows some of the pioneering green hydrogen production projects in Africa (Piebalgs et al, 2023).

Table 2. Pioneering Investments of African countries in Green Hydrogen generation (Piebalgs et al, 2023)

Country	Project Partner and Capacity	End Use
Egypt	100-3000 MW Renew Power	Mobility and Export
	4GW Masdar Project	Export and Industrial Feedstock
	100-3000 MW Siemens Project	Mobility and Export
	10MW Alfarnar green Ammonia	Industrial Feedstock
Namibia	100-3000 MW Daures Green Village	Various uses and Export
	10 MW Hydrogen Refueling Station	Mobility
South Africa	10MW Anglo American Mining Truck ArcelorMittal DRI MoU	Mobility Industry Feedstock

Morocco	3 GW HEVO Ammonia	Industrial Feedstock and Export
Algeria	Sonatrach and Eni Hydrogen pilot project	Various Use
Mauritania	3GW AMAN Ammonia 3MW Total and Chariot Nour Green Hydrogen Project	Various Use and Export Industrial Feedstock and Export

By exploiting the abundant renewable resources of the continent to produce GH₂, Africa can stimulate local socio-economic growth, strengthen regional energy security, and help ease poverty. The development of green hydrogen in Africa can bring substantial benefits to the continent, such as the building of a green economy in African countries, the improvement and acceleration of access to energy, the creation of jobs, and potentially improving access to power and fresh water.

This study uses Nigeria, a country in the western hemisphere of Africa, as the case study to examine the possibility of producing and using green hydrogen from commissioned photovoltaic grid systems in different regions of the country. It discusses how the generated hydrogen fuel can service numerous industrial and commercial needs as an alternative to fossil fuels. The study will expose how green hydrogen can act as an enabler for climate change mitigation and a carbon-free energy ecosystem. This study aims to exploit the probability of producing green hydrogen from proliferating renewable photovoltaic grids in different regions in Nigeria to showcase the countries' potential to join African hydrogen-producing nations.

2. METHODOLOGY

2.1. Case Study Analysis and PV System Simulation

Renewable electrification projects from solar have started to make noticeable impact in the rural and alternative electrification of provinces in many African Countries. This section examines system design towards the production of green hydrogen from photovoltaic power plant. The availability of renewable power to support this concept will be carefully examined. By the end of 2019, Nigeria's estimated installed mini-grid capacity was about 2.8MW, with 59 projects serving rural consumers. These are mostly residential-based mini-grids with some developed for specific productive uses. If fully commercial-served mini-grids are included, the number is expected to be significantly higher (Bloomberg and SEforALL, 2020).

According to a spotlight report published by Rural Electrification Agency in Nigeria showcasing some mini-grid photovoltaic projects commissioned across the country. This study utilizes the information in proposing using a percentage of the photovoltaic electrical power outputs to generate sustainable green hydrogen in the same ecosystem (REA, 2022).

Table 3 shows the specifications and locations of the solar grid projects considered in this study. The photovoltaic solar potential in the considered regions is obtained from Global Atlas SolarGIS of different countries. The webpage provides an aggregated and harmonized solar resource and PV power potential from the perspective of different countries and their regions. Solar Irradiance is the quantity of power received from the sun at a point on the Earth's surface measured in Wh/m² or kWh/m².

Table 3. Considered Photovoltaic Stand-alone Grid and their Capacity (REA, 2022 and Global Atlas, 2023)

Country Location (PV Grid Region)	Size of the Photovoltaic mini-grid Project	SolarGIS Annual Solar Photovoltaic Potentiality in the Region
North Central Region (PV Grid Region A)	80 kWp solar mini-grid at an isolated community in Ajaokuta, Kogi State.	1448.3 kWp
South South Region (PV Grid Region B)	100 kWp solar hybrid LGA Akwa Ibom State community in Onna	1168 kWp
South East Region (PV Grid Region C)	100 kWp solar mini-grid at Eka-Awoke community, Ikwo LGA- Ebonyi State.	1314 kWp

North West Region (PV Grid Region D)	1.6 MWp of solar power Sabon Gari Market Grid Project.	1607 kWp
North East Region (PV Grid Region E)	85 kWp solar mini-grid at Dakiti community in Akko LGA - Gombe State	1753 kWp
North East Region (PV Grid Region F)	91 kWp solar mini-grid in sarkin Kudu community, Taraba State.	1557.5 kWp

2.2. Simulation for the expected Annual Power Generation in PV Region A

The annual performance of individual photovoltaic power projects will be used in estimating the quantity of green hydrogen produced through electrolysis. In the electrolysis process, water molecules will split into their constituent elements.

