ASSESSMENT OF GREEN HYDROGEN PRODUCTION POTENTIAL FROM SOLAR AND WIND ENERGY IN MAURITANIA

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DOI: 10.21163/GT_2024.192.01

ABSTRACT.
The aim of the present paper is to estimate the green Hydrogen potential from two sources of renewable energies that are solar and wind. This estimation has been done by using satellite data taken from the Global Solar Atlas (GSA) and Global Wind Atlas (GWA). Data were integrated into a Geographical Information System (GIS) to estimate, first the theoretical electricity from solar and wind by using different models. Then we used a third model to estimate the quantity of hydrogen that can be produced from the two different sources mentioned above. As far as we know this is the first attempt to estimate the green hydrogen potential in Mauritania. The results show that the total annual electricity from solar ranged between 275 and 329 GWh/km^2/year, with the north of the country having the highest potential, especially in the region of Tiris-Zemour and Adrar, in the other hand the south of the country and across the Senegal River line was the regions with the least potential of solar energy. Concerning wind, the values were between 28 and 108 GWh/km^2/year with the coastline regions localized in the Nouadhibou-Nouakchott axis having the highest potential. The total values of hydrogen production vary between 5428 to 6272 tons/km^2/year from solar versus 23 to 620 tons/km^2/year from the wind.

***Key-words:** Mauritania, Green hydrogen, GIS, Renewable electricity, Solar and Wind Energy.*

1. INTRODUCTION

Meeting the global energy demand while striving for net-zero goals (Wang et al., 2023) presents a formidable challenge in today's world. Decarbonizing economic sectors and adopting non-pollutant energy sources are imperative steps toward achieving this objective (Acar & Dincer, 2022; Matute et al., 2022). Notably, a significant portion of CO2 emissions 86% emanates from power generation, transportation, and industrial activities (Ayodele et al., 2012; Jahangiri et al., 2020; Kojima et al., 2023). The promotion of renewable energy emerges as a crucial strategy to mitigate the adverse impacts of fossil fuels (Phap et al., 2022).

Green hydrogen, produced through renewable energy sources, emerges as a promising environmentally friendly solution (Dokhani et al., 2023; Mohammadshahi et al., 2022; S. Wang et al., 2021). However, despite its potential, green hydrogen constitutes only a small fraction (0.3%) of total hydrogen production, with the majority being derived from fossil fuels (Catumba et al., 2022; Kumar et al., 2023). To accelerate the energy transition, the European Union has set ambitious targets, including the installation of 40 GW of renewable-powered electrolysers by 2030 (Moradpoor et al., 2023).

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Notably, regions rich in renewable energy resources, such as North Africa, hold the potential to become key energy suppliers, given the high demand and moderate renewable resource availability (Gallardo et al., 2021; Mukelabai et al., 2022). Mauritania, with its abundant solar and wind resources, has attracted considerable attention for green hydrogen investment. Companies like CWP Global, Chariot Limited, and British Petroleum have signed agreements with the Mauritanian government to develop green hydrogen projects (Aman et al., 2022; El Hacen Jed et al., 2020; Eren et al., 2022). Several studies have assessed the hydrogen potential using GIS and satellite data in various countries. For instance, research in Morocco by Touili et al. (2018) revealed substantial hydrogen production potential from wind and solar energy. Similar studies have been conducted in other countries, including Ecuador (Posso et al., 2016), Canada (Okunlola et al., 2022), and Algeria (Boudries & Dizene, 2008), highlighting the global interest in green hydrogen. Despite extensive research in many countries, studies evaluating green hydrogen production in Mauritania remain scarce. While efforts have been made to estimate solar and wind potential, there is a notable gap in assessing green hydrogen production (Bilal et al., 2021, 2023; El Hacen Jed et al., 2020; IRENA, 2021; Ould Bilal et al., 2008). This study aims to address this gap and provide valuable insights into green hydrogen production in Mauritania.