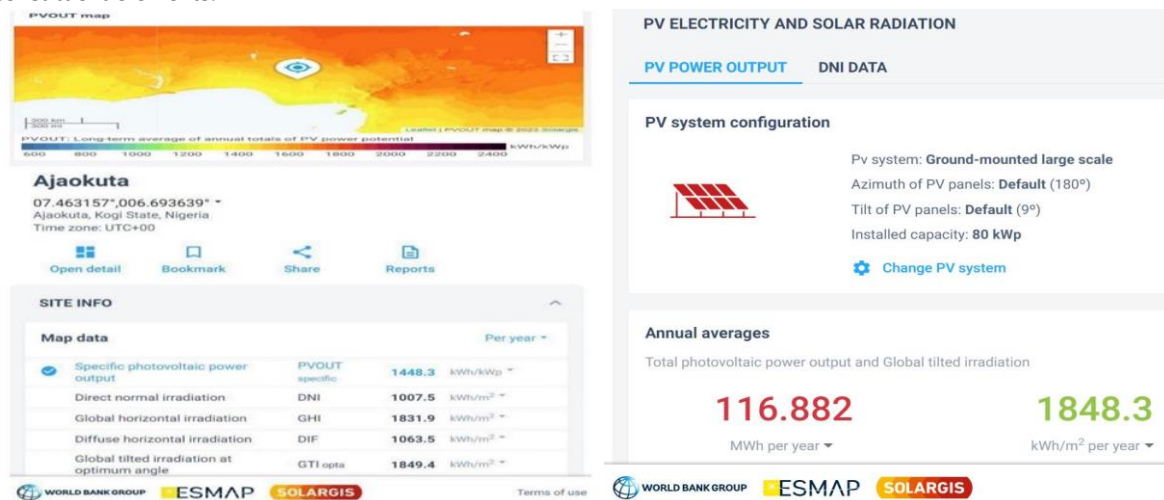


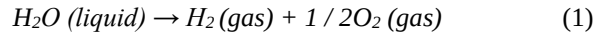
Fig. 2. SolarGIS Annual Specific Photovoltaic Power output in PV Grid Region A and the simulation result for the for 80kWp grid system

Estimating for the power generation for the first considered PV grid system installed in Region A, an 80 kWp solar mini-grid at an isolated community in Kogi State using the available photovoltaic resources from SolarGIS of the region. The site specific PV potentiality obtained from SolarGIS was used in the design simulation carried out on Global Solar Atlas, as shown in Fig .2. To start with, it is important to stress that the efficiency of a solar panel is a matter of area, not power. Let us assume we want to install 300 Wp solar panels. We would need 267 numbers of solar panels to achieve 80kWp. The simulation result for the case study PV Region A in Ajaokuta, Kogi State, Nigeria, where the grid has been commissioned. The grid configuration in the simulated design is ground-mounted as installed on the site. The simulation result shows that a total of **116.882 GWh or 116,882 kWh** per year is the expected generation. The system design will be in a hybridized form whereby an equal percentage of the generated photovoltaic power in the considered regions will service the province's primary need and supply the proposed green hydrogen generation plant in the area. Fig .3. shows the monthly and daily photovoltaic generation from the stand alone PV grid system. The highest generation is in November with a peak hourly photovoltaic power output of 55.1 kWh.



Fig. 3. The monthly and hourly distribution of the photovoltaic power output in PV Grid Region A

Green hydrogen production, as proposed in this study, helps in creating carbon-free sustainable energy. According to the obtained result of the annual generation from the photovoltaic power station. Utilizing 50% of the photovoltaic power output to produce hydrogen through electrolysis. In the process of electrolysis, water molecules splits into their constituent elements as shown in (Eq. (1).



Electrolysis requires electrical power to split apart the water molecules. In other words, generating 1 gram (1 kg) of hydrogen requires 9 grams (9 kg) of water based on the stoichiometric values with the assumption of no losses in the electrolysis process. The amount of power needed is defined by the higher heating value (HHV) of hydrogen divided by the electrolyze system efficiency (Goldmeer, 2019)

$$Electrolyzer\ Power = \frac{HHV}{System\ Efficiency} \quad (2)$$

The HHV for hydrogen is 12,756.2 kJ/Nm³ (141,829.6 kJ/kg); this is equivalent to 3.54 kWh/Nm³ (39.39 kWh/kg). Assuming a 70% efficiency of PEM electrolyzer system, which represents commercially available technology. The photovoltaic power will be used as a clean alternative power in servicing the power requirement of the electrolyzer (Goldmeer, 2019 and Patrik et al, 2016).

Therefore, in PV Grid Region A using 50 % of the power output of the 80kWp PV grid system for hydrogen production will be:

$$116882\ kWh \times 50\% = 58441\ kWh \quad (3)$$

The formula for calculating hydrogen production from electrolysis can be given as:

$$m = \frac{z * F * I}{96485 * V} \quad (4)$$

Where m is the mass of hydrogen produced (in grams), z is the number of electrons involved in the electrolysis reaction, F is the Faraday's constant (96485 C/mol), I is the current flowing through the electrolytic cell (in Amperes), and V is the voltage applied across the electrodes (in Volts). The formula assumes 100 % Faraday efficiency that is not realistic in industrial production of hydrogen. Since we have the photovoltaic energy output instead, hydrogen production can be given as:

$$m = \frac{P}{\eta * E_H} \quad (5)$$

Where m is the mass of hydrogen produced (in grams), P is photovoltaic energy input (in kWh) and E_H is the energy required to produce one mole of hydrogen (in kJ/mol).

$$E_H = \frac{\Delta H^{\circ}f}{\eta_{electrolysis} * \left(\frac{1}{molar}\ mass\ of\ hydrogen\right)} \quad (6)$$

$\Delta H^{\circ}f$ = standard enthalpy change of formation of hydrogen (approximately 285.8 kJ/mol), efficiency (η) of a Proton Exchange Membrane (PEM) electrolyzer can be assumed to be 70% depending on the operating condition of the temperature of the electrolysis water, pressure, and current density. The molar mass of hydrogen is in grams/mol (approximately 1.0079 g/mol) (Goldmeer, 2019).

$$E_H = \frac{285.8}{0.7 * \left(\frac{1}{1.0079}\right)} = 411.52\ kJ/kg \quad (7)$$

Therefore, calculating the hydrogen production in region A with the photovoltaic power out of 58441 kWh or 210,387,600 kJ as we are working with energy value from direct source and the standard unit of energy in the International System of Units (SI) is the joule.

$$m = \frac{58441 * 3600}{411.52} = 511,245\ kg \quad (8)$$

Using photovoltaic energy of 58,441 kWh, we can estimate the production of approximately 511,245 kg of green hydrogen from PEM electrolysis. Since the electricity for the electrolysis process comes from renewables (solar), there is no 'direct' release of CO₂ when generating or burning hydrogen. The schematic in Figure 4. shows how the produced hydrogen gas can be utilized in different sectors of the country's economy.