2. MAURITANIA COUNTRY PROFILE

Mauritania is an African country with a surface of 1.030.700 km^2, that has borders to the North with Morocco and Algeria to the East and South-East with Mali and to the South with Senegal. The western limit of the country is marked by the Atlantic Ocean for a distance of around 754 km (Hardy, 2017). Mauritania has a vast potential for solar energy. Masdar, an energy firm of Emirates, installed in the year of 2016 a total capacity of 16 MW solar plants. In 2017 Mauritania opened the Toujounine solar farm with a 50 MW capacity and the total installed solar capacity increased to 86 MW. The first Mauritanian wind farm capacity was installed in Nouakchott with a capacity of 30 MW followed by the Boulenouar wind farm with a capacity of 100 MW. According to the Ministry of Petroleum, Energy, and Mine, the demand for electricity in Mauritania will be around 1400 MW by 2025 (Group, 2019).

3. DATA AND METHODOLOGY

To estimate the potential of hydrogen production we need solar and wind data that are representative of the whole country. The data can be obtained by local measures or via satellite data. Satellite data and GIS were used in several studies (Jahangiri et al., 2020; Okunlola et al., 2022; Rahmouni et al., 2017; Touili et al., 2018) to estimate hydrogen potential. We first estimated the amount of energy that can be obtained from solar and wind then this energy was used as an input to an electrolyser model to estimate the quantity of hydrogen that can be produced. The satellite data used for this study was taken from the Global Solar Atlas and Global Wind Atlas.

3.1. Solar potential

Mauritania has a high potential for renewable energy resources. The solar photovoltaic (PV) potential is estimated to range between 2000-2300 kWh/m^2/year (IRENA, 2021). For estimating the solar potential, we used the data obtained from Global Solar Atlas an open-access online database application that allows access to solar resources and photovoltaic power potential for a site or a region. 228 grounds sites measurements have been used worldwide to validate the Global Solar Atlas data. The accuracy of annual Global Horizontal Irradiance (GHI) from the obtained data for the 228 site measurements ranged between ±4% to ±8% (Énergies et al., 2021). GIS data layers of the annual average of the Global horizontal irradiation with 250 m resolution were downloaded from the database and used as input to a GIS software using the models that we detailed below to deduce the Mauritania potential (Global Wind Atlas., 2023). For this study, we assumed a PV panel with 250 W rated power (Rahmouni et al., 2017), a module reference efficiency of 17%, and an efficiency of 85% for the power conditioning units (Touili et al., 2018). So, to estimate the energy that can be produced from the PV array we used the following model (Rahmouni et al., 2017; Touili et al., 2018):

$$Epv = G \times npv \times npc \tag{1}$$

where:

Epv, (kWh/km2): is the quantity of energy that can be produced by the PV solar system;

G: is the horizontal irradiation;

npv: is PV module reference efficiency;

npc: is the power conditioning efficiency.

3.2. Wind potential

Recently in Mauritania, a wind resource assessment was made by Bilal et al., (2021), using more recent meteorological data measured every 10 min over one year collected from eight sites (with three different height levels) located mainly on the west coast of Mauritania, and the annual average of the wind characteristics was determined. The average wind speed was extremely high. The values were between 4.9 m/s (on site 2 at 10 m height) and 10.0 m/s (on site 7 at 80 m height). This was done for eight locations only and the data used were collected for one year. to estimate the wind potential, we should first know the wind average velocity and the characteristics of the wind in each region in Mauritania. And for this accurate data are required in the whole country. The best thing is to get data acquired in situ and for that meteorological stations are needed in the whole Mauritania region, but that is not the case. To overcome this issue, we used validated satellite data from open online sources (Gruber et al., 2019; Okunlola et al., 2022; Rahmouni et al., 2017; Touili et al., 2018). For the wind potential estimation, we used the data obtained from the Global Wind Atlas database. GWA is a free access online database application where we can find wind resource mapping at 10, 50, 100, 150, and 200 m above ground/sea level with 250 m resolution. The GWA starts with large-scale and ends with microscale wind climate data. In this study, we used the average mean wind speed at a height of 100 m (Global Wind Atlas., 2023). The characteristics of the wind turbine considered are Suzlon-82 with a Rated power of 1500 kW, and a swept area of 5281 m2. To estimate the electricity produced by the wind we used the formula below (Ayodele et al., 2012b; Ayodele & Munda, 2019; Rahmouni et al., 2017):

$$Ew = Eo \times hm \times hg \tag{2}$$

$$Eo = \frac{1}{2} \times \rho \times C \times A \times V^3 \times 8760 \tag{3}$$

where:

Ew: is the electrical energy produced by the wind generator;

Eo: power generated by the wind turbine;

hm: gearbox efficiency 85%;

hg: generator efficiency 95%;

ρ: density of air (kg/m3);

C: coefficient of performance of the turbine, and for the purpose of this study we used 45%;

V: wind speed (m/s).

3.3. Electrolyser modeling

The reaction that split water into hydrogen and oxygen by electricity is called electrolysis. The tool used for this electrochemical reaction is an electrolyser. The hydrogen produced when the energy used to feed the electrolysers comes from a renewable source has a label of green hydrogen. DC power is used in the electrolysis process powered by renewable energy resources (Shiva Kumar & Lim, 2022). There are three main types of electrolysers in the market. The Solid Oxide (SO) Electrolyser, The Proton Exchange Membrane Electrolyser (PEM), and the Alkaline Electrolyser (AE). The SO electrolyser has a high efficiency, needs less electricity, and is able to split water into hydrogen and oxygen at high temperatures. PEM has a fast response, a small footprint, low operating temperature, and high efficiency at high density. Alkaline Electrolyser has a proven maturity, and good durability and is the predominant electrolyser in the market (Yue et al., 2021). Alkaline electrolysers represent 61% of the installed capacity, 31% for the PEM, and the rest for SOEC and other electrolysers technologies (Nnabuife et al., 2022).

For this study, we used the PEM due to its high energy efficiency, purity of gases, and hydrogen production rate (Ueda et al., 2022). The PEM was used in several studies to estimate hydrogen production (Ayodele & Munda, 2019; Folgado et al., 2022; Okunlola et al., 2022; Posso et al., 2016; Rahmouni et al., 2017; Touili et al., 2018). To produce 1 kg of hydrogen the electrolyser is supposed to consume 53 kWh (Touili et al., 2018), with an efficiency of 75% (Okunlola et al., 2022; Posso et al., 2016; Rahmouni et al., 2017; Touili et al., 2018). The following equation was used to estimate hydrogen production from renewable sources:

$$MH2 = (nelec \times E / HHVH2) \quad (4)$$

where:

MH2: *is the mass of hydrogen (ton/km2/year);*
Nelec: *electrolyser efficiency;*
HHVH2: *Hydrogen higher heating value*

4. RESULTS

The calculations performed illustrate regional variances in solar and hydrogen production (**Fig. 1** and **Fig. 2**), with higher production rates observed in the Northeast regions compared to coastal regions and other parts of the country. This indicates that certain regions may be more favorable for solar and wind energy development. The annual average of the global horizontal solar irradiation ranged between 1900 and 2300 kWh/m^2/year (**Fig.3**) and the annual average of the wind speed was between 5-10 m/s (**Fig. 4**).