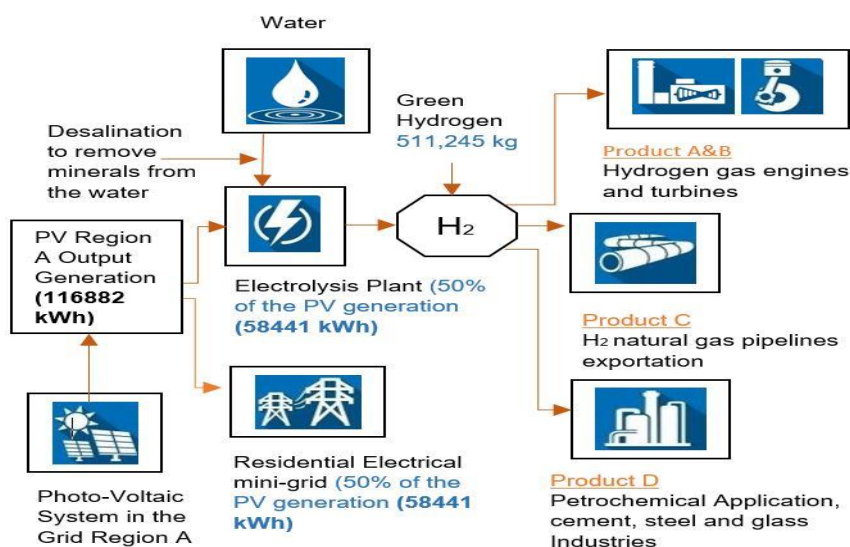


Fig. 4. The schematic showing the distribution of PV Grid Region A power output

Hydrogen production for the conventional steam methane reforming (SMH) and electrolysis of water involves the release of carbon dioxide to the atmosphere during the process. Green hydrogen production from electrolysis of water as proposed in this study will help in alleviating the environmental treats associated with Hydrogen production for commercial and industrial use (Masdar, 2022).

The procedure was repeated for the other commissioned solar grid projects in the remaining five (6) geopolitical zones. The Table. 4 below gives the output green hydrogen generation when 50 % of the annual output photovoltaic power output was used for hydrogen production.

Table 4. Green Hydrogen gas production from PV output in different region.

Photovoltaic Project	Expected Annual PV electricity utilized (50% of the total PV output)	Expected Hydrogen production (kg)
80 kWp solar mini-grid at an isolated community Ajaokuta, in Kogi State	58441 kWh	511,245 kg in PV Grid Region A
100 kWp solar hybrid LGA - Akwa Ibom State community in Onna	63899 kWh	558,992 kg in PV Grid Region B
100 kWp solar mini-grid at Eka-Awoke community, Ikwo LGA- Ebonyi State.	63899 kWh	558,992 kg in PV Grid Region C
1.6 MWp of solar power Sabon Gari Market Grid Project.	1400 MWh	12,247,278 kg in PV Grid Region D
85 kWp solar mini-grid at Dakiti community in Akko LGA - Gombe State	72182 kWh	631,452 kg in PV Grid Region E
91 kWp solar mini-grid in sarkin Kudu community, Taraba	71373 kWh	624,375 kg in PV grid Region F

3.0 USAGE ANALYSIS OF THE PRODUCED GREEN HYDROGEN

3.1. Hydrogen gas as a motor fuel (Product A)

When comparing hydrogen and diesel as motor fuels, various factors must be taken into account, including their energy content, efficiency, and emissions (Milan, 2021).

- **Energy Content:** On a mass basis, diesel fuel has a higher energy content than hydrogen, with an energy density of approximately 44 kWh/kg compared to around 33 kWh/kg for hydrogen. However, since hydrogen is a gaseous fuel, it can be stored in larger volumes, thus increasing its energy content compared to liquid fuels like diesel.
- **Efficiency:** Regarding efficiency, fuel cell vehicles utilizing hydrogen can be more effective than diesel vehicles. Hydrogen fuel cell vehicles can transform a larger portion of the stored energy in hydrogen into useful work compared to diesel vehicles, which usually experience energy losses due to factors such as friction.
- **CO₂ emissions:** In the studied regions analyzed, hydrogen produced from renewable energy sources is considered a green fuel due to its zero greenhouse gas emissions during combustion, while diesel fuel releases CO₂ and other harmful pollutants into the atmosphere when burned.

Deducing from the established relationship, 537,869 kg of hydrogen produced from PEM electrolysis in PV Grid Region A can provide more energy compared to the equivalent amount of diesel fuel and the use of hydrogen as a motor fuel has a lower environmental impact, as it produces no greenhouse gas emissions during combustion.

3.2. Green Hydrogen in the production of Ammonia (Product D)

Most hydrogen generated globally for ammonia production for fertilizers or petrochemicals comes from steam methane reforming, which releases carbon dioxide. However, the production of green ammonia involves a 100% renewable and carbon-free process. The Haber-Bosch process is a commonly used method for producing ammonia from hydrogen and nitrogen, where they are reacted under high pressure and temperature conditions to yield ammonia. The reaction can be expressed as follows:



Where N₂ represents nitrogen, H₂ represents hydrogen, and NH₃ represents ammonia. The conversion efficiency of the Haber-Bosch process is typically around 70-80%. This means that for every 100 kg of hydrogen, 70-80 kg of ammonia can be produced (Guerra et al, 2019 and Yohannes et al, 2022).