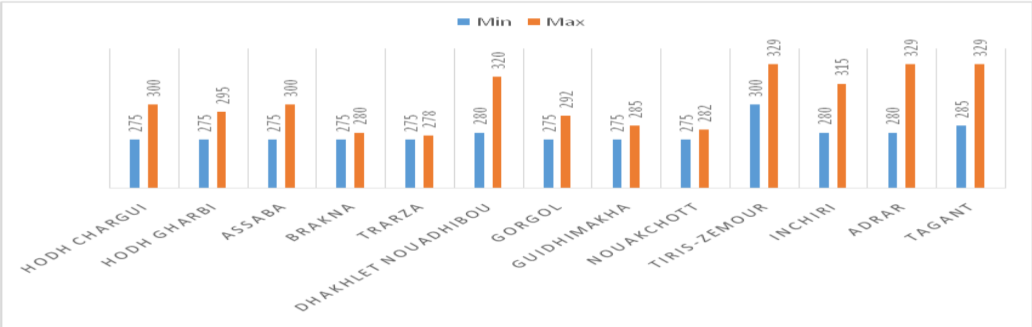

Fig.1. Solar Electricity yearly production in Mauritania (GWh/km²/year**)**

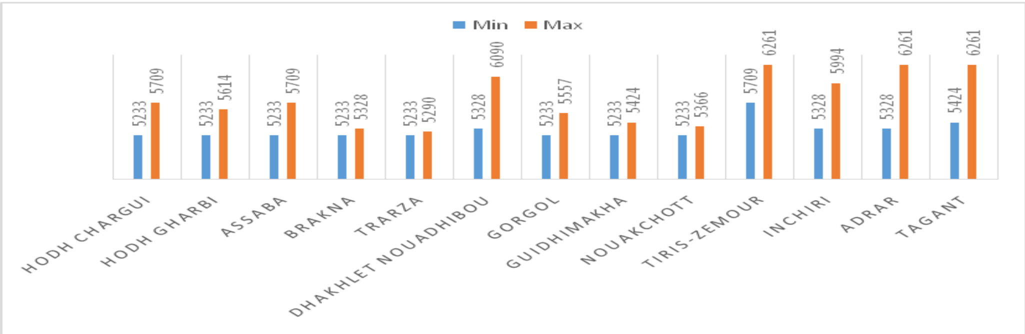

Fig.2. Hydrogen Production from Solar Energy in Mauritania (tons/km²/year).

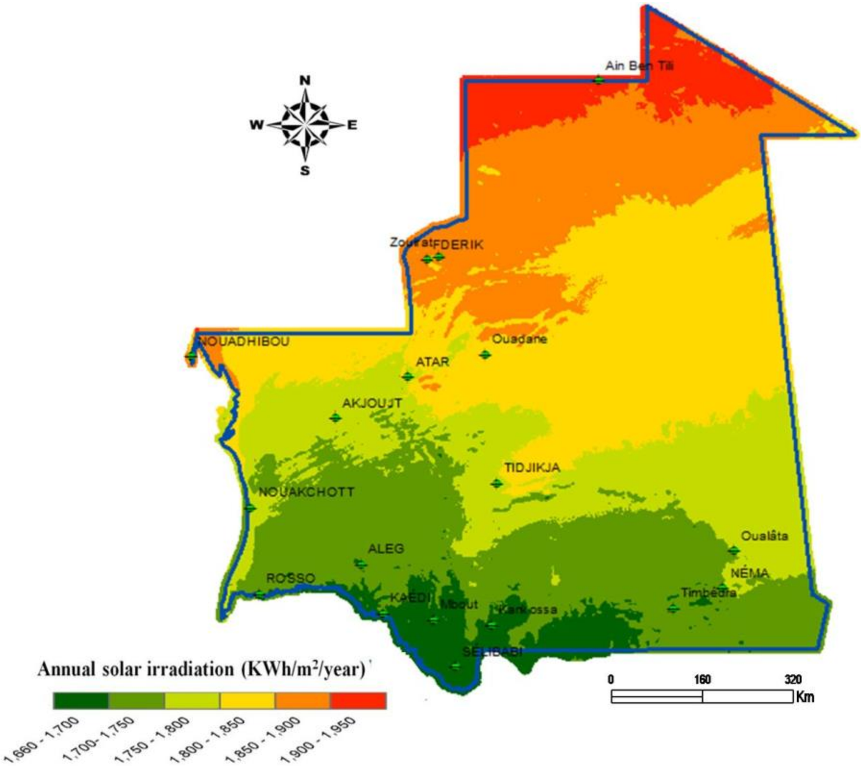

Fig. 3. Annual average of the global horizontal solar irradiation in Mauritania.

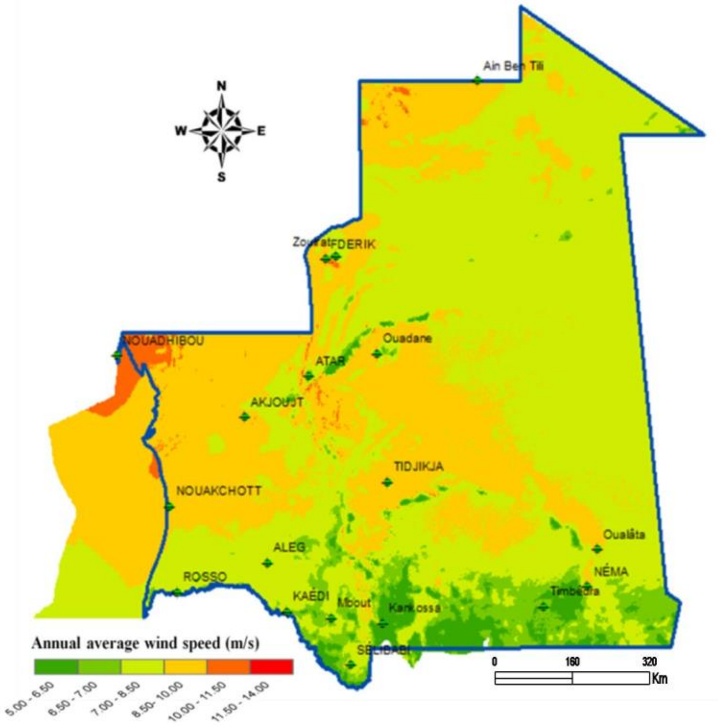

Fig. 4. Annual average of wind speed at 100 m above ground level in Mauritania.

Applying the models that we presented before regarding solar PV and wind turbines we found that the annual solar electricity production was between 275 and 329 GWh/km^2/year (**Fig. 5**) thus much higher than the wind 1-28 GWh/km^2/year (**Fig. 6**).

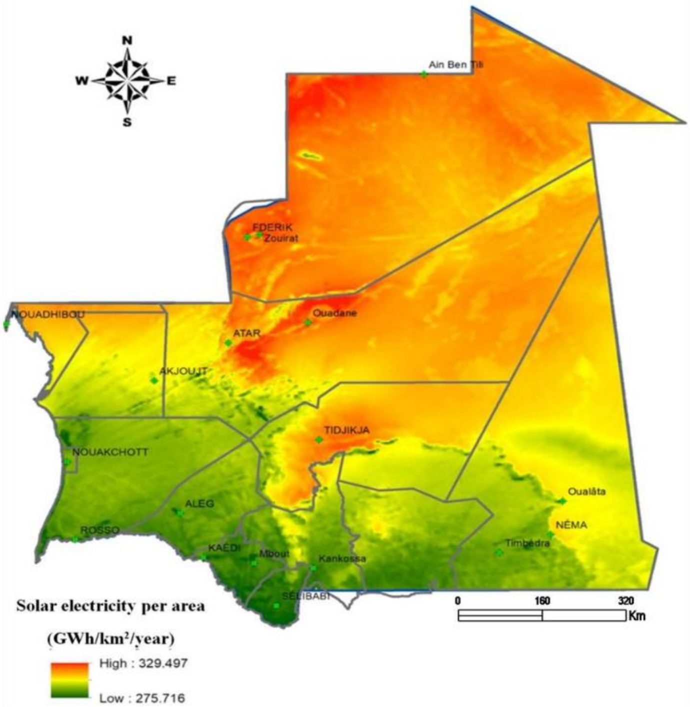

Fig. 5. Solar electricity production.