Given the amount of green hydrogen from produced in Grid Region A from PEM electrolysis is 511,245 kg, the amount of green ammonia that can be produced using the Haber-Bosch process can be calculated as follows:

$$\text{Green ammonia} = 0.70 \text{ to } 0.80 * 511,245 \text{ kg} \quad (10)$$

$$\text{Green ammonia} = 376,810.3 \text{ to } 454,095.6 \text{ kg} \quad (11)$$

Table 5. Ammonia production from the available hydrogen gas in each region

Green Hydrogen Produced	Green Ammonia Equivalent Production (kg)
PV Grid Region A production of 511,245 kg of Hydrogen	357,871.5 to 408,996 kg
PV Grid Region B production of 558,992 kg of Hydrogen	391294.4 to 447193.6 kg
PV Grid Region C production of 558,992 kg of Hydrogen	391294.4 to 447193.6 kg
PV Grid Region D production of 12,247,278 kg of Hydrogen	8,573,094 to 9,797,822.4 kg
Grid Region E production of 631,452 kg of Hydrogen	442,016.4 to 505,161.6 kg
Grid Region F production of 624,375 kg of Hydrogen	437,062.5 to 499,500 kg

3.3. Green Hydrogen usage in Gas Turbine Engines (Product B)

Gas turbine engines that are powered by green hydrogen have a higher energy efficiency than those fueled by fossil fuels. This is because hydrogen has a higher energy density per unit of volume and a lower ignition temperature, resulting in a more efficient combustion process. However, operating a gas turbine on a hydrogen/natural gas blend instead of using 100% hydrogen reduces the required amount of hydrogen flows (Goldmeier, 2019).

In terms of power generation volumes, a single General Electric (GE) 6B.03 gas turbine operating 8,000 hours annually would require approximately 33 million kg of H₂ per year. If the hydrogen were generated via steam methane reforming, it would produce around 178,000 metric tons of CO₂ annually (GE, 2023).

4.0 ECONOMIC VIABILITY OF GREEN HYDROGEN PRODUCTION PLANT

4.1. Availability of Water Source to support Electrolysis Process

Enormous availability of water resources in Nigeria favors the consideration of green hydrogen projects in the country. However, it is advisable to extract the water required from the wide spread streams and rivers in different regions of the country to avoid water resources competition with residential usage of water at any point of construction of a green hydrogen plant projects. As shown in the schematic in Figure 4, the desalination process helps in removing impurities or minerals that may be present in the water, as these can have a negative impact on the efficiency and performance of the electrolysis process.

PV Grid Region A is located in Ajaokuta, where there is abundant water bodies, including rivers and streams. Some of the major rivers in the area include the Niger River and its tributaries, such as the Anambra River and the Benue River. Furthermore, PV Grid Region B is located in Onna, Akwa Ibom where some of the major rivers in the area include the Cross River, which is the largest river in the region, and its tributaries, such as the Kwa River and the Imo River. These rivers provide a source of water for domestic, agricultural, and can serve industrial usage in green hydrogen production plant.

In general, it is estimated that to produce 1 gram of hydrogen through electrolysis, around 9 grams of water is required based on stoichiometric values and assuming no losses in the process. This is because the reaction of splitting water into hydrogen and oxygen requires a certain amount of energy, and the amount of water used in the process reflects the amount of energy required (Vaughan et al). However, the actual energy consumption may be higher due to the energy losses during the process, so the energy efficiency of electrolysis can vary.

5.0 CONCLUSION

Electrolysis is not a new idea, but the use of renewable energy sources to power the electrolytic production of hydrogen is gaining investment interest in various countries worldwide. In order not to fall behind, African nations must also begin exploring opportunities in this area. Many African countries have an abundance of renewable photovoltaic energy resources, and they should take a cue from developed countries and invest in green hydrogen production. Nigeria, as discussed in this study, has yet to consider this direction. The study's analysis reveals that the countries viability of generating green hydrogen in different regions of the country.

This study analysed six different regions for green hydrogen production and found that PV Grid Region D, situated in the northern part of the country where solar intensity is highest, produced the greenest hydrogen among the regions studied. This region has an annual output of 12,247,278 kg of green hydrogen and 8,573,094 kg of ammonia can be produced from it. Considering the abundant availability of water resources in African countries and the continuous fall in the price of deploying renewable energy projects, Nigeria and other African countries should consider investing more in this sector to promote carbon neutrality.