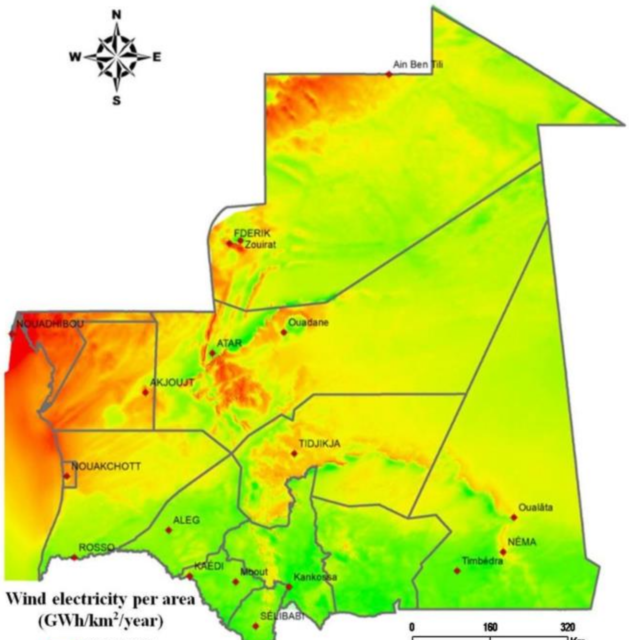

Fig. 6. Wind electricity production.

From **Fig.7** we can see that the estimated potential of solar hydrogen production in Mauritania with models that we used was high between 5248 and 6272 tons/km^2/year at least ten times greater than the estimated wind hydrogen 23-625 tons/km^2/year (**Fig.8**).

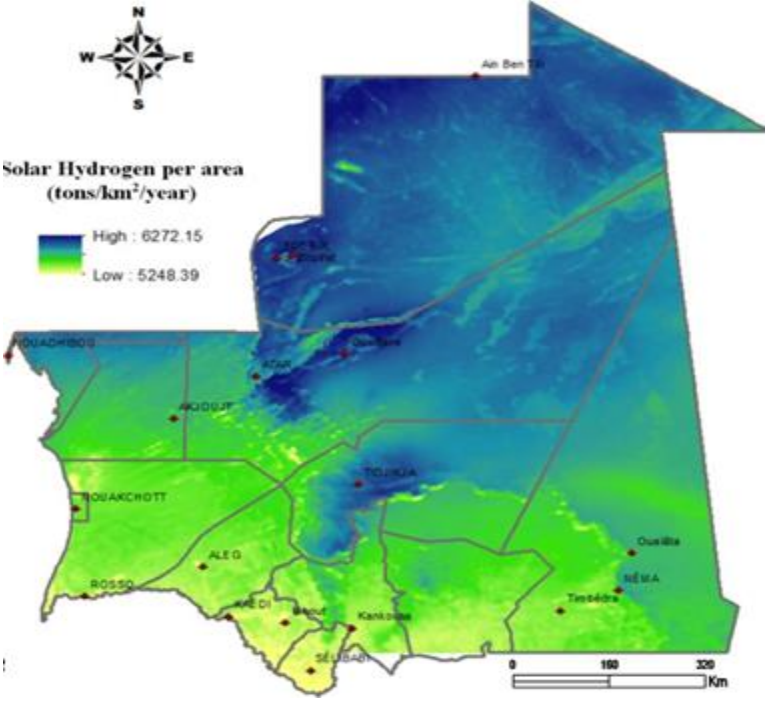

Fig. 7. Hydrogen potential from solar energy.

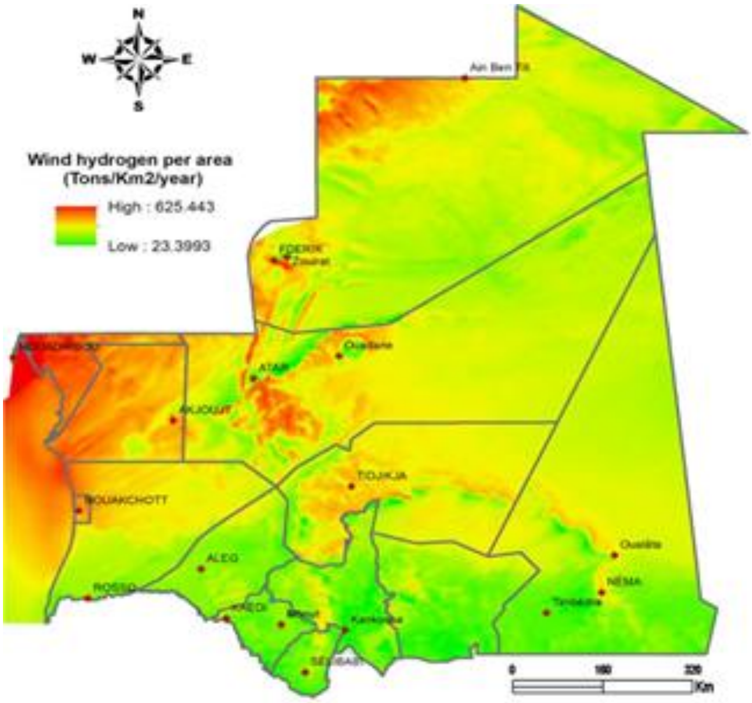

Fig. 8. Hydrogen potential from wind energy.

The bar chart displays the yearly production of solar electricity in Mauritania, broken down by region. The data is presented in GWh/km²/year, with the highest production in the Northeast regions at 329 GWh/km²/year, followed by Dakhlet-Nouadhibou and parts of Inchiri, Adrar, and Tiris-Zemour at 300 GWh/km²/year. The coastal regions and the rest of the country have a production of 290 GWh/km²/year and 275 GWh/km²/year, respectively.

The bar chart displays the hydrogen production from solar and wind energy in Mauritania, broken down by region. The data is presented in tons/km²/year, with the highest solar production in the Northeast regions at 5700-6200 tons/km²/year, followed by Dakhlet-Nouadhibou and parts of Inchiri, and Adrar at 5300-6000 tons/km²/year. The coastal regions and the rest of the country have a solar production of 5200-5500 tons/km²/year and 5300-5700 tons/km²/year, respectively.

5. DISCUSSION

The annual average of the global horizontal solar irradiation ranges from 1900 to 2300 kWh/m²/year, indicating substantial solar energy potential across Mauritania. The annual average of wind speed is between 5-10 m/s, suggesting moderate to high wind energy potential in the region.

Solar electricity production is significantly higher than wind electricity production. The annual solar electricity production ranges from 275 to 329 GWh/km²/year, while wind electricity production is only between 1 and 28 GWh/km²/year. This indicates that solar energy is a much more viable and productive source of electricity compared to wind energy in Mauritania.

Taking a close look at the solar irradiation map shows that solar irradiation decreases from the north to the south with an exception in the Nouadhibou region. In other words, the solar potential increase from the South to the North of Mauritania. Regions like Tiris-Zemour, Adrar, and Tidjikja have the highest potential for electricity production from solar panels. On the other hand, regions of Trarza, Brakna, Gorgol, and along the Senegal River with the least potential. And Dakhlet Nouadhibou, Inchiri, and the Northern part of the Hods fall in between in the matter of the potential of electricity that can be produced from solar panels.

Regarding the wind regions of Dakhlet Nouadhibou, Inchiri, the Northeast of Tiris-Zemour, the Middle of Adrar and Nouakchott has the most of potential and especially along the coastline from Nouadhibou to Nouakchott. Combining solar and wind hydrogen potential the coast of Nouadhibou region comes to be with the highest potential.

The estimated potential of solar hydrogen production is much higher compared to wind hydrogen production. Solar hydrogen production ranges from 5248 to 6272 tons/km²/year, while wind hydrogen production ranges from 23 to 625 tons/km²/year. Solar energy exhibits a potential at least ten times greater than that of wind energy for hydrogen production in Mauritania.