REFERENCES

A. Mostafaeipour, M. Khayyami A. Sedaghat, . Sedaghat (2020). Evaluating the Wind Energy potential for hydrogen production" International Journal of Hydrogen Energy pp 1-11.

A. Piebalgs, E. Zigah (2023). Has COP27 accelerated the development of Green Hydrogen in Africa?" Energy and Climate, Florence School of Regulation, <https://fsr.eui.eu/has-cop27-accelerated-the-development-of-green-hydrogen-in-africa/> (accessed:2023).

- A. Vaughan (2016).** Almost 90% of new power in Europe from renewable sources in 2016” The Guardian, https://www.theguardian.com/environment/2017/feb/09/new-energy-europe-renewable-sources-2016?_sm_au_=icH71r6FFm6sl06H. pp. 345-247.
- Bloomberg, SEforALL (2020).** State of the Global Mini-grids Market Report, 2020. <https://www.seforall.org/publications/state-of-the-global-mini-grids-market-report-2020> (accessed: 2020).
- B. Milan, H. Catlyne, J. Page (2018).** Green Industrialisation and Entrepreneurship in Africa". The Global Commission on the Economy and Climate, The New Climate Economy. pp. 4-6.
- B. Yohannes, A. Diedou, (2022).** Africa Renewal E-Magazine Green Hydrogen, A viable option for transforming Africa's energy sector, 2022.
- C. Ferrara (2023).** From Green to Sustainability, Enel Green Power Learning Hub" <https://www.enelgreenpower.com/learning-hub/renewable-energies/hydrogen>.
- Climate Champion (2023).** Green Hydrogen Catapult, Race to Zero and Race to Resilience", www.climatechampions.unfccc.int/ (accessed January, 2023).
- GE Future of Hydrogen Gas Power** "Hydrogen and CO2 Emission Calculator" <https://www.ge.com/gas-power/future-of-energy/hydrogen-fueled-gas-turbines/hydrogen-calculator> (accessed: 2023).
- Global Solar Atlas (2023).** Energy Data Info" <https://globalsolaratlas.info/download/nigeria> (accessed: 2023).
- Guerra, O. J., Eichman, J., Kurtz, J., Hodge, B. M (2019).** "Cost competitiveness of electrolytic hydrogen". J.Joule 3, pp. 2425–2443.
- J. Goldmeier (2019).** POWER TO GAS: HYDROGEN FOR POWER GENERATION, Fuel Flexible Gas Turbines as Enablers for a Low or Reduced Carbon Energy Ecosystem" General Electric Power (GEA33861), 2019.
- K. Kamil, A. Yusuf, A. Sharif, S.B Seriki, (2021).** Renewable Energy Hybridization as an Efficient and Cost-Effective Alternative for Electrification. Nigerian Journal of Technology Development. Vol. 19. pp. 2437-2110.
- IEA for the G20, (2020).** The Future of Hydrogen, Seizing today's Opportunities, Report prepared by the IEA for G20, Japan Technical Report TR-95-012.
- IEA Renewable, 2022.** How much will renewable hydrogen production drive demand for new renewable energy capacity by 2027" Fuel Report prepared by IEA Analysis and Statistics.
- Masdar, (2022).** "AFRICA’S GREEN ENERGY REVOLUTION Hydrogen’s role in unlocking Africa’s untapped renewables" Abu Dhabi Sustainability Week (2022). pp 12-13.
- M. Fereidooni, A Mostafaeipour, V. Kalantar (2018).** A Comprehensive evaluation of Hydrogen Production from Photovoltaic Power Station" Renewable and Sustainable Energy Reviews 82(2018) pp. 414-423.
- M. Patrik (2023).** Run on Less with Hydrogen Fuel Cells" RMI Energy Transformed. <https://rmi.org/run-on-less-with-hydrogen-fuel-cells/>.
- Siemens gamesa renewable Energy (2023).** Green Hydrogen Fuel for the Future, Siemens Gamesa pilot Project www.siemensgamesa.com/en-int.
- RAYmaps (2020).** How to calculate the surface area required by Solar Panels, www.raymaps.com (accessed 2022).
- Rural Electrification Agency (REA) (2022).** 'NEP's achievement in the last two years, Spotlight on Rural Electrification Agency <https://rea.gov.ng/reference-document/> (accessed: 2022).