Given the substantial solar energy potential and higher electricity and hydrogen production rates compared to wind energy, policymakers and stakeholders in Mauritania should prioritize solar energy development for both electricity generation and hydrogen production. Investments in solar infrastructure, such as photovoltaic systems and solar thermal technologies, could significantly contribute to the country's energy independence and sustainability goals. However, wind energy should not be overlooked entirely, especially in coastal regions with favorable wind conditions. Hybrid renewable energy systems combining solar and wind resources could provide a more balanced and reliable energy supply.

Further research and investment are needed to optimize the integration of renewable energy sources into Mauritania's energy mix, considering factors such as grid stability, storage solutions, and socio-economic impacts.

We compared the results with those obtained by Touili et al., (2018) in Morocco and Rahmouni et al., (2017) in Algeria, as the methodologies used were quite similar and Mauritania has a border with the countries where those study has been made.

Touili et al., (2018)found the annual average of solar production was between 340 and 436 GWh/km^2/year which was little bit higher than the value that we obtained for Mauritania which was between 275 and 329 GWh/km^2/year. On the other hand, the results obtained by Rahmouni et al., (2017) for the annual solar production between 259-367, GWh/km^2/year was closer to our results. Thus, the annual hydrogen production per square km per year was quite similar.

It worth to mention that this paper does not discuss the effect of temperature in system efficiency, and the potential capture of excess heat. According several studies the PV efficiency decreases as the temperature increases (Ouédraogo et al., 2021; Sevela & Olesen, 2013; Wang et al., 2023), and due to excess heat the cells can experience long-term degradation when temperature is higher than certain limit(Royne et al., 2005). This decreases will impact the overall hydrogen production.(Skoplaki & Palyvos, 2009). Using PVT can be a solution to capture the excess heat and cool the solar panels; it was proved in India that PVT with wavy fin system increase the solar to hydrogen production efficiency from 1.4% to 3.4% according to the experiment conducted by Chandrasekar et al., (2022) at the site of Tiruchirappalli district, Tamilnadu state, for temperatures ranging between 25-34 °C. Using a cooling system assist in improving the efficiency of PV cells (Rajoria et al., 2013; Tripanagnostopoulos et al., 2002), this is explained by the reason that only a small portion of the solar irradiation is converted to electricity and the rest is dissipated as thermal energy(Rajoria et al., 2013), thus using a solar heating and cooling system offers the opportunity to generate energy and heat (Buonomano et al., 2013). The excess heat can be used for domestic or industrial application contributing in carbon footprint reduction especially in Mauritania where the country is located in the hot dessert climate where temperature can reach up to 45 °C in some region during the summer.

6. CONCLUSION

The study reveals a significant contrast between the potential of solar and wind energy resources in Mauritania. Solar power emerges as a dominant contender, exhibiting substantially higher electricity and hydrogen production capabilities compared to wind power.

Solar electricity production ranges impressively between 275 to 329 GWh/km^2/year, showcasing the extensive energy-generating capacity of solar photovoltaic (PV) systems across the Mauritanian landscape. In contrast, wind electricity production lags behind, estimated at a modest 1-28 GWh/km^2/year.

The advantage of solar energy extends further when considering hydrogen production potential. Solar hydrogen production figures range from 5248 to 6272 tons/km^2/year, underlining the immense capability of solar energy to contribute to sustainable hydrogen generation. Conversely, wind hydrogen production, ranging from 23 to 625 tons/km^2/year, falls significantly short in comparison.

However, in coastal areas, where solar potential might not be as dominant as in other regions, wind energy emerges as a compelling alternative. The study identifies coastal regions, such as Dakhlet Nouadhibou and Inchiri, as having high wind potential, especially along the coastline from Nouadhibou to Nouakchott. These areas present favorable conditions for wind turbine deployment, suggesting that a diversified energy approach incorporating both solar and wind resources could be advantageous.

It's essential to acknowledge the study's limitations, particularly the lack of discussion on temperature effects and excess heat management. Temperature fluctuations can impact PV efficiency, and implementing strategies such as photovoltaic-thermal (PVT) systems and cooling mechanisms could further optimize energy production.

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